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Version 1.0
Release Date February 2015

STONE & CONCRETE PAVING INSTALLATION

Recommendations for the laying of large format natural stone, manufactured stone, and concrete pavers

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NOTES



Purpose

The 'Stone & Concrete Paving Installation Recommendations for the laying of large format natural stone, manufactured stone, and concrete pavers' serves to provide Landscaping Victoria members with current techniques and learning's from industry practitioners with a view to overcoming issues experienced in the field around 'lifting' pavers.

Assumptions

The paper assumes basic knowledge of landscaping terminology and methodology.

The paper further assumes that, in line with current practices, all paving is being completed on a concrete substrate.

Definitions

Paver

In the context of this paper, 'paver' refers to a tile, paver or stone made from natural stone or manufactured from a variety of natural and man-made materials when installed and used as an external ground surface.

Lifting

'Lifting' will be used in this paper to summarise terms such as 'curling', 'cupping', 'popping' and 'drummy'.

Audience

This paper has been written for all members of Landscaping Victoria.

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Summary

The *Stone & Concrete Paving Guidelines for natural and manufactured stone and concrete large format pavers laid on a concrete substrate V1.0* is a paper which has been released in response to a growing number of queries by Landscaping Victoria Members seeking advice on the recent performance of stone and concrete tiles or pavers.

Stability issues are becoming common, with reports of paving jobs lifting being reported almost weekly.

Causes of this instability can be attributed to installation techniques, material choice, or a combination of both.

Installation

Issues can include failure to;

- apply a full coverage of the bedding material
- properly prepare substrates
- choose the right laying method

Material Choice

Anecdotally, one of the main causes for concern is that some pavers are being cut thinner to save costs.

Whilst there may be an initial saving for the consumer in choosing cheaper, thinner products, the money saved on the purchase price will quickly be consumed by increased installation costs or worse still, re-laying costs incurred by you as the designer/landscaper/contractor having been responsible for specifying or laying the paver.

Other factors beyond depth of product come into play too, such as:

Colour

The darker the paver, the more heat it absorbs. This is particularly problematic if the paver is moisture sensitive and strong sunny conditions are experienced after a period of rain. The top surface will heat and dry out quicker than the base, which can ultimately lead to curling.

Shape

Integrity of the paver is maintained at a higher level when the paver is square, or its sides are at a ratio of 1:1. The natural forces of expansion and contraction in a rectangular paver of ratios 2:1 or above are very different and as such the reaction of the paver is more volatile and particularly susceptible when too thin.

Suggestions covered in this paper should provide you with enough information to avoid problematic issues with paving for outdoor landscaped environments regardless of the origin, material content or size of the paving materials being worked with.

Content Topics

Areas covered include

- Paver Supplier & Type
- Paver Preparation
- Bedding Types
- Bonding Agents
- Joints
- Weather and Maintenance

As always, should there be any element of a job that is questionable, seek advice from your Supplier network, a structural engineer or contact Landscaping Victoria for further direction.

Paver Supplier & Paver Type

Paver selection is key to a good paving job and there are two elements that you need to consider when making your choice of pavers, or suggesting a paver to a client:

The Supplier

Ensure that the supplier is selling you pavers which are **fit for purpose**, for example paving around a swimming pool; are the pavers suitable if exposed to chlorine or salt water? Will the pavers be suitable for heavy vehicular traffic areas, etc?

The supplier should be able to provide you with specific information about the most appropriate paver type, about laying techniques for that particular paver as well as specifications for sealing and maintenance. To provide the supplier with the best opportunity of giving you the best advice regarding selection and laying you should consider the following pavement related performance criteria;

Selection Criteria:

- *The type of traffic (pedestrian/vehicular) likely to be carried*
- *The weight of the traffic likely to traffic the area*
- *The frequency or amount of traffic carried*
- *Abrasive characteristics of the traffic*
- *General layout of the pavement (surface grades/alignment)*
- *Environment (rainfall/humidity/surface drainage)*
- *Any relevant site specific issues*

Recommendation:

Establish a good working relationship with your supplier. You need to be able to trust that they will provide you with the right advice.

If a supplier is unable to provide you with specifications about their product and how to correctly install it, it would be suggested to source another supplier.

The Right Paver

Having determined that your chosen paver is suitable for the environment it will be laid in, you now need to choose the right size. As already mentioned, pavers are becoming thinner. Providing the size of the paver is less than 400-500mm and at least 20mm thick you shouldn't experience any of the issues mentioned here.

Where the thickness is problematic is with larger pavers, and current design trends are seeing some pavers over 1000mm being specified on jobs, or chosen by the client.

The thickness of the paver is important for load bearing but more importantly it mostly governs the integrity of the paving unit itself, in the form of **stability** and **deflection**.

