CCAA T59

Guide

Guide to Concrete Flatwork Finishes

CEMENT CONCRETE
& AGGREGATES AUSTRALIA

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CEMENT CONCRETE
& AGGREGATES AUSTRALIA

Cement Concrete & Aggregates Australia is a not-for-profit organisation established in 1928 and committed to serving the Australian construction community.

CCAA is acknowledged nationally and internationally as Australia's foremost cement and concrete information body – taking a leading role in education and training, research and development, technical information and advisory services, and being a significant contributor to the preparation of Codes and Standards affecting building and building materials.

CCAA's principal aims are to protect and extend the uses of cement, concrete and aggregates by advancing knowledge, skill and professionalism in Australian concrete construction and by promoting continual awareness of products, their energy-efficient properties and their uses, and of the contribution the industry makes towards a better environment.

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Contents

1 Introduction

Concrete flatwork (pavements and floors) has become a key part of the built environment, providing floor slabs and enhancing the appearance of the streetscape or property by providing a range of solutions involving a variety of colours, textures and forms while adding to the value of adjoining properties and buildings. The durability of concrete flatwork provides a long service life with minimal maintenance.

This guide covers various options for colouring and finishing the concrete surface and related construction issues. It collates information from a range of other CCAA documents and various research reports and publications relating to concrete flatwork and the use of concrete materials for these applications. The information is relevant for suspended slabs as well as to those built on the ground. It has been prepared to assist designers, specifiers and contractors with the important aspects of particular flatwork finishes and their detailing, specification and construction to ensure that the element provides a high level of performance and serviceability during its design life.

The information provided in this guide does not cover roads and streets (including intersection thresholds and traffic control devices) required to carry heavy vehicles on a daily basis. Pavements covered include those for use by pedestrians and driveways for use by vehicles up to 10 t gross mass and infrequent use by heavier vehicles that do not exceed the statutory limits for tyre, wheel and axle loads.

2 Colouring

2.1 GENERAL

The surface of concrete flatwork that is exposed to view is often coloured in conjunction either with basic finishing (eg trowelling, bullfloating) or with any of the more elaborate patterning and texturing techniques described in **Section 3**. Colour can be readily introduced to concrete in both the plastic and hardened state.

In the plastic state, common methods include:

- using different coloured cements in the concrete mix;
- adding a mineral oxide pigment to the concrete (for the slab itself or that for a topping);
- applying a dry-shake or 'dust-on' topping (containing a pigment) to the surface;
- adding a dye to the concrete mix;
- selecting special aggregates for exposed aggregate finishes.

Hardened concrete paving, both new and old, can be coloured by:

- chemically staining the surface;
- applying a dye, tint or other coating/sealer to the surface;
- exposing the aggregates within the concrete.

Note that when applying any thin layer such as a tint, coating or sealer to the surface of the concrete, reapplication may be needed to maintain its appearance over time.

Which method is used depends on factors such as the colour required and its consistency over the surface, the durability of the colour, whether patterns are required or whether the concrete surface is in its plastic or hardened state. Two or more of these methods may be combined to extend the colouring options available.

Coloured surfaces can assist with glare **Figure 1**, delineate specific features and areas, and complement other landscaping or streetscaping work.

2.2 CONCRETE CONSTITUENTS

2.2.1 Cements

The colour of concrete is first of all influenced by the colour of cement used in the mix: normal 'grey', off-white or white.

The grey colour of cement is primarily due to its iron content. By lowering the iron content, off-white and white cements can be produced. Both 'grey' and off-white cements are manufactured in Australia to meet the requirements of AS 3972[1] for General purpose portland (Type GP), General purpose blended (Type GB) or High early strength (Type HE) cements.

Grey cement is used for the majority of flatwork applications as colour control is seldom specified for external applications and general flooring work. Off-white is, however, generally specified for architectural flatwork finishes as it tends to give a more consistent colour when used alone **Figure 2** and results in brighter colours when pigments are incorporated.

