TECHNICAL PAPER – TP 002
Issues with Determination of Adhesive Bed Coverage Stack Stone Glue and Mosaic Mesh Adhesive

Introduction

Common issues with adhering all types of tile revolves around the required tile adhesive contact with the tile, the effect of mesh and mesh glue on mosaic tiles, stackstone lath adhesive and tile wash have on adhesive coverage and bonding. This paper discusses some of the issues concerning adhesive beds and gives some ideas for estimating coverage.

Adhesive Coverage—What Does the Standard Say?

In March 2007 the new standard for installation of ceramic tiles, AS39581.1-2007 Ceramic Tiles, Part 1: Guide to the Installation of Ceramic Tiles, was released and came into force. In this standard under Clause 5.6.4.2 are included minimum recommendations for adhesive bed coverage on tile face and substrate in certain applications:

- Internal residential walls- 65%
- Residential floors- 80%
- Commercial and industrial walls- 80%
- Commercial and industrial floors- 90%
- Wet areas- 90%
- Swimming pools- 90%
- External walls- 90%
- Exterior floors, decks and roofs- 90%.

As can be seen the effective minimum is 80% coverage between the tile back face and the substrate. The standard also says '*optimum coverage requires pressing of the tiles into the adhesive bed and moving them perpendicular to the direction of adhesive notches*'. This means that it is not sufficient to just have 80% coverage of the adhesive with hollows and ridges left over from the adhesive, it means that the adhesive ridges must be collapsed to merge together by pressing down and sliding the tiles across the lines of adhesive to achieve a continuous adhesive bed in full contact with the tiles

The coverage needs to be distributed in such a way that the tile is fully supported, particularly including the tile edges and large individual areas are not left without adhesive.

Ardex has historically recommended that the minimum coverage is 85% as a general application rule. However, where the application is submerged in water a 100% coverage is preferred and voids in the adhesive are not present. For high load and/or exposed external situations, the recommendation was typically 90% or higher coverage being required.

What Happens with Notch Trowel Adhesive Beds?

There is a perception that to actually cover the tile or substrate with adhesive constitutes coverage. This is regardless of whether or not the adhesive lines have been squashed down and how much adhesive is really bonded to both the tile and the substrate.

Where the tiles have not been pushed down sufficiently, or not moved sideways to collapse and merge the lines of adhesive, or the adhesive has started to skin off, the resultant coverage would be less than expected. This is shown diagrammatically on the next page and is a very common situation in encountered in the field. Indeed, drummy sounding but well bonded tiles are very common due to voids under the tile. This may not be technically a defect, but allows for impact damage, and can shorten the adhesive

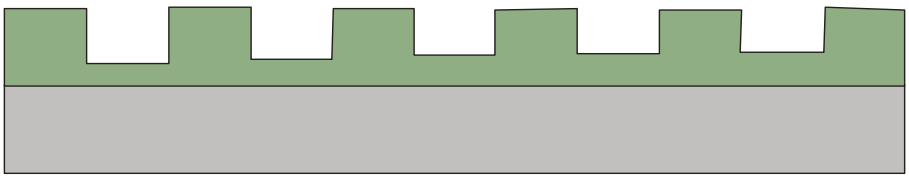


Figure 1. The above figure shows a substrate with a notch trowel adhesive bed (green) on top. As applied the adhesive coverage at the top of the notches is 70% on the tile side and 100% on the substrate side.

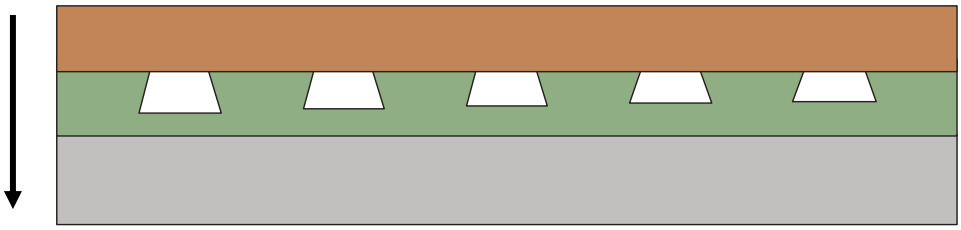


Figure 2. A tile (brown) has been placed onto the bed and slightly pressed down, but not moved from side to side to smear the adhesive ridges. In this case the adhesive coverage at the top of the notches is only 80% on the tile side, but still 100% on the substrate side. This coverage may be satisfactory for a domestic floor, but not any other situations where the minimum is 85% or 90%. If the voids are large enough sections of the tile may sound drummy, even if bonded overall.

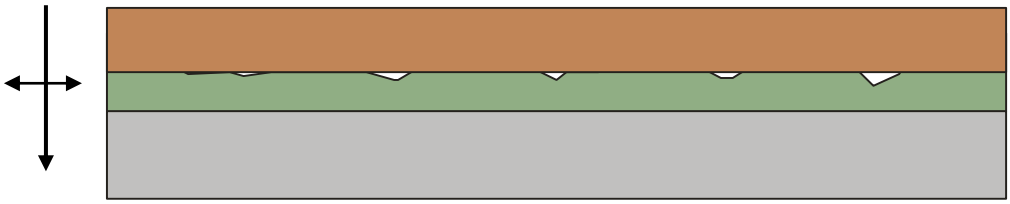


Figure 3. A tile has been placed onto the bed, pressed heavily and moved from side to side to smear the adhesive ridges. In this case the adhesive coverage at the top of the notches is around 95% on the tile side, and 100% on the substrate side. This would provide a sound bed for all installations.
In an immersed situation with transparent tiles these voids may appear as dark areas due to refractive index effects, or the voids may fill with water seepage and become visible.

service life (see the next section for more on this topic).