The stability of the paver is about whether the paver is moisture or heat sensitive, meaning that the paver would curl if there is excessive moisture present in the laying process or allowed to get into the laying system. If this happens the paver will warp, becoming 'drummy' in all 4 corners while remaining solid in the centre.

Deflection has to do with the paver being able to handle point loads. These issues can be reduced or eliminated with some laying techniques that will be covered later.

Abrasive wear and slipperiness may also be significant problems in some circumstances.

Recommendation:

The larger the surface area of a paving unit, the thicker it should be.

- *A paver over 600mm on any one side should be **30mm minimum** thick*
- *A paver over 1000mm on any one side should be **40mm minimum** thick*

INSTALLATION TECHNIQUES

Paver preparation

For most pavers the preparation is as simple as cleaning the paver with a sponge and water so as to remove any dirt residue and dust. This can also assist to 'even out' the porosity of the material creating a consistent drying time of the bonding products (being mortar or adhesives).

Cleaning

The cleaning of the material of course helps with the bonding of the product, for the main reason that the bonding products are bonding to the actual paver, and not the dirt or dust. Some pavers may need more preparation such as a steel brush or pressure wash or the extreme being mechanical removal of any quarry residue.

Sealing

More moisture sensitive or more porous products may need to be sealed prior to laying, or at least prior to grouting. This could consist of dip sealing all surfaces prior to laying.

Sealing may be necessary for the prevention of staining but can also be utilised to achieve a certain aesthetic. There has been significant development in sealing products in recent years with greater resistance to wearing and ability to withstand UV. Always ensure that pavers are cleaned and fully dry prior to sealing.

Reduce Moisture Content

Some manufactured pavers may need to be acclimatised prior to laying. If the paving unit has not been cured properly, it can shrink after the paver has been laid and break the bond to the bedding. This type of issue can be overcome by simply standing the paver on edge with a gap between to allow air flow which will lower the moisture content of the material.

Product Blending

Often natural stone is packed as the stone is cut and therefore variation in the stone may be inconsistent if not inspected and blended prior to installation.

Foundation and substrate preparation

The supporting base (and possibly sub-base) structure/s should be fit for purpose, giving the system the ability to handle the traffic load anticipated as determined in the planning process. The stronger the base structure (and the supporting soil substrate) the better the ability to support the bonding system and therefore the paving material.

The supporting base or screed surface must be made clean and dust free so as to enable it to be bonded successfully to the paver.

Drainage

Subsurface drainage and waterproofing is an important consideration in paving preparation, and as such, some supporting base structures or screed surfaces may need to be waterproofed to not only repel water but to also reduce the amount of efflorescence.

A gradient 'fall' in the subsurface (and subsequently the paving) will also assist with drainage and prevent water pooling. Dependent upon the physical quality of the pavers, fall should be a minimum of 1%, where paving material is quite even and smooth, and a discretionary higher gradient where rough/natural pavers are being used. Higher gradients, whilst helpful in dispersing water, can be unappealing visually.

Depending on the situation, a waterproofing membrane may be required (e.g. rooftop terrace).

Recommendation:

In all scenarios of laying pavers, the supporting base structure (if concrete) must be left to cure prior to laying.

Bedding Types

The minimum and maximum bed thickness depends on the task at hand, but is also determined by the system of bonding such as adhesive fixing or mortar fixing.

The installation of bedding is one the most important parts of the paving process. It is not only important to ensure adequate load bearing of the paver, but is critical to the bonding of the paver to the substrate.

Ensure that the bedding material is compacted – the better the bedding is compacted the better the ability to handle loads.

Concrete Substrate

Recommendation:

All external paving should be executed on a concrete substrate.

Thickness

A reinforced concrete base should be specified or engineered for vehicle trafficked areas, such as road ways, carparks or driveways.

As a general guide - Slab Thickness:

- Pedestrian Traffic - Min 75mm with reinforcement
- Vehicle Traffic - Min 100mm with reinforcement

Standard curing times should be allowed prior to laying all pavers or tiles onto fresh concrete.

Mix Ratio

Concrete base should be minimum 20mpa strength

Screed Bed

Thickness

The minimum bed thickness should be 20mm.

(This could be around 15mm if a latex additive is used.)

The maximum thickness should be 60mm before some form of metal reinforcement needs to be installed into the bed.

Mix Ratio

Screed beds should be a ratio of

- 3-4 parts washed sand
- 1 part cement or as per manufacturer specification if using a substrate preparation product such as a latex additive
- The grain or aggregate size of the sand is relevant to the thickness of the bed.
i.e. thicker bed = heavier grain of sand

Mortar Mix Bed

Thickness

The minimum thickness should be 15mm.

The maximum thickness should be 40-60mm before some form of metal reinforcement needs to be installed into the bed.

