by **Richard Bowman, Geoff Quick and My Dieu Do**

Re-engineering the dimensional stability of ENGINEERED STONE

"Engineering engineered stone installations to prevent failures"[1] reported some fixing requirements that engineered stone manufacturers place on the use of tiles in order to deal with expected movements. Inspections of differential movement tiling system failures reveal that tile fixers often ignore the minimum grout width and movement joint requirements. Since consumers typically want floors that appear seamless, can engineered stone tile manufacturers minimise the number or size of joints by reducing the linear thermal expansion of the tile or improving its dimensional stability? The development of an accelerated test method for dimensional stability would enable manufacturers to reformulate their products and fine tune their manufacturing processes, so as to produce more stable products, whilst also enabling better quality assurance.

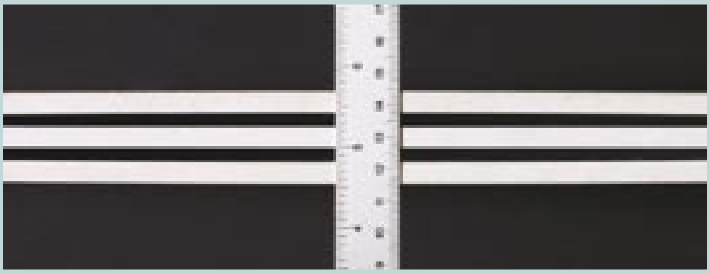
It has generally been thought that the warping of tiles, due to water absorption at one face, manifests itself rapidly. However, there is virtually no published independent research on the dimensional instability of engineered stone products. Mapei[2] published the following table based on their measurement of 989 products between 1991 and 2000, where classes A, B and C respectively relate to dimensional movements of less than 0.3 mm, 0.3 to 0.6 mm, and more than 0.6 mm, during a six hour period after continuous wetting of one face of the tile, as previously detailed[1].

Table 1 Mapei dimensional stability data[2]

Tile Product	Number	Class A	Class B	Class C
Natural stone	455	367 (80.7%)	37 (8.1%)	51 (11.2%)
Cement-based reconstituted stone	249	87 (34.9%)	95 (38.2%)	67 (26.9%)
Resin-based engineered stone	285	180 (63.2%)	59 (20.7%)	46 (16.1%)
Total	**989**	**634 (64.1%)**	**191 (19.3%)**	**164 (16.6%)**

An analysis of the Mapei data indicates that some stones are reactive whilst others are not. It is well known that some so-called green marbles (actually serpentines) are reactive, and it might be anticipated that most of the reactive stones that Mapei has encountered are limited to different sources of the same few sorts of stones. By contrast, true marbles and granites are usually dimensionally stable [in the case of some so-called marbles, they may contain stylolitic veins that could contain clay minerals that might expand].

However, reconstituted stone tile manufacturers can avoid the use of reactive stone components. Cement-based tile products are characterised by natural (irreversible) shrinkage phenomena that are associated with most cementitious products, together with a degree of reversible moisture movement. The behaviour of cement-based tiles upon being wetted is thus a function of their age and their current water content. On the other hand, the behaviour of resin-based reconstituted stone appears to be more a function of the resins that are used, and how the tiles are cured, although there will be other



Photos 1 and 2 Full view and close-up of bowing of two 600 x 300 x 6.8 mm tiles, where the rear of the tile was continuously exposed to moisture, compared to a flat new tile (centre).

factors such as the size and amount of the stone chips.

Although several resin bound reconstituted tiles were classified as highly reactive (Class C), few manufacturers indicate how reactive their tiles are. None indicate the rate of any such reaction, or the time period over which such reactions might extend. Some tile manufacturers have indicated in their technical literature, that adhesive manufacturers can identify suitable adhesives for fixing their products. However, adhesive manufacturers should not be expected to undertake tile quality assurance testing or to be responsible for the tile characteristics. Tile manufacturers are responsible for identifying potentially reactive products, and to publish details of key product characteristics, so that there is no ambiguity about what is required to ensure the integrity of the tiling system. Adhesive manufacturers are responsible for identifying which adhesives are suitable for fixing which class of tile.

A 6 or 12-hour Mapei dimensional stability test can identify those products that contain natural stones that will most readily curl when the stone reacts with water, particularly during the phase when the tiling adhesive is setting. However, it does not indicate the long-term potential of tiles to warp.