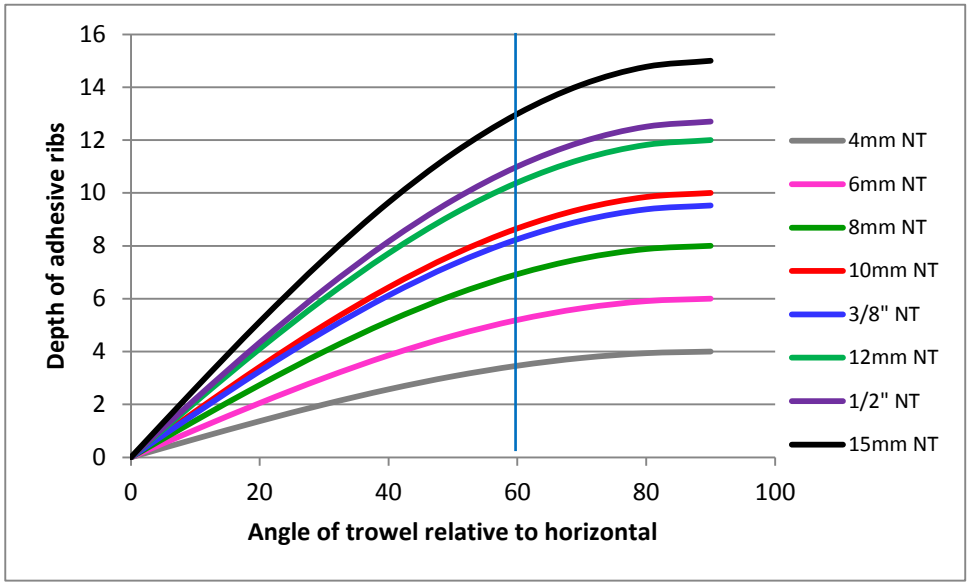
This problem is also interlinked with the bed thickness as too thin a bed will also result in poor coverage. The initial thickness is function of the size of the notch trowel, and also the angle of trowel attack to the surface (relative to the horizontal). The suggested angle is 60^0 from the horizontal, but it is not unusual for it to be less because it is easier to swing the trowel at lower angles, and also because it increases the adhesive spread rate and makes the job pseudo cheaper. The next three graphs show empirical calculations for the nominal adhesive thicknesses expected. The first shows a range of trowels, whilst the other two are specifically related to a 10mm notch trowel.

WHY IS THE COVERAGE AN ISSUE?

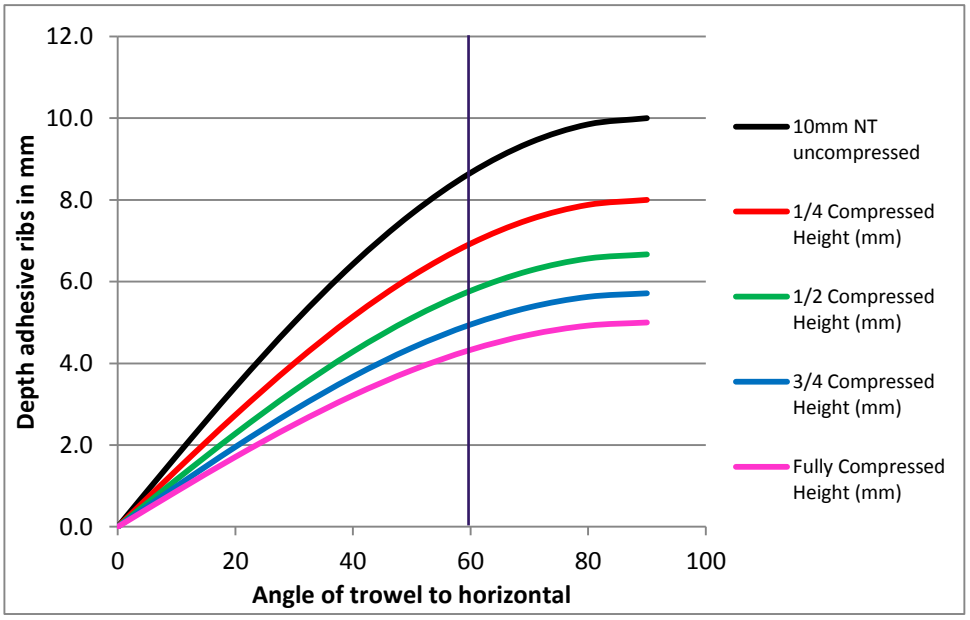
Where the adhesive coverage is not sufficient, the tiles are neither fully supported physically, nor correctly bonded to the substrate.

This means that these tiles are more likely to:

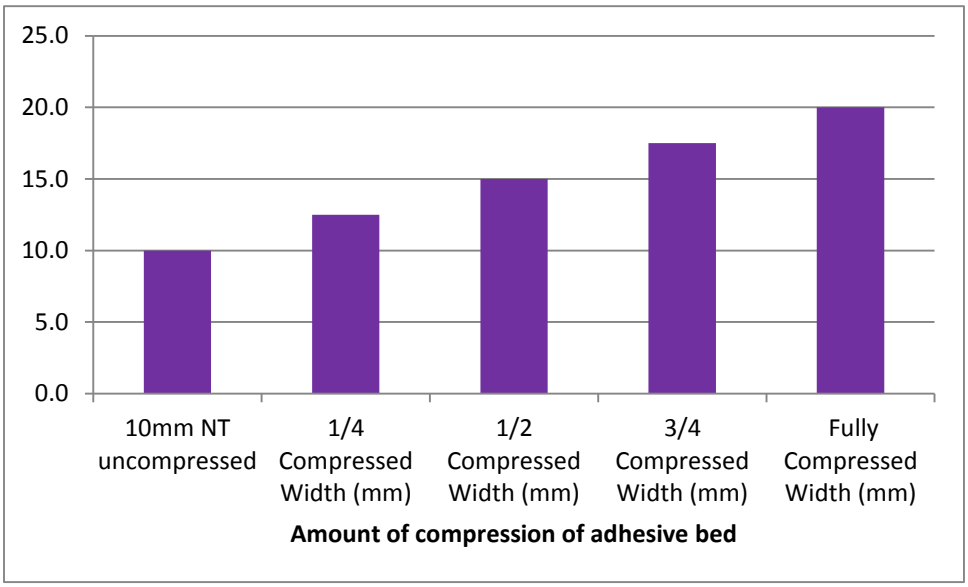
a. de-bond or crack due to the high strains imposed by flexible substrates (e.g. de-



Graph 1. The empirical depth of the adhesive notch ribs in mm is shown above for a range of notch trowel sizes. The recommended angle is 60^0 to the horizontal; angles above this make little difference, but below the final bed thickness and width will be compromised.



Graph 2. The **empirical** depth of the adhesive notch ribs in mm is shown above for a 10mm notch trowel typically used for floors and heavy larger format tiles on walls. The individual lines refer to how much the adhesive ribs have been flattened, which is a function of the amount of pressure used to lay the tiles.
The recommended trowel angle is 60^0 to the horizontal and the suggested degree of compression is to achieve full flattening down for a final 100% coverage, but not overly squeeze the adhesive such that it is lost out the sides.
Using these criteria the empirical final bed thickness for a 10mm notch comb adhesive bed, fully flattened would be between 4 and 4.5mm. Since the trowel angle of attack is rarely as recommended, the actual figure is commonly 2.5 to 3mm.