Mix Ratio

Mortar beds should be made up of

- 3 parts washed concrete sand,
- 1 part (White) brick sand and
- 1 part cement

Higher early strength cement (white cement) is preferable. It cures quicker than GP cement which encourages a better bond to the paver.

Adhesive Bed

Thickness

The minimum thickness should be 3-4mm.

The maximum should be 10-12mm.

Mix Ratio

Adhesive should always be mixed

- As per manufacturer's specification
- With full contact/coverage of the back of the paver surface. This is critical.

Bonding Agents

The bonding agent that is applied to the substrate to bond the screed or mortar bed, or that is applied to the back of the paving material to bond it to bedding, is very important for correct bonding. It is very under-rated and often not mixed or applied correctly.

Slurry as bonding agent

The slurry should consist of either water and cement or a latex additive and cement, mixed to a creamy type consistency. When applied, the bedding or paver should be installed when the slurry is still wet; (a wet on wet scenario).

- If the slurry is allowed to dry prior to laying it will not bond properly
- If the slurry is too watery it will be washed away with water in the bedding material, or be lost when drawn up into the back of porous pavers

The slurry must have some substance so that it can do the job it is meant to do. Never rehydrate any cement-based mix that has started to go off.

Adhesive as bonding agent

When laying larger format (particularly rectangular) paving, a better bond can be achieved by using an adhesive as a bonding agent.

The adhesive should be applied to both the substrate and the back of the paving material (6mm notched trowel is suitable.)

This process allows the bonding agent some flexibility in the initial curing process of the mortar mix.

Note: Always check previous days laying to ensure the methodology being used is achieving the desired results. If there is evidence of de-bonding, methodology should be modified immediately.

Recommendation:

- *Make sure the wet on wet aspect is followed*
- *Make sure the bonding agent is worked into both the substrate and the back of the pavers*
- *Full back-buttering/pasting (corner to corner) of the paver prior to placement on the bed material is essential to achieving full bonding i.e. the better the coverage the less chance of deflection in the paving material*
- *Make sure the pavers are worked into the bedding, not just placed on top of the bedding; this will create the correct coverage*
- *To avoid "picture framing issues" - light tiles should be laid with white glues/mortar and dark tiles should be laid with dark glue/mortar*

Joint in pavement

Movement (or expansion) Joints

Movement joints are essential in pavement. This includes the surfacing material (pavers), the mortar beds, as well as in the balance of the supporting structure (base layers). All these components absorb moisture and heat and expansion is inevitable. Soil movement may also be reflected through the pavement. Movement due to any of these factors may damage the structure in part or as a whole if the structure is not engineered to accommodate this movement.

Movement joints should be approximately 6-10mm in width and should be in consistent alignment through all properties of the pavement (substrate, bedding material and paver). Ensure all movement joints are free of bedding material or any restricting material prior to being filled with flexible material/s.

If the joint is more than 10mm deep then foam backing, filler rod or the like should be applied prior to the installation of the flexible sealant. The flexible sealant can be silicone, be it neutral cure or acidic cure (depending on the paver) or polyurethane.

The more porous the paver and the darker the colour, the more frequent the movement joints need to be. This could mean that the joints may be as close as every 3 metres.

Recommendation:

Expansion joints are (usually always) required. It is up to the contractor to determine where they go based on the site conditions, pavement application, and pavement structure. Site specific structural engineering advice should be considered.

Joint Width

The width of the grout joint is determined mostly by:

- the paver being of a certain standard
- the edge finish of the paver
- the edge profile of the paver
- and of course the desired look

The minimum recommendation is 3mm and the maximum is subject to the desired look and grouting product specifications.

Grouting joints

As with laying, weather will also have an effect on the success of grouting joints so note the recommendation above.

In preparing the joint, as with all other stages of the laying process ensure it is free of debris. The edge of the paver should also be ready to accept the grout i.e. free of dirt, dust, wetted down (moist but not awash) if necessary etc.

The grout mix, be it factory blended or blended on site, should be mixed correctly. Ensure it is not too wet or rapid dehydration will cause shrinkage, with potential for the cement component to be washed to the bottom of the mix which can result in a mottled colour finish.

The darker the grout colour the more important that the grout is mixed, allowed to rest and then re-mixed prior to use.

Recommendation:

- *Mix grout as per manufacturers' instructions, ensuring consistency is not too wet as this can reduce strength and result in cracking*
- *Ensure full depth of grout in the joints is achieved. If grout is not worked into the full depth of the joint there will be resulting grout failure. Failure of grout allows moisture into the substrate and causes widespread issues*

IMPORTANT!!

Before any grouting or expansion joints are installed, all paved areas should be checked for de-bonded or 'drummy pavers'. In most cases the de-bonding occurs through the initial curing period of the bedding mix (5-12hrs).

This is the ideal time to undertake remedial works to rectify this issue. If ignored and grouting is installed it will greatly increase the likelihood of cracking and spalling of grout lines.