Figure 1 compares the unrestrained centre curvature of two (Mapei Class A) 600 x 300 mm engineered marble tiles. It can be seen that the 6.8 mm thick product, which is shown in elevation in Photographs 1 and 2, warps more readily than the 12 mm thick product. One former manufacturer, on a website that no longer exists, stated that as the tile size doubled, the inclination to warp increases fourfold, and that as the tile thickness doubled the strength to resist warping doubled. However, flexural strength is normally a function of the square of the tile thickness. The data in Figure 1 indicates that as the tile thickness increased, the centre curvature increased as a function of the square of the tile thickness.

This test unfortunately requires much space in that individual tiles need to be individually laid on level supports, where space is invariably at a premium in rooms that are maintained under constant temperature and relative humidity conditions. Since one must also ensure that the feed of water is kept up to each tile, it is also

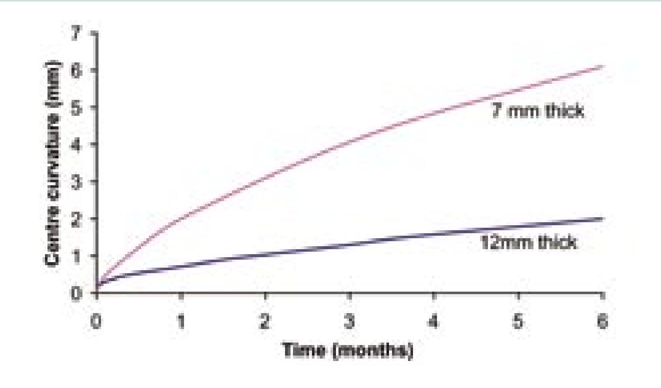


Figure 1 Centre curvature of two unrestrained 600 x 300 mm engineered marble tiles, where the rear of the tile was continuously wetted

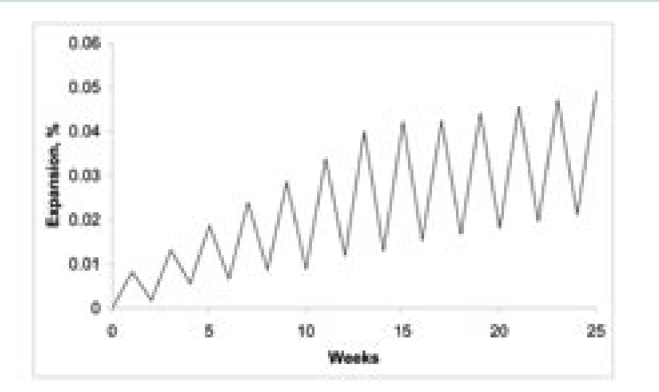


Figure 2 Progressive expansion of 10 mm thick engineered marble tile prisms on weekly cycling between 50 and 100% relative humidity at 23ºC.

somewhat labour intensive. Another limitation of this test method is that as the tile curls, contact is eventually lost between the tile corners and the water reservoir (towel). The curling may have been more pronounced if a cut-to-size towel and an impervious backing had been held to the tile corners by elasticised tapes, similar to some pre-fitted mattress overlays.

One can calculate how much centre curvature would theoretically result from a certain amount of expansion of one face of a tile with given elastic properties and geometric proportions. Thus rather than measuring the amount of bow across the tile diagonal, one could assess the relative moisture reactivity of a material by measuring the length changes that occur in specimens subjected to uniform changes of environment.

Figure 2 depicts this type of long-term dimensional stability study, where the tile is cut into slender prisms. The length change measurements are made in a comparator under constant temperature and relative humidity conditions. The specimens are typically measured each week, after being cycled between conditions of 50 and 100% relative humidity, both at 23ºC. While other atmospheric conditions could be selected, the major disadvantage is again that it is somewhat labour intensive and requires long exposure times. However, the smaller size of individual specimens allows the use of climatic chambers, significantly reducing the demand for laboratory space in rooms maintained under constant temperature and relative humidity conditions.

As **Figure 2** indicates, the typical pattern of such cycling is that of expansion on exposure to wet conditions and shrinkage during drying. However, the amount of expansion recorded after each wetting cycle increases and there is a greater residual expansion after each ambient exposure condition cycle. In this instance, there was a reversible moisture movement component of about 0.025%. When the tile was fully dried (at 40ºC), there was a residual expansion of about 0.01%. It should be noted that this 10 mm thick 300 mm square tile had a centre curvature bow of 0.4 mm after the rear of the unrestrained tile had been continuously exposed to moisture for two weeks.