Toppings

Applying a topping (a thin layer of concrete on top of the main structural concrete slab or pavement) is one of the most common methods of providing a decorative finish and/or colour to concrete flatwork. A damaged or worn concrete surface can also be revitalised by the application of a topping. Other benefits of using toppings are that they:

- limit the amount of pigment required for integral colouring – particularly significant when using expensive pigments (eg blue and green);
- limit the amount of special aggregate required for exposed aggregate finishes;
- enable good colour consistency to be achieved over a large area since it can be covered by a single batch of concrete;
- may provide a surface that will more readily accept stains and dyes;
- are placed at the end of the project and therefore reduce the risk of damage to the finish from construction activities;
- allow special finishes to be achieved, particularly those that require various materials to be embedded or set into the surface of the pavement;
- can be used to correct surface levels in the pavement.

BACK TO CONTENTS PAGE

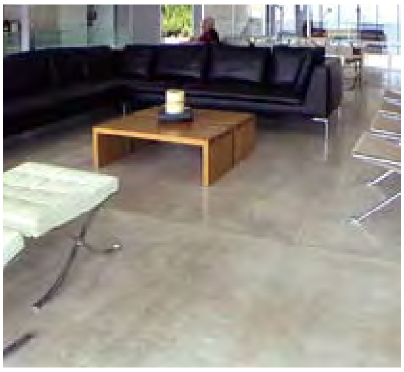


FIGURE 1
Pigment used to reduce glare from concrete surface

FIGURE 2
Colour consistency achieved by use of off-white cement (in concrete topping)

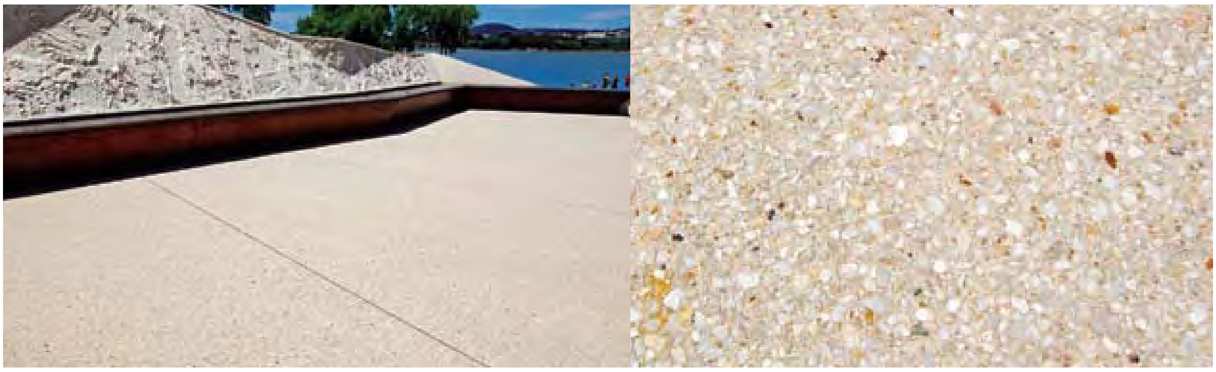


FIGURE 3
White quartz exposed aggregate paving using off-white cement and white titanium oxide to brighten the finish and complement the colour of the concrete wall
National Emergency Services Memorial, Canberra

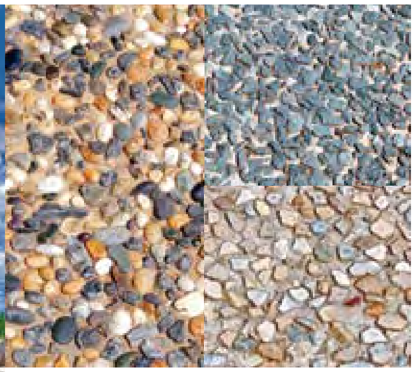


FIGURE 4
Coloured aggregates used to create patterns

FIGURE 5
Part of the range of powdered mineral oxide pigments

← BACK TO CONTENTS PAGE

White cement is imported to Australia and this is reflected in the high cost. If a 'white' colour is required for a particular architectural finish, an alternative is to use off-white cement with a pigment (typically white titanium oxide). The pigment both brightens and gives a more consistent colour to the finish. The availability of white cement, particularly if being considered for premixed concrete, should be checked prior to specifying its use.

