

Thermal movement and moisture stability issues

During the last few weeks the Australian Stone Advisory Association (ASAA) has received several calls in relation to problems associated with moisture sensitivity issues. In each instance ASAA was able to assist in providing a satisfactory outcome. In two instances the material in question was bluestone from China. Some imported Chinese bluestone is comparable to the excellent material which is available from local producers. Unfortunately, some imported product has a tendency to stain. One caller explained that she was unable to move into her new home because of moisture sensitivity problems. The homeowner tried six different cleaning solutions before contacting ASAA.

Figure 1 (left). Adhesive show through on spot fixed limestone tiles.

Figure 2 (right). Picture framing on marble tiles either due to adhesive or grout related moisture problems.



The following article (Technical Paper TP005) produced by Ardex Australia deals with some of the problems which arise in relation to moisture sensitivity and stability. It's interesting to note that several architects have recently contacted ASAA seeking guidance in relation to choosing the right stone for a specific project. Prevention is always better than cure.

Since 2007 the tile market has seen a significant growth in the sale and usage of tiles made from quarried rocks (*senso lato* – 'natural stone'). In particular the market has seen a gradual increase in the size of the tiles with lengths of 600 to 900mm becoming common. Such dimensions create an issue for adhesive dead loading, but another more critical set of problems have appeared, thermal movements and moisture stability.

Traditional stability issues

The market is familiar with the peculiarities of some types of rock used for tile and dimension stone. In particular, the problems of warping, grout or silicone picture framing and adhesive show through for marble and limestone, but also the dimensional instability of so-called 'green marble' (*senso stricto* – Serpentine and Blue Schist) are well known to the industry.

These problems can be minimised by the correct usage of products for fixing the tiles and finishing the installation. In particular the use of non-water based or specialised adhesives and grout eliminate moisture effects for porous and sensitive tiles.

Neutral cure silicones eliminate the Acetic Acid attack on carbonate stones, but these must also not contain mobile solvent or low molecular weight polymer phases that can migrate and create problems as well.

Unexpected stability issues

We can ask, why are these issues being problematic now? It is because some of these

stones do not show the problem when used as "ashlars", it is only when the block is cut into thin section slabs for use as tiles that the issue becomes evident. Also the use of thinner stone and the mesh backing embedded in resins create other issues.

The current trend towards cheaper imported tiles, and away from locally quarried quality tiles or higher market end European sourced dimension stone, but in particular black and dark colours, has led to a number of other unexpected problems with stone tiles.

Ardex has seen a range of unusual stability issues associated with tiles produced from imported types of stone. These problems include temperature related warping, moisture related warping and also weathering of unstable minerals and components. Darker colours can create problems with substrate stability, and also premature ageing and stress fatiguing of the adhesive.

The movement problems can be either overall growth, due to expansion through the entire tile body, or more commonly differential movements due to one side of the tile being exposed only. The former produces expansion and peaking at the joints, and the latter cupping/oming and peaking/down curling at the edges and corners of the tiles. Both effects can create adhesive de-bonding and loose tiles.

In relation to movement, it is important to recognise the three dimensional quality of these changes. Traditional moisture movement testing of stone tiles is done in the horizontal X (length) and Y (width) directions with fully saturated samples, but less commonly in the Z direction (vertical axis = tile thickness changes or deflections). Movements in X and Y produce overall growth and shrinkage, whereas Z axis movements create either slight vertical expansion of the tile, or larger bowing and cupping movement due to differentials.

Tile thickness

Traditional 'ashlar blocks' are thick and heavy tiles, used for their structural and decorative properties. Such large formats possess their own kind of stability, even when made from suspect stone types. The reason being, that the thicker tiles are more resilient to deformation and take longer to be affected by either moisture or thermal effects. However, such large tiles are hard to fix, hard to transport and require specialised installation. As a result the same types of stones are being cut into thinner slices, with a common thickness of 12-15mm. The result of this is to remove the resistance to movement that thicker stone allowed encouraging, more rapid and proportionally larger movements to occur.