Weather conditions

Do not lay when it is over 35 degrees; the substrate can be too hot, paving material can be too hot, material for the laying process can be too hot. This can all lead to rapid dehydration of the laying system, thus creating de-bonding due to slurry and mortars not binding together and rapid shrinkage of the laying system and possibly the pavers.

Conversely, rainy conditions can over hydrate the system which can cause the slurries to be washed away and the cement components being washed to the bottom of the mortar mixes, making the bond and the integrity of the mortars weaker.

Recommendation:

Cover your work space to protect components of the job from the heat and rain.

Maintenance

All paving work, once complete, should be kept clean from dirt, dust, mould and efflorescence. These potentially damaging elements are usually controlled quite simply using just water. However if the elements are left to grow or stain they are harder to remove and can do permanent damage. This maintenance should be the obligation of the owner of the property unless otherwise organised with the contractor.

It is recommended to advise the property owner against using acid based cleaning products. Acid cleaning of the paver surface is required to remove cement-based residue from the laying process, and is best done by the paving or cleaning contractor.

Recommendation:

For advice on suitable proprietary cleaners for general maintenance of pavers, talk to your paving supplier.

Prepare to update your techniques

Just like any industry, Landscaping experiences the release of new materials and new products from time to time. With these advances comes the need for new techniques, methods or standards.

'We've always done it like that' is no longer a valid comment – the industry has to come to terms with the fact that these changes are taking place and learn, adjust and adapt as needed.

The fact that some paving units are more like tiles means our methods have to change. Working within the confines of the weather conditions, the method of screeding and allowing the screed to dry, waterproofing the screed and then using adhesive fixing is going to become more prevalent in the industry because of the moisture sensitive products being sold.

Direct fixing to concrete using adhesives is also going to be more prevalent for the same reason but also due to the thin pavers coming onto the market. Adhesive fixing is going to be a skill that paving contractors are going to have to learn and implement in their businesses.

Adhesive in large format pavers has to be applied both onto the back of the paver and onto the substrate, and again worked in properly.

Waterproofing and adhesive fixing needs to be discussed and learnt by the landscaping trades when it comes to water features and walling, such as retaining walls, feature walls and the like.

"...the issue of warping is in part due to using old practices on new products. For the industry to grow it is important that all aspects of the industry – the quarry, the tile shop and adhesive manufacturers – stay informed and work together to reduce the mysteries within stone and provide the consumer with a low risk product."

Jim Mann, Director ASAA

Continue to Learn

Appendix 1

For further information on stone thickness relating to stability, supported by technical details, refer to;

“Thermal movement and moisture stability issues”

First published in *Discovering Stone*, Issue 18

Appendix 2

For further information on the physical properties of basalt (bluestone) including density and porosity and how these properties react, refer to;

“Basalt – the warping issue”

First published in *Discovering Stone*, Issue 22

Further reading – *Discovering Stone*

Landscaping Victoria recommends all members sign up to receive *Discovering Stone*, a publication of the Australian Stone Advisory Association. Go to www.asaa.com.au then navigate to Publications.

Thanks to

Bruce Grogan, Anston Pavers
Bruce Winstanley, Winstanley Landscapes
Brian Rankin, Life Member - Landscaping Victoria
Ian Winstone, Melbourne University
Paul Buckley, Mapei
Tim Finocchiaro, Pavers Plus
For their generous contribution of time and knowledge in preparing this paper.

Future Releases

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Updated releases will be distributed to Members as information and content is revised.

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 latto* – '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.

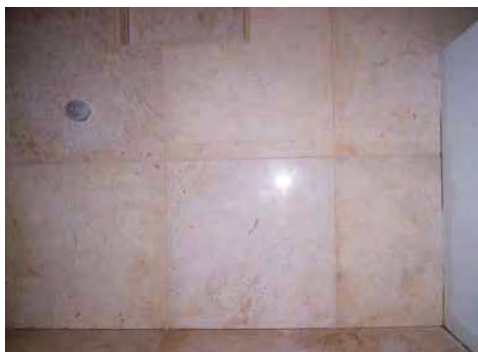
Ardex has seen a range of unusual stability issues associated with tiles produced from imported types of stone. These problems include temperature related warping, moisture related warping and also weathering of unstable minerals and components. Darker colours can create problems with substrate stability,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