Graph 3. The empirical width of the adhesive notch ribs in mm is shown above for a 10mm notch trowel typically used for floors and heavy larger format tiles on walls. The individual bars refer to how much the adhesive ribs have been flattened, which is a function of the amount of pressure used to lay the tiles.
The recommended trowel angle is 60^0 to the horizontal and the suggested degree of compression is to achieve full flattening down for a final 100% coverage, but not overly squeeze the adhesive such that it is lost out the sides.
Using these criteria the empirical final bed width for a 10mm notch comb adhesive bed, fully flattened would be in be fact continuous, however there are normally faint lines which show each rib has been flattened to ~20mm wide.
The centre to centre distance for tooth/void of the trowel is fixed, so the line width on a tiled bed gives a clear indication of both the degree of flattening, but also the actual type of trowel that was used.

flection of timber floors), dynamic loads from being walked on, or have heavy objects dropped or placed on them,

b. from thermal and/or moisture related movement strains particularly in external exposures and

c. the creation of pathways for moisture to travel leading to problems with efflorescence, adhesive saturation and leaching.

There are some other ways that poor coverage can occur, one being problems with the tile itself which we will examine in the next chapter, but also the practice of spot fixing.

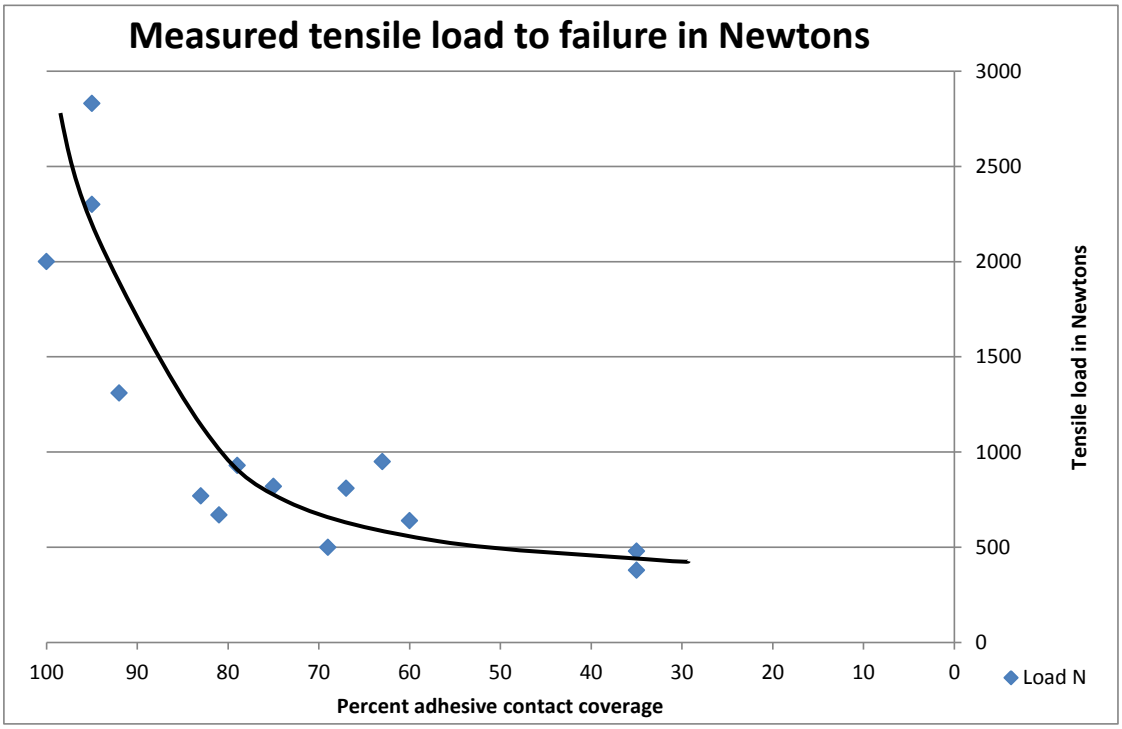
The standard says this about drummy tiles in section 5.4.7,

> *" In some installations small hollow sound areas may be found. Although they do indicate incomplete bond they are not necessarily indicative of imminent failre; however, cases where more than 20% of the tile sounds hollow when tapped ('drummy') would have to be considered suspect over the long term. Needless to say this ratio would need to be varied depending on-*
>
> *1) Where the tile is fixed to the floor or wall; and*
>
> *2) The anticipated form and amount of traffic."*

Examination of the effect that changes in coverage can have are shown the next graph (4). Tensile testing based on ISO13007 was performed with a cement based C2 adhesive which was allowed to cure for 7 days at room conditions. The tensile results are shown as loads in Newtons (N) vs the actual measured contact coverage between the tile and the concrete test block. The ultimate load in N (a measure of

force) is the raw strength data normally used to calculate the tensile strength in MPa (a pressure unit). The N load can be converted back to a dead load in kg by dividing by 10, but this does not account for any dynamic loading.

What is clear from the results, is that the achieved tensile strength is significantly effected by contact coverage and that between 100% and 80% the values fall around one third. The implications are that by reducing the contact coverage you are reducing the ability of the tile to take load and remain securely bonded.



Graph 4. Tensile load to failure vs percent adhesive coverage.

The other point to understand is that these results were obtained under laboratory conditions. In the field it is normal in engineering practice to use a safe working limit which is two or three times lower than the proof loads. This is because site conditions are uncontrolled and the performance achieved is unlikely to be the maximum possible. Taking this into consideration, the values shown above can be reduced by 50% to 66% to have a working limit. It is then clear that reducing the contact coverage will compromise the proof load results by between 4 and 6 times.

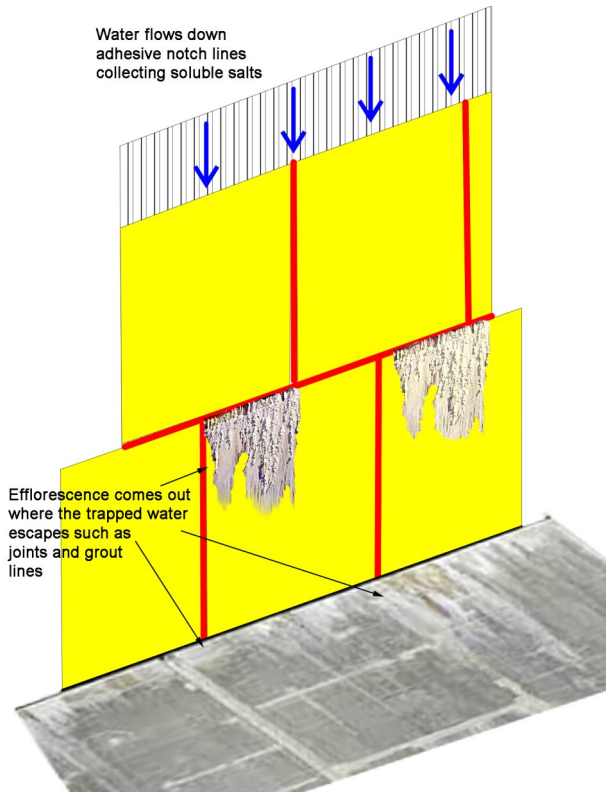


Figure 4. Effect of void spaces under tiles creating moisture pathways leading to efflorescence and staining issues.