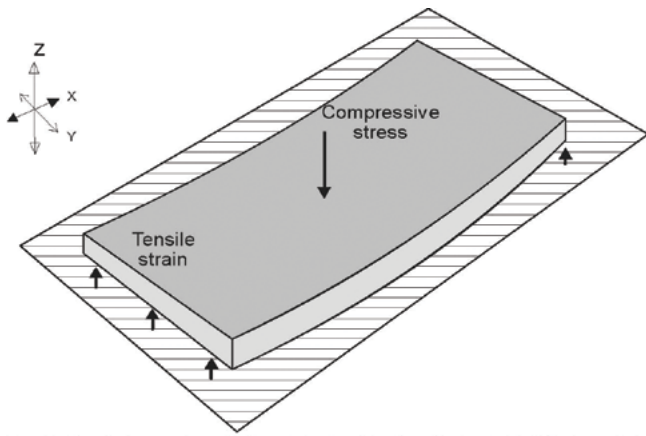
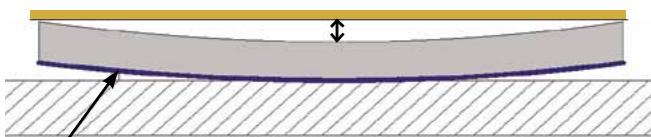


Figure 3. Schematic diagram showing the three strain axis and how they relate to a tile. The X-Y in horizontal plane for length and width changes, and Z in the vertical plane representing thickness changes or vertical deflections. The positions of tensile strain and compressive stress applied by the tile to the adhesive (and also underlying substrate) for a rear face expansion are shown (edges lifting). The positions are reversed for front face expansion (centre lifting). The cross-hatched area represent the tile adhesive bed.

Observing Z axis deflection in a tiled surface using a straight edge



Moist lower face expanding relative to top



Heated upper face expanding relative to back

Figure 4. Schematic diagrams showing the differential movement effects observe in natural stone tiles. The upper face expansion can also occur with moisture sensitive tiles exposed to ponding rain water.

Thermal movements in detail

Stone possesses relatively low thermal co-efficients which act as insulators. Where the sun falls onto the tile surface, be it outside, or through a large window, the tile surface is heated more rapidly than the tile body. This effect is far more pronounced on dark coloured tiles which are highly effective at absorbing radiant energy. Ardex has measured surface temperatures on dark coloured tiles exposed to the sun slightly in excess of 600C, on warm but not excessively hot days with air temperatures around 30-320C. The high surface temperature results in the upper layers of the tile expanding relative to the back, and producing differential movement in the tile (this occurs until the tile heats all the way through, which may not occur in thick tiles or slabs in the time exposed during the diurnal period). This creates high tensile strains in the centre of the tile and increasing compression around the edges. Each time the tile is exposed it heats up and expands, but when it is not exposed it cools down and contracts. This cycle contains a degree of time lag hysteresis and so the tile does not exactly go back to its initial state before the next cycle.

This cyclic effect can, over time, stress fatigue adhesives. If it occurs before the tile adhesive has developed high strength (for example less than 24-48 hours old), the adhesive can shear cohesively and the tile becomes drummy. If the stone is 'strong enough', that is has a high compressive strength, but more critically a high E-modulus, then combined with large Z direction movements, it can exert very high strains that exceed the nominal tensile strength of most cement based adhesives and cause cohesive failure within the adhesive. (The same effect occurs with moisture movement as well).

This description is the normal expected deformation for heated tiles with doming of the tile as the upper face expands. However, in some instances the opposite may occur and the edges curl upwards. The reason for this is not clear, but in the worst case seen to date, the tiles deformed purely due to heated air temperatures and direct sun exposure.

Where the tiles are exposed all day to the sun (i.e. E-N-W walls) the tiles will eventually heat through and start to have effects on the underlying materials. Depending on the day time temperature and the darkness of the colour, the temperature rise may exceed the nominal 700C service temperature for the adhesive. It can also produce durability issues with the substrate over time. In general fibre-cement manufacturers for one, do not recommend external tiling onto their sheets. This is in part a loading issue, but also a weathering issue which high temperatures accelerate.

