4.2 STONE TESTING: VARIATION AND QUALITY CONTROL

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BACKGROUND

Dimension stone is a variable material. Large amounts of variation occur between different varieties of the same class of stone. For instance, the physical properties, appearance and performance of individual granites can vary greatly.

Further, considerable variation can occur even within a particular variety of stone. Differences between quarries located in the same deposit are well known, but even within a single quarry, variations can be large. This is particularly so with respect to sandstone, where a number of different 'beds' with widely varying appearances and properties can occur on top of one another. Even granite and marble, however, can vary within a quarry. The marble from Chillagoe in Northern Queensland displays substantial variation in colour over distances of several metres in some quarries. Granites can also show large variations in colour and strength with increasing depth within a quarry.

Variations within a single variety of stone can be due to some or all of the following factors:

- location of quarry;
- position within a single quarry;
- mineralogical composition;
- degree of weathering;
- direction of cutting;
- orientation of structural features (microcracks, bedding);
- surface treatment during processing.

The variation itself may be manifested as:

- differing colour or texture;
- differences in durability and long-term performance;
- differences in physical properties; the most significant are porosity and strength (compressive - sandstone, limestone; flexural - marble, granite).

It should also be noted that some variation can be due to the testing program itself. Differences in values can be caused by small numbers of samples, limited specimen sizes (particularly for flexural strength), effects resulting from operator influence during testing procedures (as is possible in water absorption tests on low porosity stones such as granite and marble), or different standard testing procedures (as is the case between Italy, Australia and USA).

This paper illustrates some of the implications of typical variation in dimension stone on the testing and evaluation process, and the resultant effect on the cladding design process by reference to some extensive testwork performed on a coarse-grained red granite.

COARSE-GRAINED RED GRANITE

The stone is a very coarse-grained granite originating from Scandinavia. The stone is dominated by large red potassium feldspar crystals up to 40 mm in diameter. An extensive system of sub-parallel shears, identified by the tendency for black biotite flakes to align with each other, extends throughout the stone. A strong system of microcracks is associated with these shears, many of which are clay-lined. A secondary system of microcracks is present in most samples, and appears to run at approximately right angles to the direction of shearing. However, due to the uneven nature of the shears, it is difficult to identify this subsidiary structure in most samples.

There is some alteration of the plagioclase and biotite, but this is not considered to be significant.

The water absorption of this granite is around 0.12 to 0.15% by weight. This is typical of red granites, although unusually low for granites exhibiting the extent of microcracking and shearing of this stone. However, it is considered likely that the low water absorption value results from the coarse-grained nature of the stone, and the resulting reduction in amount of grain boundary and pore space.

The appearance of the stone varies considerably between slabs originating from different blocks, with some slabs appearing quite pinkish-red, with the feldspar cleavage lines often stained darker red, other slabs containing far greater amounts of white plagioclase and comparatively few dark shears, and yet other slabs dominated by strongly parallel shears identifiable by the concentrations of black biotite.

The stone is to be used as external cladding, in both polished and flamed (exfoliated) finishes, and hence both conditions were tested in the first instance.

The bending strength was evaluated at the initial design thickness of 30 mm, on samples of polished and exfoliated material. Modulus of rupture (3-point bending, 200 mm span) tests were performed on specimens cut parallel and perpendicular to the shear structure, and tested in both oven-dry (48 hours at 65°C) and soaked (48 hours in water) conditions. In addition, a small number of polished specimens were tested for flexural strength (4-point bending) over a large span (900 mm). The initial results are summarised below:

		Polished	Exfoliated
Modulus of rupture (MPa)	Parallel to shear structure		
	dry	9.0	6.8
	soaked	7.3	6.4
	Perpendicular to shear structure		
	dry	11.0	10.4
	soaked	10.9	9.9
Flexural strength (MPa)	Parallel to shear structure	6.6	
	Perpendicular to shear structure	8.6	

These results showed a considerable variation in strength depending on the orientation of the specimens with respect to the shear structure. In addition, a significant reduction in strength occurred when the stone was exfoliated. The flexural strength values for polished material were sufficiently lower than the modulus of rupture results to suggest that a similar reduction may also occur for exfoliated material.

Subsequent calculations by the structural engineers indicated that the material was unlikely to meet the required factors of safety if used at a thickness of 30 mm, and a decision was made to use 40 mm thick panels when exfoliated, which was the majority of the building.

Further testwork was performed on samples of 30 mm and 40 mm thick material which had been honed, and then one half exfoliated. This meant that the variation due to different slabs was minimised, and the reduction in strength due to exfoliation determined. The results of modulus of rupture testing of these samples is given below (XX is perpendicular to YY and approximately 45° to the shear direction of the previous table):

Modulus of rupture	Bending axis parallel to	
	XX direction	YY direction
B (40 mm thick)		
Honed:	8.4 MPa	8.3 MPa
Exfoliated:	6.6 MPa	6.1 MPa
Reduction in strength:	21.4%	26.5%
C (30 mm thick)		
Honed:	10.6 MPa	7.3 MPa
Exfoliated:	5.6 MPa	4.1 MPa
Reduction in strength:	47.2%	43.8%

This shows the variation resulting from an applied finish. The large reduction for 30 mm thick material indicates the increasing effect of exfoliation on the flexural strength of granite with reduction in thickness.

All of the testwork outlined above had been performed on limited samples, and in the first instance, were all taken from the same block. After the awarding of the cladding contract, the curtain-wall designers wished to obtain information about the degree of variation which could be expected in the stone during the course of the project.