Creation of moisture pathways occurs when the notch comb marks are not compressed and allowed to line up from tile to tile. Moisture gets into the system through edges and the grout lines, and then filters down through the adhesive bed. As it does so it collects soluble materials which when the water escapes again at the lowest point produces salts deposits and unsightly stains. Further exacerbating this problem is the trend towards large format tiles which reduces points of escape, increasing residence time, and

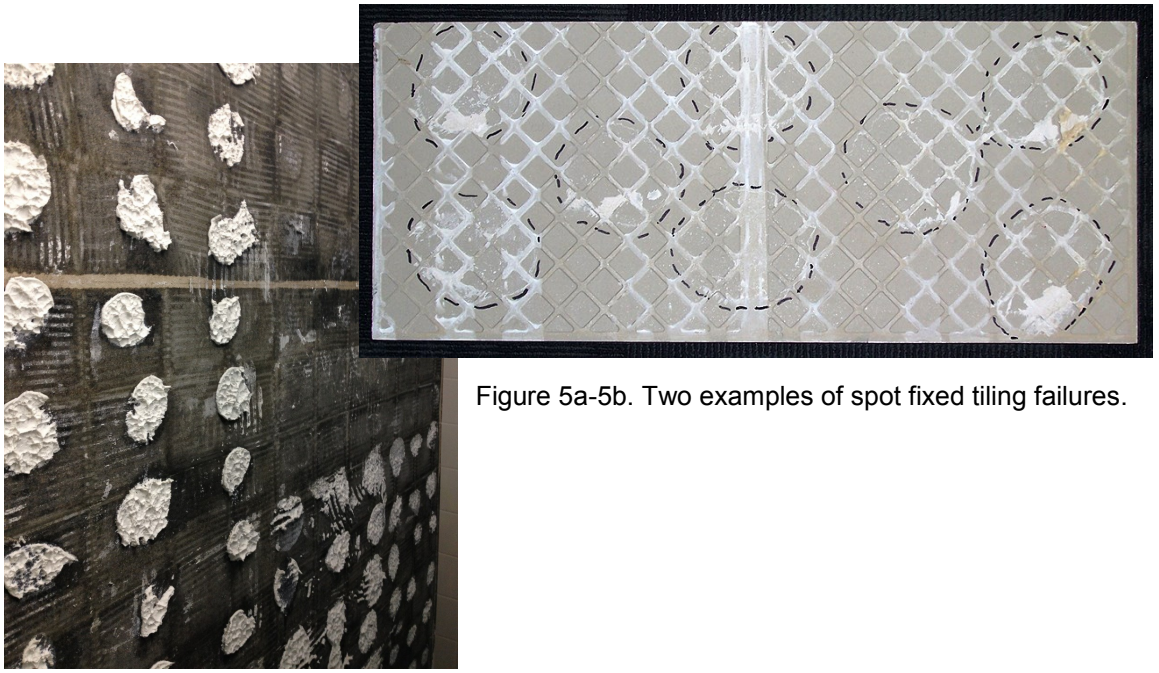


Figure 5a-5b. Two examples of spot fixed tiling failures.

also the use of dark tiles which promoted thermal baking of the system. Heated water is better at leaching adhesives, though less able to carry lime.

The other obvious problem is the use of spot fixing in the field to adhere tiles, especially large format tiles on walls. This is a method which is not suited to cement adhesives, but can be used with structural epoxy. Where spot fixing is used, the dobs of adhesive rarely in our experience add up to more than 40-50% effective coverage.

Another thing to consider is that the dead and live loads that affect the tile are transferred to the substrate through the adhesive. Where the adhesive tensile and cohesive strength exceeds that of the underlying substrate, this fails instead. Fibre-cement sheeting, plasterboard and rendering can have tensile strength lower than the adhesive system, and then the failure is transferred to the substrate.

We have already indicated that the proof test loads for adhesive are stated in MPa which is a unit of pressure; it is defined as force N divided by area in metres.

However, we can look at it the other way from the point of view off applied loads; the most common being dead load and wind load, but also can include thermal movements of the tiles. Assume an external porcelain 1000x1000x10mm (SG 2.8) tile surface weighs 32kg/m^2. Add in some wind pressure, which in engineering commonly uses a failure design pressure of 1.0kPa, which equals 100kg/m^2 . It is easy to see how poor coverage can have negative effect on the tile adhesive performance. The added load on the substrate and adhesive is 132kg/m^2 (1.3kN) but if you reduced the coverage to 40% by spot fixing, this becomes 330kg/m^2 (3.3kN) as experienced by the ad-

hesive and the substrate.

As with other forms of poor coverage the standard has something to say about spot fixing with thin bed adhesives, from section 5.6.2 (c);

"'*Spot fixing' where the tiles are fixed with four or five dabs of adhesive is not recommended and should be avoided at all times*."

The following series of photos shows a number of examples of adhesive contact coverage problems.