These two contour maps show the measured deflections in a so-called. 900x450x25mm 'basalt' tile exposed to the sun at Ardex's laboratory in Sydney during March 2009. The vertical Z axis deflections are defined by the contours and colour changes. It can be seen that this tile displayed a range of movement in excess of 2.5mm during the course of the day's sun exposure. This is sufficient to strain adhesive beds and create drummy tiles and lipping issues.

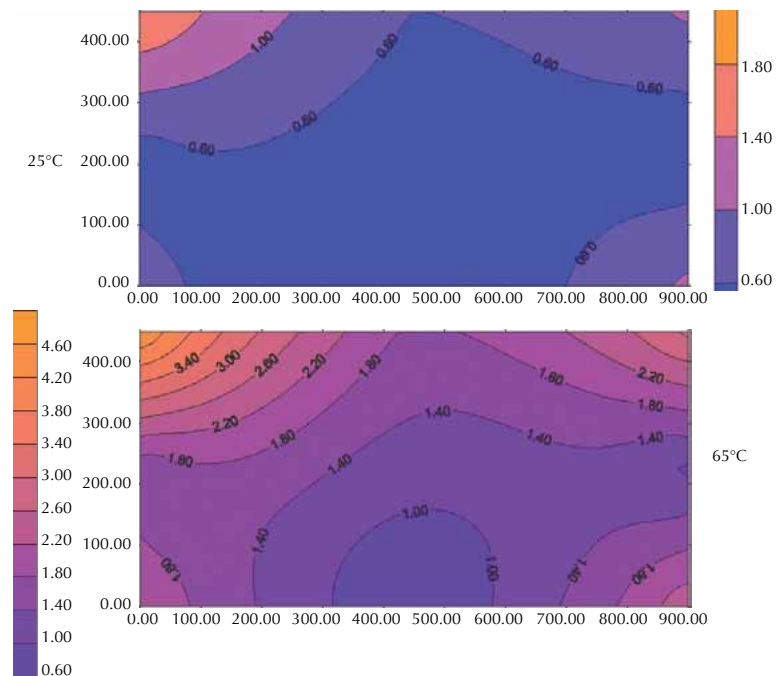


Figure 5. Vertical (Z axis) deflection contour maps for a thermally unstable stone tile exposed to direct sunlight. The contour measurements are in mm. This tile produced unacceptable deflections on a job site in hot weather during the summer months in 2008-09. As can be seen, there was a significant difference in the tile flatness between cool and hot conditions with the tile dishing by >2mm.

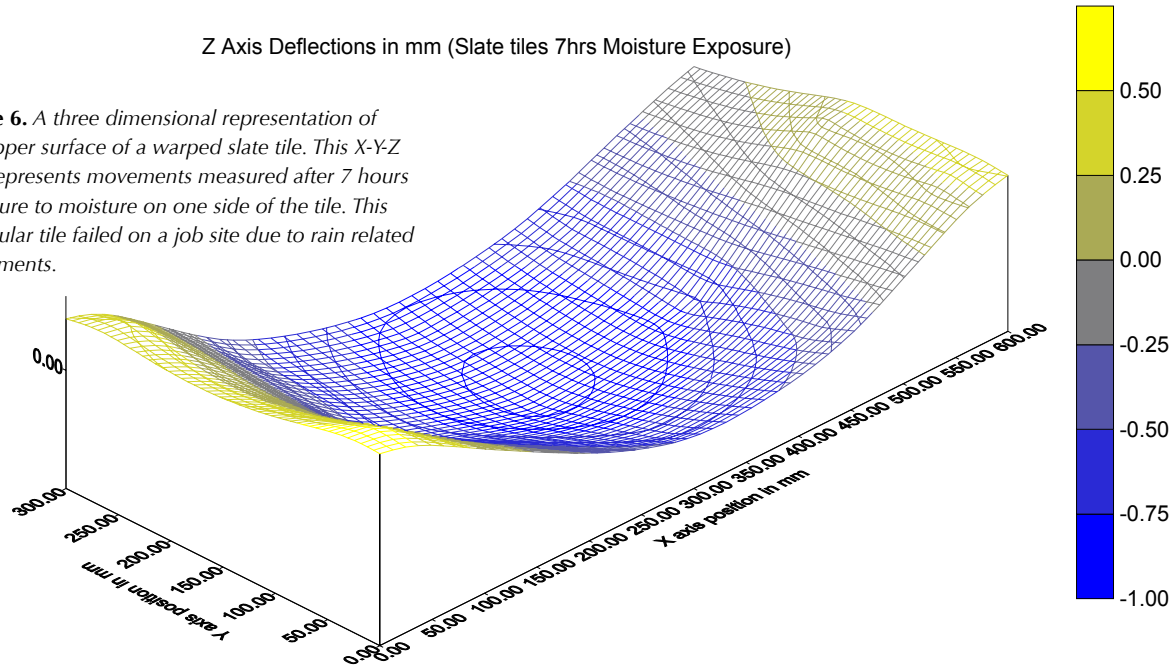
There are only two ways to get around this type of problem, either select light coloured natural stone types that do not heat up as severely, or stones that do not display significant thermal movements. Unfortunately, the latter is not necessarily easily determined without testing, and is likely outside the scope of the suppliers range of quality control properties. The former, using light colours, has advantages for reducing thermal cyclic strains on the underlying materials, and would also no doubt assist in the buildings