The following points should also be considered:

- Off-white and white cements are not colour controlled (a common misconception). The colour is more consistent simply due to the lower iron content which results in a lighter colour and hence less variation in the shade of colour between different batches of concrete.
- The actual cement colour within a generic category may vary considerably depending on the source of raw materials and the manufacturing process. There are many different shades of grey, off-white and white cement. If colour is critical to the finish, then a sample panel should be constructed to ensure the colour is acceptable.
- Colour variations may also occur due to other materials within the mix, changes in materials over time (particularly for larger projects), batching tolerances, water content and variations in placing, compacting, finishing and curing procedures. If colour and consistency of colour are important, the use of a pigment (see below) to mask possible colour variations is recommended. Refer also to **Section 4.12 *Colour Control***.
- To achieve more-vibrant colours from pigments, off-white cement is usually required. Normal 'grey' cements tend to give the darker more earthy colours when pigments are added.
- The availability of off-white cement should be checked with the concrete supplier prior to specification as the majority of plants do not have the capacity (additional silo) to stock off-white cement. Depending on the size of the project, the option of stocking off-white cement in an existing silo within a concrete batching plant may be available.
- For finishes such as white quartz exposed aggregate where a 'white' surface is required, the use of an off-white cement (and possibly white pigment) to lighten the colour of the cement matrix will enhance the colour of the stones and hence the finish **Figure 3**.
- The colour of Type GB cements (eg slag and fly ash blends) will be different to Type GP cements. Whatever the cement colour and type selected, all cement for a project should be from the same source and of the same type if colour consistency is important.

2.2.2 Aggregates

Once the aggregates within the concrete are exposed (by honing or by removing cement mortar from the surface layer), they tend to provide the dominant colour to the concrete surface. Similar to pigments, most aggregates (both sand and stones) will not degrade or change colour over time and, once exposed at the surface of the concrete, provide a permanent colouring solution. The range of colours, however, will be limited by the available aggregates **Figure 4**. Honed finishes are discussed in **Section 3.2.4** and exposed-aggregate finishes in **Section 3.3.7**.

2.3 PIGMENTS

2.3.1 General

The use of pigments is the most common method of provided a coloured finish to concrete flatwork. Pigments can be used to colour the entire volume of concrete used for a slab or only that for a topping layer (integrally-coloured concrete). They may also be broadcast onto the surface of pre-hardened concrete as a dry-shake topping or applied to the hardened surface in the form of a tint (see **Section 2.6**).

The most common pigments are mineral or inorganic oxides. They are ultra-fine particles (a fraction of the size of cement particles) which disperse as fine solids throughout the concrete matrix and become bound into the concrete in the same manner as the other aggregates. Similar to exposed aggregate finishes where the predominant colour is that of the aggregates, pigmented concrete takes on the colour of these ultra-fine particles that are exposed at the surface of the concrete and thus mask the colour of the cement matrix.

Pigments come in a wide range of colours **Figure 5** and are available as either powders, granules or aqueous slurries (liquids). Granular colour oxides may be bound together with either an organic or inorganic binder. The organic binder dissolves in the presence of moisture during batching and disperses quickly, whilst the inorganic binder relies on the shearing action of the aggregates to break down the granules. Powders and granules are generally added into the concrete truck in bags which dissolve during mixing. Aqueous slurries are produced by mixing powdered pigments in water with dispersants and stabilisers to avoid settlement of the pigment particles. These are often used at major batching plants as they avoid dust and can be connected to automated batching equipment for accurate measurement of quantities.

The majority of colours (reds, yellows, browns and blacks) are oxides of iron. Most are now manufactured, hence the name synthetic iron oxides. The extensive colour range is made possible by also using white titanium oxides plus green chrome and blue cobalt oxides.