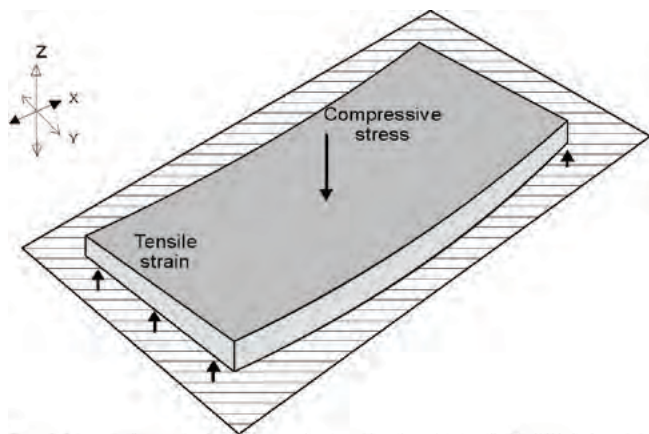
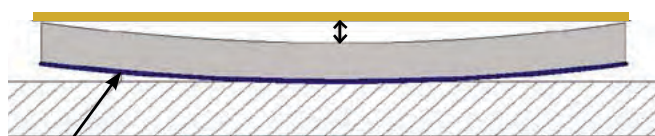
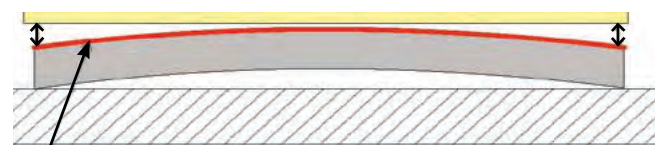


Figure 3. Schematic diagram showing the three strain axis and how they relate to a tile. The X-Y in horizontal plane for length and width changes, and Z in the vertical plane representing thickness changes or vertical deflections. The positions of tensile strain and compressive stress applied by the 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.

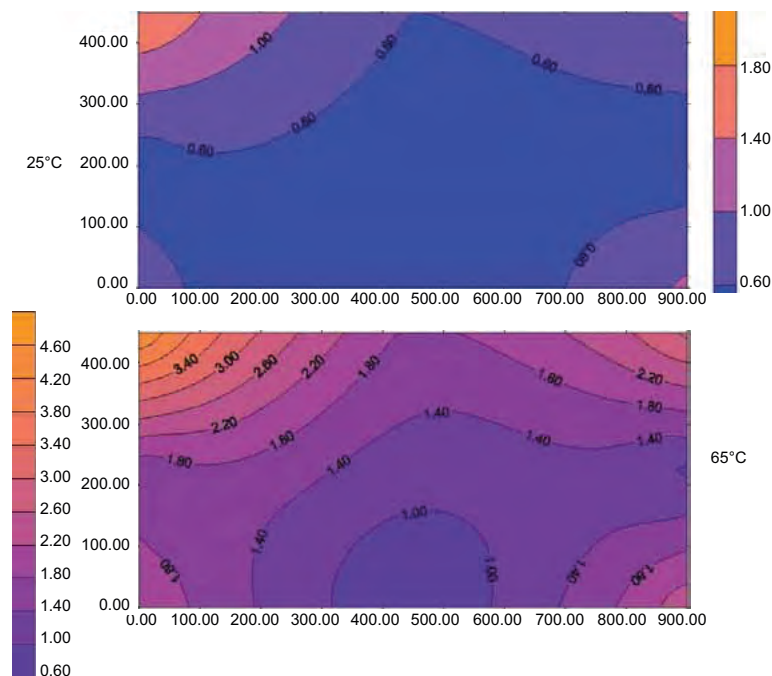


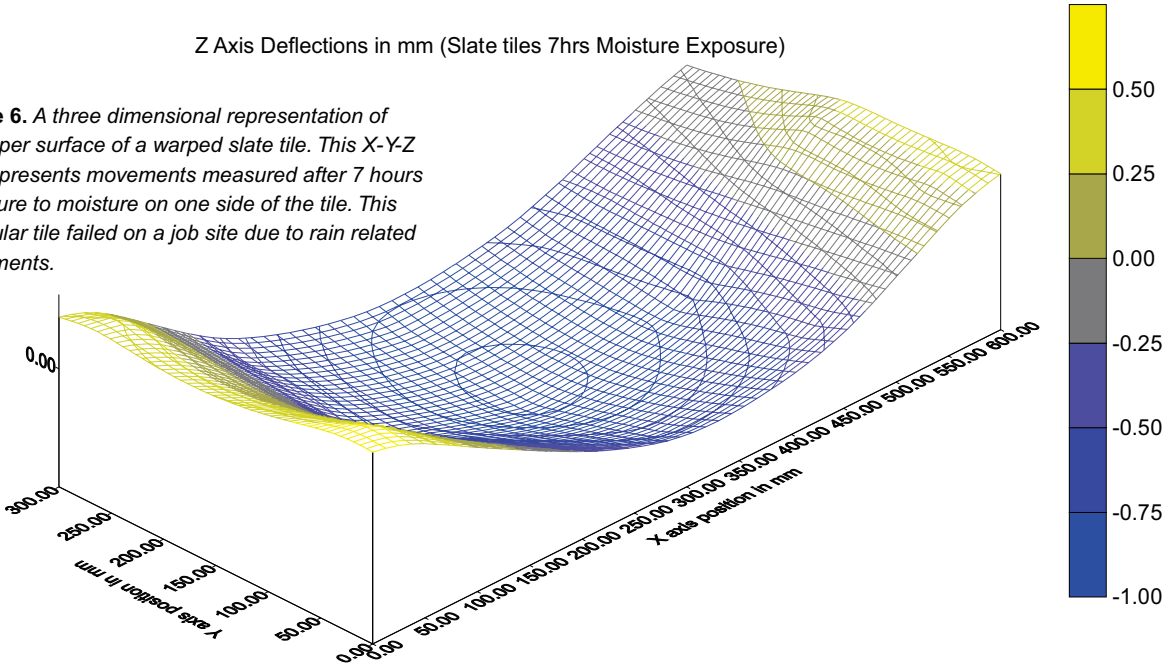
Figure 5. Vertical (Z axis) deflection contour maps for a thermally unstable stone tile exposed to direct sunlight. The contour measurements are in mm. This tile produced unacceptable deflections on a job site in hot weather during the summer months in 2008-09. As can be seen, there was a significant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