thermal efficiency, in terms of reduced requirements for cooling. Dark coloured paving surfaces can create unpleasant problems for pedestrians in summer.

(Editor's note: It is of course necessary to point out that it is common practice to fix natural stone tiles and ceramic tiles, using mechanical fixing techniques, where the height of the tiling exceeds 3 metres. This process provides greater scope for movement, increased stability, thermal efficiency and a substantial decrease in the risk of failure.)

Z Axis Deflections in mm (Slate tiles 7hrs Moisture Exposure)

Figure 6. A three dimensional representation of the upper surface of a warped slate tile. This X-Y-Z plot represents movements measured after 7 hours exposure to moisture on one side of the tile. This particular tile failed on a job site due to rain related movements.



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Moisture movement in detail

Movement in stone tiles is a function of a stone's porosity, together with the stability of the constituent minerals and also the matrix. The term matrix really refers more to sedimentary rocks than crystalline igneous and metamorphic rocks and is the binder that holds the particles together. That being said, fine grained volcanic igneous rocks can be composed of a background matrix and crystals as well, and finer grain metamorphic rocks can also display this texture.

Porosity

The porosity of stone is a measure of the amount of pores within the stone structure which allow the penetration of water. Non-porous or 'tight' stones do not allow the penetration of water and are more resistant to moisture related issues. The tightness is a function of the interlocking boundaries of the mineral crystals that make up the stone. Most crystalline plutonic igneous and metamorphic stones are considered tight, with low porosity, however volcanic equivalents are often highly porous. Sedimentary stones such as sandstone are also porous, and are well recognised as conduits for artesian water supplies, and also underground oil reservoirs. Limestones such as travertine and caliche are also highly porous.

There are two issues with porosity, the first is that highly porous stone tiles can easily stain or discolour, and the second is that high porosity can lead to dimensional stability problems. With staining and marking, this can either be a permanent or temporary effect. Temporary marking is purely due to the stone being wet, and is a result of moisture in the adhesive, or possibly the substrate. Permanent staining is either due to changes in the stone itself due to the water, or the stone capturing water mobile salts or polymer phases, and producing a physical or chemical alteration.

Matrix components

The matrix of sedimentary stones usually features very fine grained minerals, down to silt or clay size (these are particle size names and range from 0.06 to 63µm), and the composition can vary widely. The most common matrices are the actual clay minerals (i.e kaolin), lime mud, re-deposited silica and in the case of volcanic rocks devitrified glass. The fine grained matrices tend to display a similar affinity for absorbing water which either produces a physical appearance change (staining), or swelling and dimension change with warping. The higher the amount of matrix, the more unstable a stone is likely to be.

These problems do not appear to be a major issue for sandstones bonded with redeposited silica. The most heavily affected stones include materials like fine grained sandstone (with clay or fine lime matrices), muddy limestone (travertine etc.) and some light coloured volcanic stones. Slate, whilst a metamorphic rock can also display this effect because it is composed of aligned clay minerals.