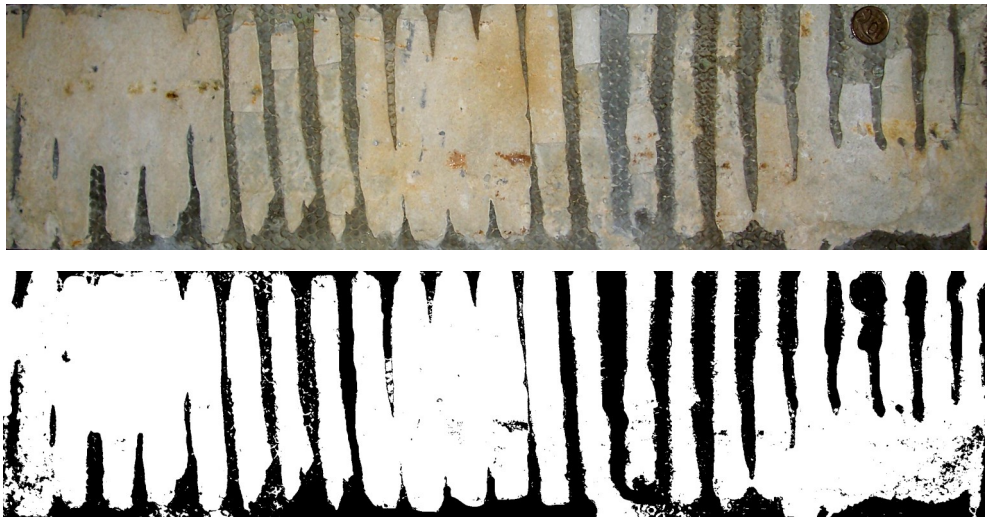


Figure 6. The above example is a heavy format tile that had de-bonded. As can be seen the notch trowel lines are clearly visible on the back of the tile in the top picture. The lower picture has been re-processed to allow the coverage to be electronically measured. The white is the adhesive and the black is the tile back. The coverage works out to be 70% whereas it should have been 90% or higher.

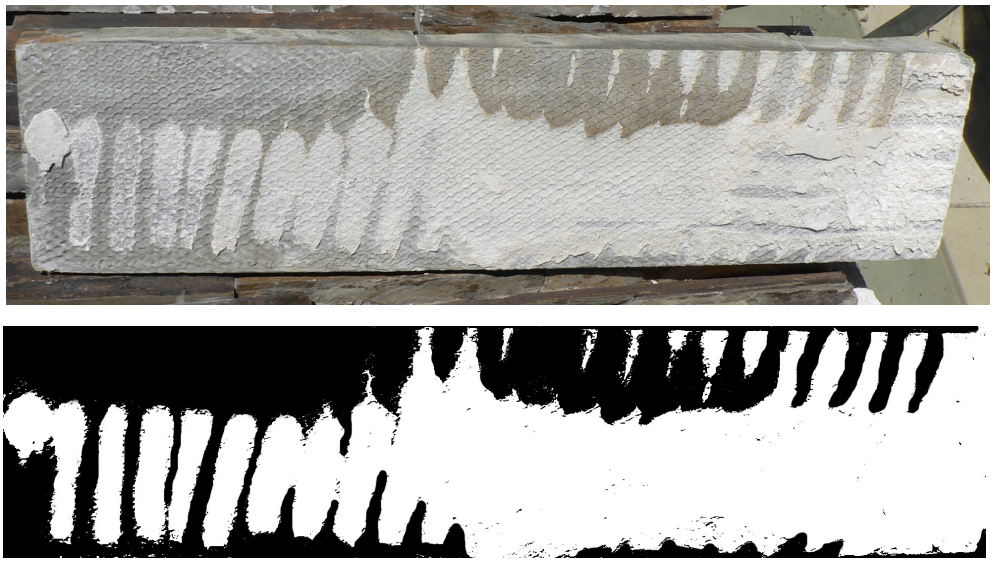


Figure 7. The above example is another heavy format tile from the same site as fig 4, and is a more extreme example. The coverage works out to be only 60%. As can be seen there are also large areas of no coverage, particularly on the top left hand edge.

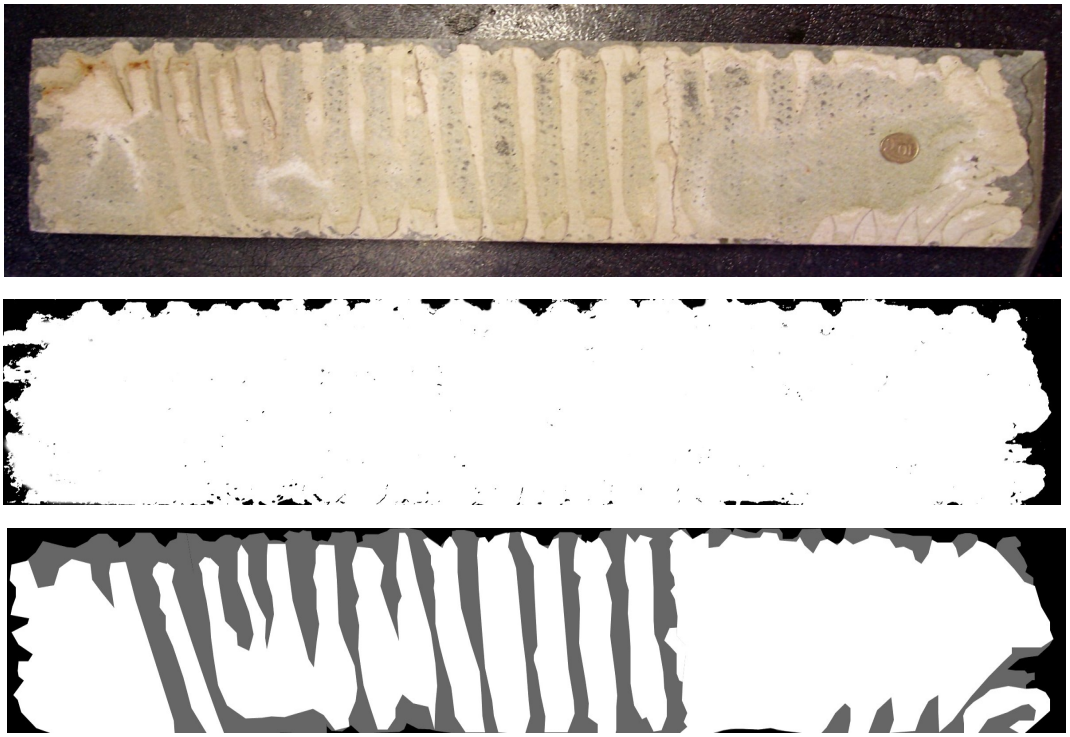


Figure 8. An example where the apparent coverage is significantly higher than the true coverage. At first sight the coverage on this tile appears to be high, and indeed the back surface of the tile has a layer of adhesive on it that covers 93% (second picture). However closer examination shows that the actual coverage of adhesive between the tile and substrate is really restricted to the notch trowel ridges and is closer to 65%. Traces of the adhesive (shown in grey in the third picture) are only a thin layer on the tile itself, do not reach the substrate and so do not contribute to the bond strength.