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.



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 re deposited 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

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.⁶⁹

Basalt — the warping issue

WORDS: Jim Mann

The characteristics of Australian bluestone on show at Hamer Hall, Victoria (Courtesy Victorian Bluestone).

Property	Typical Victorian Basalt	Typical Imported Basalt
Modulus of Rupture – MPa (3-point bending strength)	15 - 19	16 - 22
Bulk Density (kg/m³)	2450 - 2600	2590 - 2900
Apparent Porosity (vol %)	2.5 - 5	1 – 3.5
Total Porosity (vol %)	5 - 12	1.5 - 5
Saturation Coefficient (%)	40 - 50	65 - 70

If you were to compile an ABC of Victoria, the letter B would have to stand for basalt (or bluestone). This stone has been commercially quarried in Melbourne and surrounds for over 180 years and could be considered an icon of the state. The popularity of basalt has spread Australia-wide and with this popularity has come a wide range of imported stone types which offer the consumer a broader selection of materials that are similar but in some ways different to local basalt. Some of the differences in these new materials have led to failures and the need to develop new installation practices.

Among the challenges faced by installers has been the propensity of some types of imported basalt to curl or warp upon installation whether laid on a cementitious adhesive or a mortar bed. Before we start to explore the warping phenomenon it is necessary to understand the similarities and differences between typical Victorian basalt and some imported basalt materials.

Formation

Basalt is an extrusive igneous rock type predominantly composed of plagioclase feldspar, pyroxene and olivine with smaller amounts of iron oxides and titanium oxides. Basalt forms at or near the surface and in Australia is typically quarried from volcanic lava flows. During its deposition the expulsion of the molten lava leads to a reduction in pressure allowing dissolved gases to form as fine bubbles within the flow. These bubbles coalesce as they drift upwards within the flow creating larger bubbles most of which are captured within the solidifying stone. The size and distribution of these captured bubbles (vesicles) vary in size throughout the profile of the deposit from less than 1mm to 10mm or more. The appearance of the pores within the stone will also vary depending on the depth and mode of formation of the deposit.

Physical Properties

The table below compares the physical properties for 'typical' Victorian and imported basalt from countries such as China.

In the way of explanation, apparent porosity could be described as the volume of pores which will readily absorb water under normal atmospheric conditions, while total porosity is determined by 'forcing' water into the pores under a vacuum. The saturation coefficient represents the ratio of the apparent porosity compared to the total porosity, so a higher saturation coefficient indicates that the stone more readily achieves saturation point.

The table shows that the materials typically have a similar bending strength (modulus of rupture) although the imported stone usually has a higher bulk density, and lower apparent and total porosity, with a finer pore size which has led to the stone being produced as thin tiles (to ~10mm). Victorian basalt has historically been produced as thicker flags (30 to 40mm).

Capillaries at Work

The difference between the ranges of saturation coefficients for the two stone types is a crucial issue and can be explained in part by the range in pore size within the two stone varieties. Victorian basalt is typically scoriaceous (frothy) which produces large pores known as vesicles (colloquially known as cat's paws) while imported basalt is typically massive with more pores of a finer size. The difference in pore size is important as it affects the way the stone absorbs water due to the stronger capillary action which increases the suction of the stone as shown in **Figure 1**

Although the pores within basalt are not usually connected, the passage of water (permeability) through the matrix of the stone is assisted by capillary action with finer pores more readily reaching saturation point (i.e. saturation coefficient near 100%).

In a practical sense the strength of the capillary forces can have an impact on how a tile behaves when it is laid as the speed and distribution of moisture absorbed is governed by permeability and pore size. **Figures 2 to 5** consist of a series of schematic drawings which show how moisture is absorbed by a thin moisture sensitive tile upon laying on a wet adhesive bed.