The fine grained matrix absorbs moisture from the adhesive and warps upwards, whilst others change colour and darken, usually in patches producing a blotchy light-dark appearance (see Figs.1 & 2). In the case of crystalline marble, the amount of matrix is minimal or non-existent and the effects that occur with these tiles are usually show through or shading due to translucence.

Warping

Warping is a differential effect with the stone expanding on the wet side relative to dry side. Where the tile is not bonded, the warping normally disappears when it dries out, or conversely when it is fully saturated. The moisture source that affects the base side can be from the substrate or adhesive, but also rain and ponded water can effect the upper face as well (see Fig.4).

A deformable free tile is one thing, but when the tile is glued down that is a different problem. Where the tile bottom contacts a water

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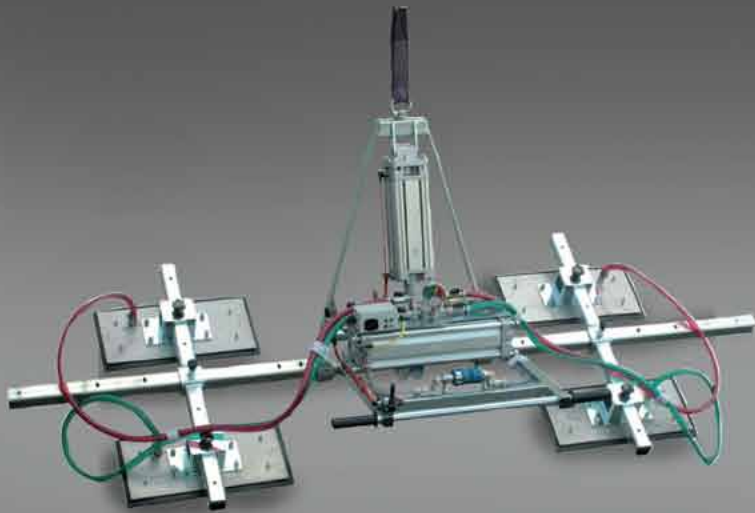
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based adhesive (or wet substrate), the surface can begin to expand and the tile starts to warp into a dish. When the adhesive is soft it could accommodate this movement, provided the relaxation occurs before the adhesive hardens (unless it is so great that it cohesively fails the soft adhesive). However, the more common situation is the adhesive dries and has developed a degree of cure before the tile stabilises. This can either lead to compressive stress being applied to the adhesive around the tile perimeter, or excessive tensile strain being applied to the tile centre, cohesively shearing it with resultant drumminess. (Rain onto an unstable tile produces the reverse effect with doming of the tile in centre and down curling at the edges, but results in the same type of ultimate failure).

Solutions

The solutions to using natural stone tiles made from unstable stone types are not simple. Ideally such stones should not be quarried, but realistically that is not commercially going to happen. This means that 'work around solutions' are required, for example using specialised adhesives when these tiles are encountered, but in some cases not using them at all and selecting something else for the job which is more appropriate.

In terms of thermal effects, tiles with light colours will not develop such high temperatures and hence reduce potential movements. However, there is no quick check when purchasing these tiles to determine whether they will move, or simply just get hot and sit there.

Moisture sensitive types can usually be identified by a careful examination of the tile for porosity and matrix types, but some varieties of limestone and marble are well recognised moisture sensitive products.

Of late, one suggested solution for moisture related problems is to use a stone sealer on all sides, however this requires careful selection of the sealer since many appear to interfere with the adhesive bond leading to later failures. Again, this is something that can only be identified by testing so is not a simple thing to do in the field. Sealing does not do anything to solve thermal problems.

Some adhesive based solutions to the problem of unstable stone tiles are:

- Use high strength non-water based adhesives
- Use rapid cure cement based systems which develop a high proportion of their tensile strength in a short space of time
- Use specialised adhesives that do not allow free water to penetrate the tile surface before they dry. Such adhesives also develop rapid cure as well providing high strength rapidly
- Use hybrid systems where the tile back is coated with a lower viscosity 100% solids epoxy which whilst wet is laid into a high strength cement based adhesive bed

Finishing also requires the use of specialised grouts and also specifically designed sealants to prevent picture framing.

Ultimately though, the old customer protection maxim, '*caveat emptor*' (let the buyer beware) needs to apply when selecting natural stone tiles for any external or critical job. 