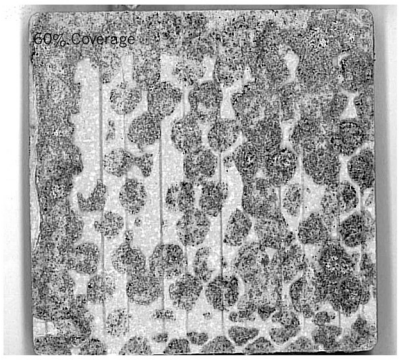
Figures 5-9 come from failures where the tiles have de-bonded. It is important when laying the tiles to actually apply a sufficient bed of adhesive and then to lay the tiles, press them into the lines of spread adhesives and slide them back and forth across at least one full line to collapse and merge the adhesive to form a continuous bed under the tiles. When in doubt, use a combination of notched trowel combing the adhesive and back buttering. Section 5.6.2 (a) i of the standard gives some recommendations for the notched trowel size for different sizes of tiles.

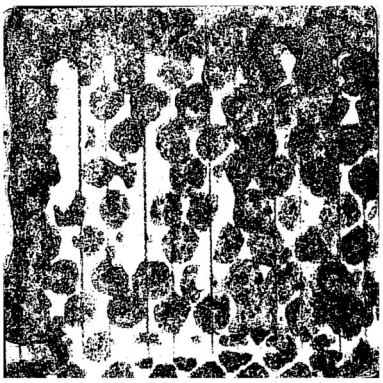
Mosaics Meshes, Mesh Adhesives, Lath Adhesives and Tile Wash

Related to the coverage issue, is the problem of mosaic mesh, mesh adhesive and the structural adhesive used to bond stack stone tiles together (for simplicity I will call them collectively call them re-inforcement). The relationship is that where there are large quantities of these materials on the back of the tile, it effectively prevents correct tile adhesive coverage. This might not seem to make sense where the tile adhesive has actually formed a high percentage coverage onto the re-inforcement, but the objective of the adhesive is to form a bed between the tile and the substrate, not the re-inforcement and the substrate.

Ardex has found that often the mesh adhesives are weak or do not bond well to the tile. This means that the tile adhesive is in fact bonding to weak surface. As a result the long term bond is not guaranteed, and the problem will be worse where the tiles are on a high traffic floor area, or are external and exposed to the extremes of all climatic conditions. The other problem with mesh glues is that they are commonly formulated from water soluble or unstable materials like PVA which then softens and becomes weak

Figure 9. Another example where the actual adhesive coverage is far less than required, in this case 60% adhesive coverage.
In this case the tile mesh also interfered with the coverage achieved





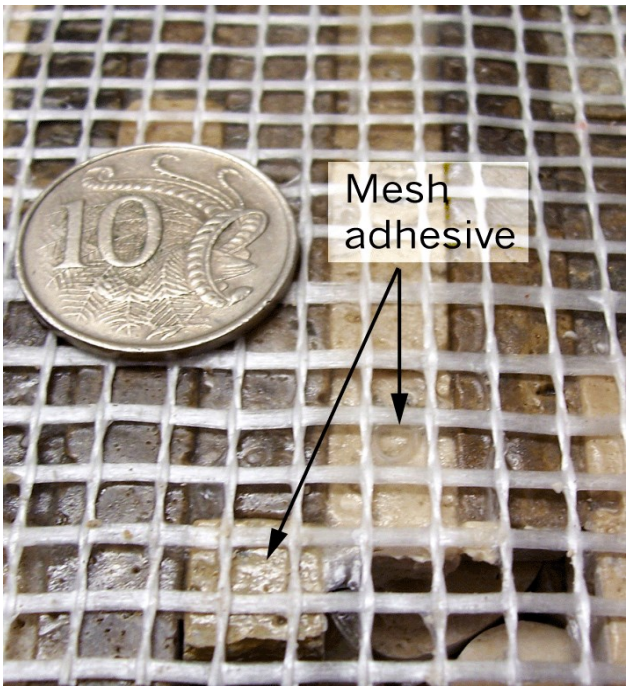


Figure 10.
A mosaic tile sheet made from marble laths held together with fibre-glass mesh bonded with a water based glue.
The actual mesh coverage is approximately 25-30%, but the mesh glue actually increases the coverage to near 100% as the glue also covers the tile back between the mesh lines.
Whilst this mosaic sheet may be potentially be bonded in some cases, use on floor or in wet areas would be very risky, and in immersed areas highly risky.

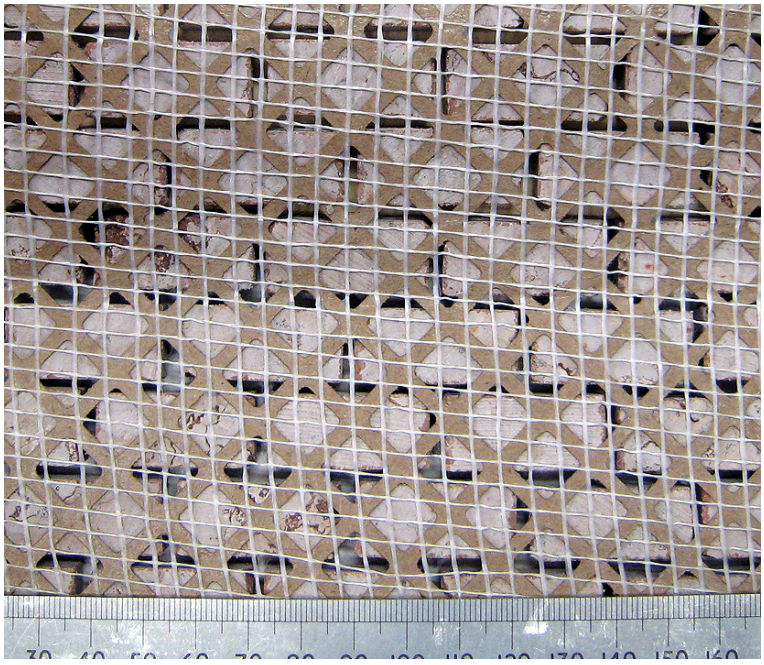


Figure 11.
Another sheet mosaic, but in this case there are two meshes. The actual mesh coverage is around 50% of the tile surface.