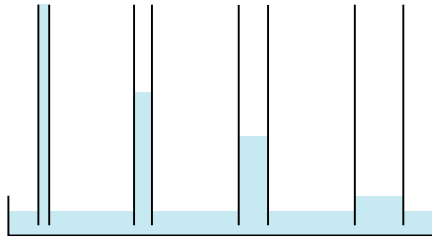


Figure 1. Capillary action at work. The finer the pore throat size the greater ability the water has to rise.



Figure 2. Initial condition of dry tile laid on a wet bed shown below with a magnified view of pores within the tile shown above.

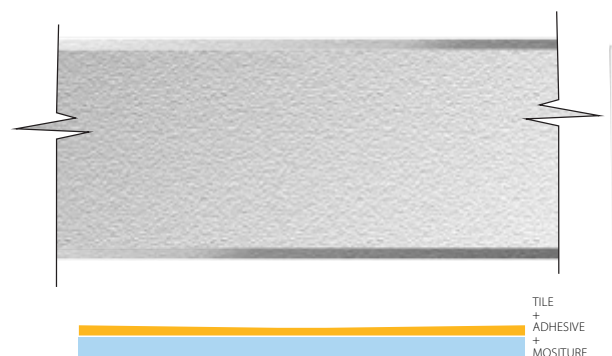


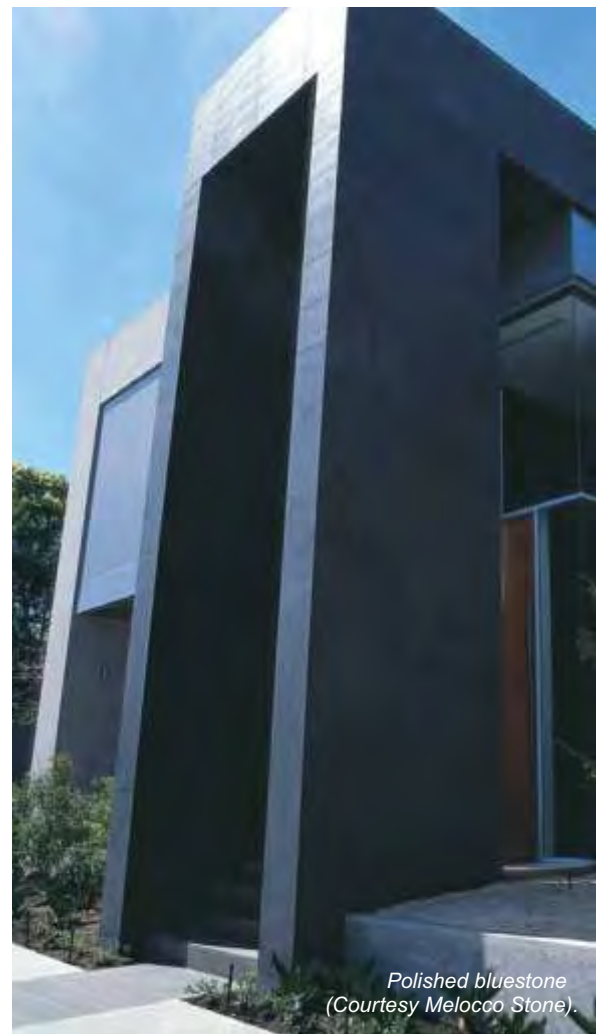
Figure 3. The tile begins to absorb moisture soon after installation.



Figure 4. As the tile continues to absorb moisture a differential develops where the lower section of the tile contains pores that are near saturation while the top section is still dry which causes unequal dimensional change which presents itself as warping of the tile.



Figure 5. Eventually the tile will achieve a relatively uniform moisture content (depending on thickness) which will result in a consistent rate of dimensional change and absence of any (or minimal) warping.



*Polished bluestone
(Courtesy Melocoo Stone).*



Bamstone are proud of how their product performs at Southern Cross Station.

The warping generally occurs quite quickly but return to equilibrium is a much slower affair as shown in **Figure 6**.

In Figure 6 we can see that in this instance the majority of the warping occurred within the first five hours. The consequence of the rapid dimensional change is that if the tile is installed with an adhesive which sets after five hours it may become fixed in a warped condition, unless the stresses are sufficient to cause failure of the adhesive bond between the tile and substrate resulting in a drummy tile.

The other major consequence of the high rate of suction through capillary action is the mobilisation of soluble minerals onto the surface of the tile from the adhesive or substrate as shown in **Figure 7**.