Further comprehensive testing programs, initially on small flexural strength specimens (span: 450 mm; width: 100 mm; thickness: 40 mm) and modulus of rupture specimens, and later on large specimens (span: 1000 mm; width: 250 mm; thickness: 40 mm), were carried out. In each case, the sample slabs were obtained from a number of different blocks and were intended to represent the range of stone available. As the sample panels were all selected by the stone processor in Italy, some difficulties were experienced due to the orientation of slabs with respect to the shear structure. In order to have strictly comparable flexural strength values, it was necessary to test specimens parallel and perpendicular to this structure. However, it was not possible to do so in all cases, and consequently a wide spread of results was obtained.

A total of 80 modulus of rupture specimens, and 50 small flexural strength specimens, from about 8 different slabs, were tested in the first of these programs. Depending on how the specimens were grouped (having been tested in various conditions), a range of mean values between 7 to 9 MPa for modulus of rupture and 6 to 9 MPa for small flexural strength were obtained. The standard deviations of these also varied depending on the groupings.

The second program involved testing of 60 large flexural strength specimens, and subsequently approximately 130 modulus of rupture specimens cut from the ends of these larger specimens. The specimens were obtained from slabs cut from five different original blocks. The modulus of rupture specimens were prepared to enable comparison of bending strengths parallel and perpendicular to the shear structure, because the large specimens had been cut by the stone processor at a range of angles to the shear structure.

The mean flexural strength values ranged from 4.5 to 9.2 MPa, depending on the block and orientation of specimens with respect to the shear structure. Standard deviations varied between 0.1 and 1.3 MPa. The mean flexural strength values for all specimens were similar to those obtained for polished specimens in the first stage, around 6.6 MPa, but with a much higher standard deviation of 1.7 MPa.

The modulus of rupture values showed a similar range of values, although slightly higher, as would be expected due to the small specimen size and 3-point rather than 4-point loading.

A large number of specimens, in a range of sizes and testing configurations, results in an enormous amount of data. This data can be extremely confusing. However, the example illustrates the high variation in strength which can occur within some granites, and which can at times be dependent on the preparation of test specimens and selection of samples. Wind load design using bending strength values of 9-10 MPa for this granite, as obtained for the initial modulus of rupture tests, would have resulted in a cladding system which had a factor of safety for the granite in the vicinity of 1.5, rather than the more typical 3-4.

NEED FOR REDUCTION OF VARIABLES

This example illustrates some of the factors which can influence the test data obtained for a particular stone. It is important to reduce the number of variables which may influence the results obtained prior to commencement of any physical testwork. This will always require some petrographic work, and may need detailed structural analysis of samples of the stone. In some cases, quarry inspections and basic mapping may be required in order to ascertain structural features and to select preferred locations for quarrying of block.

Once the presence of any structures have been identified in the stone, it is critical that test specimens be tested in a known relationship to those structures. This allows the effect of structure to be identified, and direct comparisons between different blocks made. The variation inherent in the stone may thus be calculated. This then provides data for engineering design.

QUALITY CONTROL

Total quality control for the use of stone in an individual building project may be considered in the following stages:

(1) Selection of the best available stone, quarry and processor at the commencement of the project;

(2) Comprehensive testing of the selected stone to provide detailed physical data for design of the fixing or installation system;

(3) Determination of Variability of the stone by comprehensive testing, with the acceptable variation outlined in quantifiable terms in the specification for supply;

(4) Checking and inspection during processing, including some physical testwork as appropriate;

(5) Complete acceptance inspection procedures on the stone panels; ideally this should occur prior to shipment from the processing plant in order to minimise delays in replacement of rejected material;

(6) Final inspection of completed stonework on the building in order to ensure that fixing has been carried out correctly.

Observation of, and involvement in trouble-shooting investigations for a number of major projects during the past few years suggests that very little quality control is being performed on stone used in buildings.

Whereas concrete batches will be routinely tested, and manufactured products such as aluminium cladding panels and planes of glass will be subject to quality control testing in the factory, little consideration is given to quality control of dimension stone. Yet stone is a natural material, and hence has a much greater inherent variation.

Unfortunately, most stone processors seem to approach quality control by means of a handling method - if the stone can be processed without falling apart, then it is satisfactory! This method may be appropriate for monumental or massive masonry, but for use as the far more sophisticated thin veneer cladding, more complicated quality control procedures are required.

QUALITY CONTROL TESTING

Testing will generally be required in the second and fourth stages of total quality control outlined above. Some limited comparative testing may also be undertaken during selection of the stone. Comprehensive testing, as mentioned in the second stage, will generally involve a wide range of test procedures, as discussed in the previous paper.

Quality control testing, however, should generally be limited to the quickest, cheapest tests which will provide appropriate information about the variation in the stone. For example, the flexural strength of thin granite or marble is the most appropriate procedure for quality control of cladding panels, and specimens can often be prepared from slab offcuts. If the stone has a significant porosity (such as sandstone or limestone), then the water absorption can often be an useful quality control parameter. Determination of the abrasion resistance may be of assistance during large paving projects using softer stones - granites generally do not wear significantly when used as paving.

Durability tests would generally be considered to provide the most useful information for quality control purposes, but are mostly too lengthy or complicated to be practical in this situation. If a long timescale is available, then performance of salt crystallisation testing on sandstone and limestone is useful.

However, all quality control testing should be preceded by comprehensive testing of the range of stone likely to be encountered during supply, and specification of the minimum or maximum values allowable. Rejection procedures should also be documented in the specification.

The trend towards performance specifications places the onus for quality control on the supplier. This is considered to be inadvisable in an industry which is dealing with a new use (thin veneer cladding) for a material, and which does not have a good understanding of the long-term behaviour of this material. The added cost of quality control, in an industry where it is neither expected nor demanded, may be sufficient to render some suppliers uncompetitive.

Regardless of performance specifications, if the stone fails in the cladding, all involved with the project will be embroiled in the resultant traumas.