Mineral or inorganic oxides are permanent and not affected by the sun's ultraviolet (UV) rays. This is because oxides are materials in their most basic form and hence there is no mechanism for them to further degrade or change. They are insoluble (prevents leaching out), chemically inert (do not interfere with the cement reaction), alkali resistant (suitable for concrete which has high alkalinity), harmless to the environment, and once bound into the cement matrix they provide a permanent colouring solution.

Note that some colours such as blues and greens are considerably more expensive than the natural/synthetic yellows, browns and blacks due to the manufacturing process to produce these special metal-oxides. The use of off-white or white cement and light coloured aggregates enhances the brightness of former colours.

The following should be considered when using pigments:

- Pigment concentration. The amount of pigment required is normally specified as a percentage of the mass of cement within the concrete mix eg 5% of the weight of cement. The percentage required to produce different colours may vary depending on the pigment and its tinting ability, but generally lies in the range of 3 to 8%.

  Figure 6 gives the saturation points for various colours, beyond which no increase in the colour intensity will occur. It also shows how various pigment concentrations affect the colour intensity. A pigment concentration (or loading) of 5% typically provides good colour intensity; lower concentrations may not give the colour intended; while adding more than the saturation point is an expensive way of simply adding more fine material into the mix. With adequate pigment concentration, weathering will generally have little effect on the colour **Figure 7**.

  Because the colour is affected by the pigment concentration and tinting strength of the pigment, it is generally preferable to specify colour by selecting a particular colour from a manufacturer's range. Manufacturers can assist with determining the correct pigment concentration for the proposed concrete mix, specification requirements and method of dispersion through the concrete mix.

  For exposed aggregate finishes, because the dominant colour is that of the aggregates, if the mortar between the stones is to be coloured, typically only 1 to 2% pigment is added so that the mortar complements the colour of the aggregates without dominating the finish.

- Cement colour. Grey cement will always take the brilliance out of any colour, which is why the colour of concrete made with off-white and white cements will be brighter. However, much depends on the desired effect and pigment colour. A range of pleasing colours can be obtained using grey cement; there will be no difference with black pigments, little difference with dark reds and browns, but a significant difference with the lighter yellows and blues. With the lighter coloured pigments the use of off-white cement should be considered in preference to the more expensive imported white cements. Note that variations in the colour of each type of cement can also influence the final colour of the pigmented concrete. The addition of supplementary cementitious materials may also impact on the colour.

- Concrete strength. Pigments added at the typical concentration of 5% will not affect the strength of the concrete. However, the introduction of excessive amounts of fine material (pigment) beyond the saturation concentration will increase the water demand and hence water-cement ratio and may affect the strength.

  Increasing the concrete strength usually means increasing the cementitious content which in turn increases the amount of pigment needed, possibly causing colour variations. For projects requiring consistent colour and incorporating different concrete strengths, test panels should be used to assess colours.

- Weathering of pigments. Mineral oxide pigments do not change colour over time. However, there is a change in the base concrete colour which may give the perception that they do. This can be seen in the concrete having no pigment loading in **Figure 7**. With increasing pigment loading, the change becomes masked. Little difference is apparent at 5% pigment loading and beyond the saturation point, no change is evident. The change in colour is less perceptible with dark pigments than it is with lighter ones.