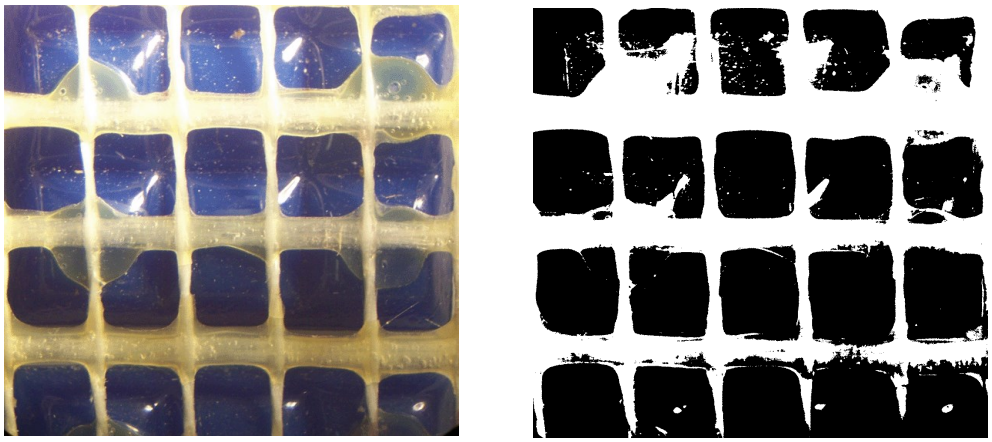


Figure 12.
The above mosaics tiles are held together with fibre-glass mesh bonded to the tile with a glue. The mesh coverage in this case was 38% of the tile surface, thus reducing bonding for the tile adhesive to around 60%. To complicate matters this mesh glue was also water soluble, resulting in the mesh falling off when the tiles were immersed.

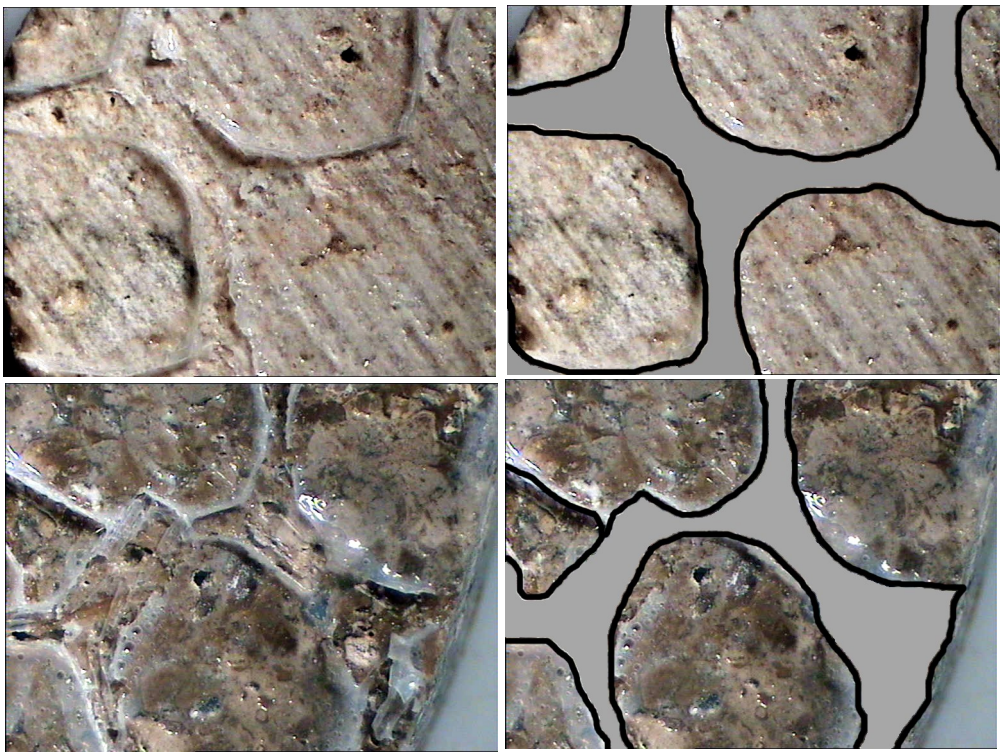


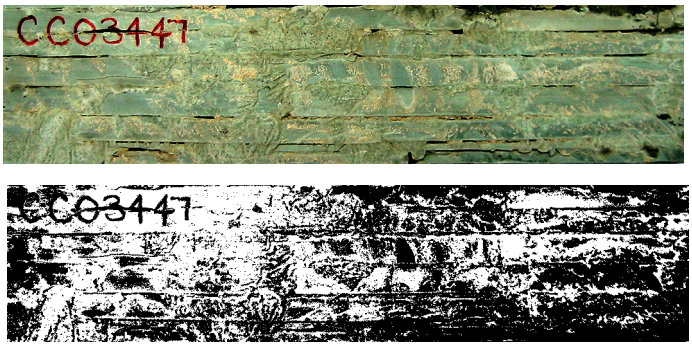
Figure 13. Examples of residual mesh adhesive on the rear face of individual mosaic tiles after the mesh was removed. As can be seen, the adhesive covers almost the entire tile contact area. In the right side illustrations the area originally covered by the mesh has been greyed out. This adhesive was also water unstable.

when exposed to continuous wetting. This is a significant problem for pond and swimming pools, where the tile adhesive remains bonded to the mesh, but the mesh debonds from the tile which then falls off.

Where tiles are made from laths of stone bonded together ('stack stone'), or are reinforced with a structural adhesive, there is the problem of the adhesive covering the bonding surface of the tile, and interfering with the bond between the ceramic tile adhesive and the tile. Common structural adhesives are polyester resins and high solid epoxies, which tend to have smooth and hard surfaces not conducive to forming a good bond with the tile adhesive.

In these situations the historical Ardex recommendation has been that no more than 15% of the tile surface be obscured by the structural adhesives. With the introduction of the new standard for tiling, the minimum coverages are now specified and for a number of applications 10% would now be considered the maximum.

Figure 14.
An example of stack stone tiles bonded together with a structural adhesive. The adhesive covers around 45% of the rear face of the tile. In this particular example the structural adhesive was not compatible with the tile adhesive resulting in the tiles de-bonding.



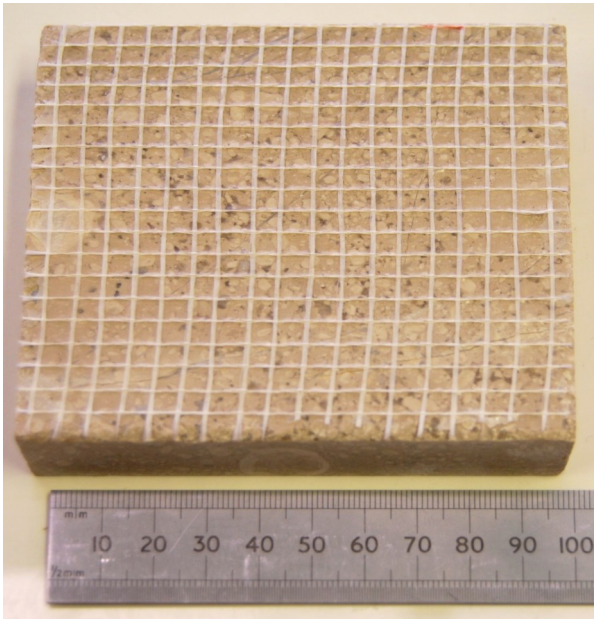


Figure 16.
An example of a large format marble tile where a polyester or epoxy adhesive has been applied over the entire tile surface and fibre-glass mesh applied. There is no contact possible between the tile adhesive and the tile surface. This tile would likely require the use of a structural adhesive such as an epoxy to achieve a bond.