The question that must be asked is “How meaningful are such measurements?” If Class A tiles can bow so much, why don’t we see more failures? There are two aspects to the answer. The first is the relative availability of water at the rear of the tile after fixing – if one obtains the recommended 90% minimum contact coverage for floor tiles in wet areas, there is little of the tile that is available for reaction once the adhesive has set. However, the level of restraint that is provided by the bonded tiling system is more significant.

Restrained vs unrestrained expansion

In trying to accommodate inevitable differential movement, the inevitable choice has always come down to a question of providing more restraint (a stronger adhesive bond) or allowing more movement (through use of a more ‘flexible’ adhesive). The new AS 4992 ceramic tiling adhesive standards have significantly increased the tensile bond strength requirements for ‘standard grade’ adhesives bonding impervious tiles to concrete. The use of transverse deformation measurements, as a de facto measurement of flexibility, provides an indication of the adhesive to allow movements to occur in such high bond strength materials. Such adhesives should restrain the tiles so that curling should not occur once the adhesive has set, presuming that the substrate is quite rigid and capable of resisting any applied stress.

However, the escalating use of one or more intermediate tiling layers (waterproof membranes, acoustic membranes, heating systems, etc) complicates matters. A weak or highly deformable membrane that is weakly bonded to the substrate might provide insufficient restraint to prevent bowing of the tile. Working Group 3 of ISO Technical Committee 189, Ceramic Tiles, is preparing standards for testing membranes as an element of tiling system performance.

There are other causes of deformation and stress, such as temperature changes and concrete shrinkage, creep and deflection, which act in conjunction rather than in isolation. The superimposition of a transient thermally induced movement might initiate a localised failure that facilitates subsequent moisture induced bowing. Some membranes act as barriers permanently trapping water within the tiling system. As one manufacturer advised “When the water cannot escape through the underlying screed, the grooves between the tiles or the perimeter border, it results in detachment and tension, which inevitably leads the tiles to warp in an uncontrolled manner”.

Very few manufacturers indicate that their engineered stone tiles can be used for external flooring. One manufacturer states that their products must be at least 20 mm thick for external flooring and fixed using polyurethane based adhesive, with tile-size related grout joint widths and defined intermediate and perimeter movement joints. Large exterior floor tiles (60 x 60 cm) must be at least 30 mm thick.

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Accelerated testing

A potential means of accelerating such a dimensional stability test is to autoclave, steam or boil specimens. Ceramic tiles are boiled to assess their moisture expansion potential (AS 4459.10, Determination of moisture resistance) and bricks are steamed to determine their coefficient of expansion (AS/NZS 4456.11:2003, Determining coefficients of expansion). Ceramic whitewares have been subjected to various autoclaving treatments in order to determine their moisture expansion (such as ASTM C370, Moisture expansion of fired whiteware products) and crazing resistance (AS 4459.11, Determination of crazing resistance for glazed tiles, and ASTM C424, Crazing resistance of fired glazed whitewares by autoclave treatment). The advantage of such tests is that they can take less than a week to conduct. A potential difficulty always lies in establishing correlation between the accelerated expansion and the natural expansion that might occur under ambient atmospheric conditions.

The use of some autoclaving treatments will induce expansions in ceramic bodies that would not occur under normal ambient conditions. While ceramic tiles have good thermal resistance characteristics, resin bonded tiles are more likely to be permanently altered by the use of extreme conditions, which might cause phase transformations or surface degradation.

Concluding remarks

While the causes and kinetics of ceramic tile moisture expansion are complex, experts agree on the fundamental principles. The dimensional instability of engineered stone tiles does not seem to have been similarly investigated. Although very few standards have been specifically prepared for engineered stone tiles, development of an accelerated dimensional stability test method would seem a productive investment.

Is it optimistic to expect that the industry will define tests and classes for the potential movement of natural and reconstituted stone tiles? The new adhesive standards would provide an excellent framework for specifying minimum classes of adhesives based on the size and movement classifications (dimensional stability) of tiles, when preparing a new AS 3958 Part 3, Adhesive fixing of natural and reconstituted stone tiles.

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(Footnotes)

[1] Discovering Stone, Issue 5, March 2004, p 66, also available at http://www.asaa.com.au/publications/e-digest/6/

[2] Realtá Mapei, No 46, November 2000, pp 33-36

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