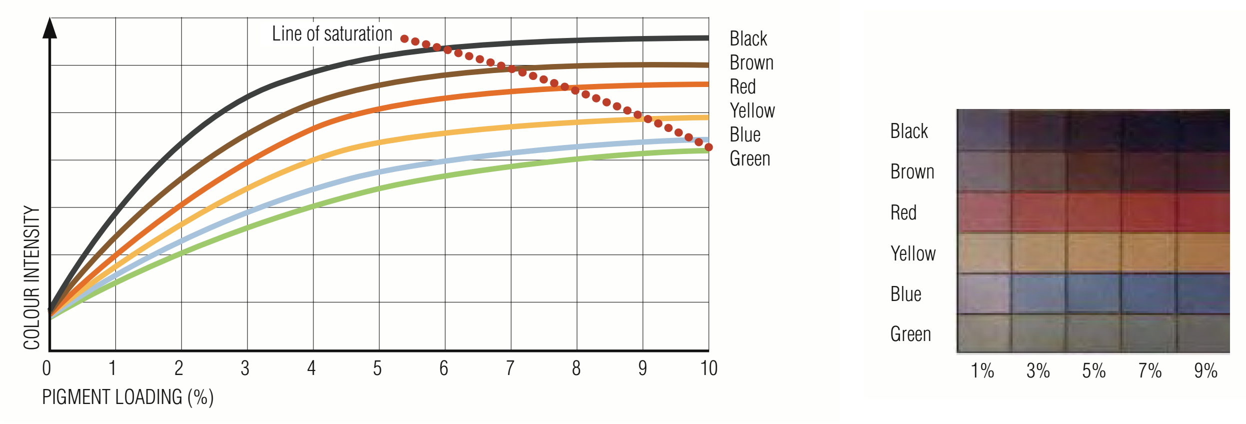


FIGURE 6

Saturation points for various pigment colours *[above left]* and colour intensity and pigment loading *[above right]*

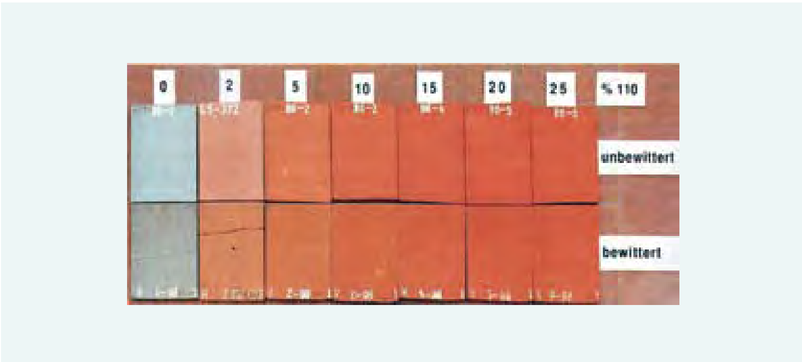


FIGURE 7

Effect of pigment concentration on weathering

> top row unweathered

> bottom row weathered for 4 years

Reproduced with the permission of Betonwerk + Fertgeil-Technik

FIGURE 8

Efflorescence may give the appearance of fading/lightening of the colour

FIGURE 9

Effect of aggregate exposure – different types and percentages

Reproduced with the permission of Betonwerk + Fertgeil-Technik

- Efflorescence. The formation of efflorescence (a white coating on the surface) can appear to lighten the colour and give the impression that the pigment has faded **Figure 8**. It will have less impact on light colours.
- Aggregate colour. Aggregates are usually covered by a thin layer of coloured cement mortar (cement, sand and pigment). However, if the aggregates are not completely covered or become exposed through abrasion of the surface (wearing), weathering or even subsequent tooling of the surface, then the final colour will be affected by the colour of the aggregates; the sand initially and then the coarser aggregates. **Figure 9** shows the change in colour once the aggregates are exposed. The lighter the colour, the more influence the aggregate colour will have. Thus the selection of appropriate aggregates and aggregate colours may be an important consideration.

  For surfaces with subsequent treatments that highlight the aggregate colours, the pigment concentration can be as low as 0.5 to 1.0% by mass of cement, to complement the aggregate colour rather than as a source of colour.

2.3.2 Integral colouring

Integrally-coloured or colour-through concrete refers to the addition of pigments to the concrete or topping mix in order to colour the entire volume of concrete, therefore providing a coloured surface on the top and sides of a concrete element. Pigments are added at the batching stage or to a concrete transit mixer on site, and thoroughly dispersed through the concrete mix.

After placing, the concrete surface is screeded, floated and finished in the same way as ordinary concrete. Particular care should be taken with curing to produce the best finish (see **Section 4.17**).

For uniform colour, a consistent mixing procedure is crucial (whether it is done at the batching plant or in the barrel of a premixed concrete truck) and every aspect of the concrete and its method of placement, finishing and curing should be consistent. Note that variations in the curing procedure or use of an inappropriate curing method may result in significant colour variations (see **Section 4.12**). Test panels are useful to find the right mix and colour, confirm that construction methods will deliver the desired outcome and provide the basis for quality control.