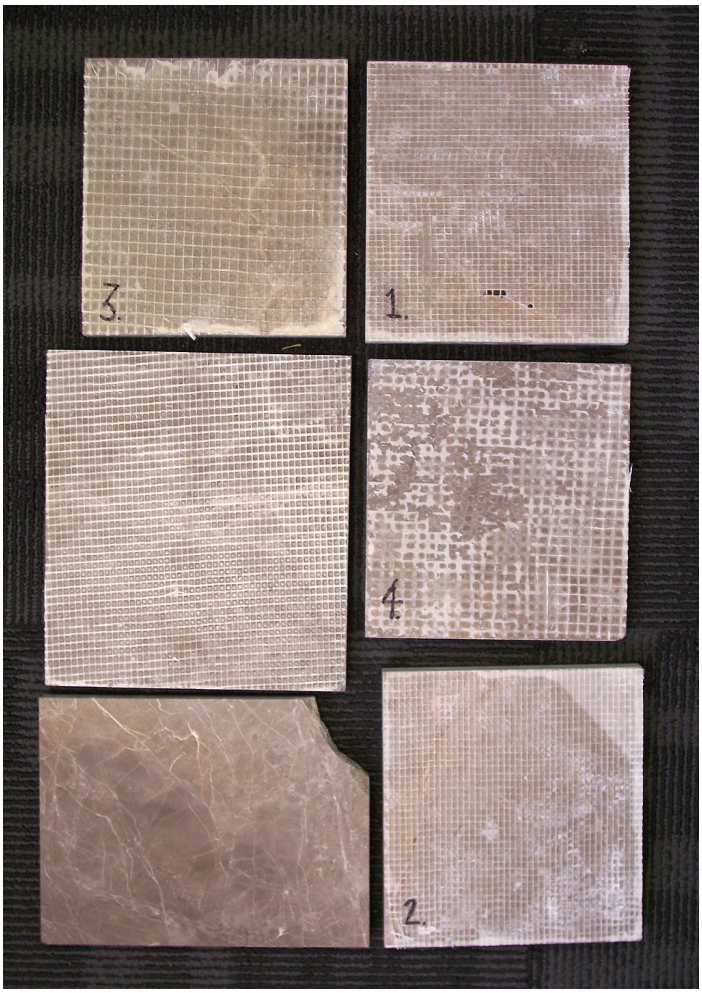


Figure 17.
A truly awful selection of limestone tiles where the mesh on the back face was very poorly bonded to the tile. The bottom right hand tile, shows the mesh/ polyester lifting off the top right hand corner of the tile.
In this instance the mesh was held with polyester resin which failed bond to the tile, and would prevent the tile adhesive obtained a sound bond, but is also susceptible to chemical attack from the alkaline materials in the cement based adhesive.

Tile wash or anti blocking/mould release compound is an alumina-silicate material which is applied the back of tiles during their processing, to prevent the tiles sticking together. It is typically a bright white powdery material which fairly easily rubs off the back.
The powdery material can act as a bond breaker and lead to the adhesive coming off the back of the tile. This material should be removed, and this means either scrubbing it off or using a wire brush on a drill or grinder to remove it. The recommendation is that it should not cover more than 15% of the tile back face.
The problem is more pronounced with glassy porcelain tiles than porous biscuit type tiles because the porosity appears to be permit the adhesives to bond more effectively with the wash in place.

Figure 18.
Tile blocking agent on the back of a tile. Coverage is around 50%.

ESTIMATING COVERAGES

When inspections are done for complaints it is necessary to estimate coverages. It is therefore important to recognize that the true coverage only applies where the adhesive contacts both tile and substrate. When looking at the coverage, sometimes estimates can be difficult due to colour contrast issues or that darker colours tend to 'overwhelm' the light ones leading to over-estimation.

Two simple methods involves dividing the area up into a 9x9 grid with each grid square 11% or dividing the area in to 10 or 20% blocks and estimate coverage in each block.

Previous versions of this paper (v.003) contains a series of black and white shadow diagrams for estimating coverage. Copies can be obtained on request from Technical Services.

FURTHER READING

Apart from the relevant Australian Standards, good articles by the tile expert Peter Hartog concerning mesh backed mosaics in swimming pools are worth examining. These are:

Hartog P. (2000) "*Tiling at the Deep End*" *Tile Today 28*. Elite Publishing.
Hartog P. (2006) "*Tiling at the Deep End*"—Revisited, *Tile Today 50*. Elite Publishing.

Articles about coverage are,

Cass C. (2014) The assessment of hollow or drummy tiling. *Tile Today 83*. Elite Publishing.
Cass C. (2014a) The assessment of hollow or drummy tiling. Qualicer 2014. XIV World Congress on Ceramic Tile Quality; Castellón (Spain)
Cass C (2004) Achieving 100% adhesive coverage, and industry wide approach. QUALICER 2004. VIII World Con-gress on Ceramic Tile Quality; Castellón (Spain); [general Conferences, Papers, Posters, Panel Debate]. 400 pages.
Gray F. (2017) Trowel choice makes a difference. *Tile Today 92*. Elite Publishing.
Tarver J.A. (1996) A primer of bedding large size tiles. QUALICER 96 : *IV World Congress on Ceramic Tile Quality.* [general Conferences and Communications; 10/13 March 1996, Castellón, Spain] Volume 2. 389 pages.

Ardex Technical Bulletins which contain relevant information include, TB001 Large format tiles, TB148 Fixing stack stone, TB161 Resin backed tiles, TB223 Dead loads-Thermal movement in stone tiles, TB224 Fixing sheet porcelain tiles and TB228 Alkaline attack of tile mesh backing. Ardex Technical Papers TP011 and 012 discuss efflorescence issues from poor coverage.

REASON FOR REVISION—Minor revision of references and new contact details

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