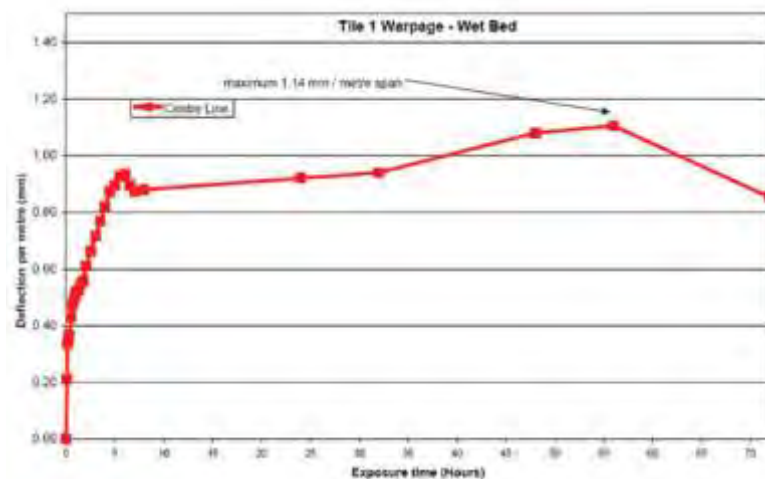


Figure 6. Chart showing deflection of tile surface over time when laid on a wet sand bed.

Solutions

There are numerous approaches to overcoming the challenge of moisture sensitive tiles which involve controlling the material or the method of installation.

Increasing the thickness of the tile provides multiple benefits. Using a thicker tile makes the tile stiffer which reduces the risk that the tile will warp. An increase in thickness also reduces the likelihood that moisture and soluble minerals will migrate to the surface of the tile.

An added benefit from increasing the thickness is the greater load bearing capacity of the tile. Breaking load increases exponentially with an increase in thickness – double the thickness and the breaking load increases fourfold.

The plan size of the tile also has an effect on any apparent warping. A tile that has a length to width ratio of 1:1 will appear to warp much less than a tile with a ratio of 3:1 or greater (see **Figure 8**).

Tiles with a mid-brown or grey tonality such as basalt are highly sensitive to colour changes from contaminants and moisture, especially on finely finished surfaces (e.g. honed). Surface finishes with a coarser texture such as sawn or sandblasted are more forgiving as they tend to hide minor blemishes.

Careful selection of the installation method is crucial for all types of tile especially when the material may be

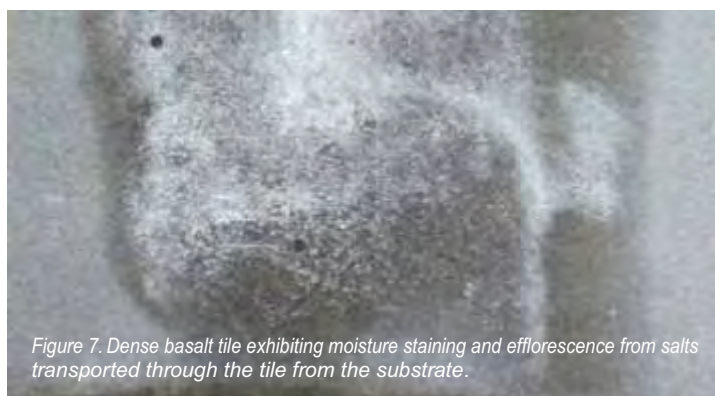


Figure 7. Dense basalt tile exhibiting moisture staining and efflorescence from salts transported through the tile from the substrate.



Figure 8. Comparison of warping of a 1:1 and 3:1 tile in plan and cross section view. Minimising the length to width ratio reduces any apparent warping.

moisture sensitive. The choice of the correct adhesive is vital to a successful installation. Rapid setting cement based systems which achieve an early set and a significant portion of their tensile strength in a short period of time can reduce any warping that may occur.

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Two-part, high strength non water-based adhesives are also an alternative and involve adding a powder (Part A) to a proprietary liquid (Part B) to provide a rapid set adhesive which also minimises excess moisture. Epoxy adhesives specifically designed for moisture sensitive stone are also available and these provide a very high strength rapid-set fixing systems especially suited for challenging areas such as swimming pool surrounds, bathrooms and external wall cladding.

Six-sided sealing of tiles with some types of penetrating sealers dramatically reduces the uptake of moisture into a tile, which can improve stability, reduce staining and improve durability. It is very important to determine compatibility between the sealer and adhesive to ensure the adhesive bond is not affected.

Know Your Stone

In all aspects of our daily life we are bombarded by innovations and new products and the stone industry is no different. As we are exposed to new stone types it is important to understand their strengths and limitations and to learn how they behave in different environments. The popularity of basalt has to some degree been marred by the issue of warping and is in part due to using old practices on new products. For the industry to grow it is important that all aspects of the industry – the quarry, the tile shop and adhesive manufacturers – stay informed and work together to reduce the mysteries within stone and provide the consumer with a low risk product.