Because minor colour variations from batch to batch are inevitable, borders of different colours or materials (eg pavers, tiles, timber) can be used to divide large areas into smaller more manageable sections which can be placed from a single batch of concrete **Figure 10**. Also, separating areas from different batches helps to mask any minor colour variations by preventing direct comparison of colours (side by side) and gives the opportunity to form patterns **Figure 11**. Thinner toppings are often used to allow placement of larger areas from the same batch of concrete.

If unacceptable differences in colour occur, correction with dyes may be possible. Mild-acid washes should be a last-resort method of trying to moderate the colour intensity or colour variations and should be attempted only by contractors experienced with the technique. Note that when using such chemicals, all mandatory safety and environmental protection measures should be strictly observed.

Minimising shrinkage cracking and maximising surface strength are particularly important for coloured surfaces. Cracks can affect the appearance and a weak surface will be prone to dusting, abrasion and chipping. Basic quality issues relating to the compaction and curing of the concrete are often the simplest measures available to reduce the risk of cracking. Note that inadequate compaction and curing could result in the concrete at the surface achieving only half its design strength.

2.3.3 Dry-shake or 'dust-on' toppings

Dry-shake or 'dust-on' toppings are commercially available products containing cement, sand, and pigments, and (in some cases) special hardeners to increase the strength of the finished surface; they are therefore sometimes referred to as 'coloured surface hardeners'. They come as ready-to-use premixed products, are available in a wide range of colours and while often used in conjunction with stencilled and stamped pattern finishes, can be used to simply provide colour to the surface of concrete paving **Figure 12**.

Dry-shake toppings can also be made on site from similar materials. The usual blend is 1 part cement to 2 parts clean sand (by volume); plus pigment measured by weight in the ratio of 1 part pigment to 10 parts cement (ie 10% of the weight of cement in the mix). The powdered pigment is first blended with dry cement before combining with the sand.

The manufacturers of coloured surface hardeners claim that correct use of the products produces 40- to 60-MPa surface strengths; considerably increasing the abrasion resistance of the typical 20-MPa concrete specified for most flatwork applications, including stencilled and stamped concrete finishes. Note that being cement-based products, they must be finished and cured in the same way as concrete to achieve optimum strengths.

FIGURE 10
Panels of coloured concrete divided by borders of dark brown coloured concrete

FIGURE 11
Floor placed in chequerboard pattern to conceal colour variations between concrete batches (unbonded integrally coloured topping over existing timber floor)

FIGURE 12
Dry-shake toppings used to create surface colour

FIGURE 13
Dry-shake topping being applied

FIGURE 14
Adjacent surfaces (slabs and walls) should be protected

FIGURE 15
Dark colours may require three applications of colour hardener to ensure uniform colour

FIGURE 16
Sealing the surface to prevent staining and to highlight the colour

The addition of straight pigment to the surface is not recommended as either a weak, powdery surface or one that may 'flake' off can result. Also, it is difficult to obtain an even colour due to the difficulty of uniformly spreading such a fine powder by hand.

Dry-shake toppings are cast by hand over the surface (hence the term 'dry-shake') of the fresh concrete **Figure 13** and worked into the surface by trowelling to produce a coloured thin monolithic topping. All traces of bleedwater must be allowed to evaporate before applying the powder. Using the powder to soak up bleedwater is bad practice, and invariably results in a much weaker surface, which will wear quickly and may dust, delaminate or chip. A concrete mix with just enough water to make it workable reduces the amount of bleedwater, allowing earlier application of the dry-shake topping. Adding polypropylene fibres also helps bind the mix and reduce bleeding.

Because the bleedwater must evaporate first, dry-shake toppings are normally applied towards the end of the concrete setting process and there may be insufficient time to provide the required steel trowel finish over large areas, limiting the area that can be finished. Also, the steel trowel finish is normally done by hand to avoid the risk of the heavier power trowelling machines mixing the topping with too much of the base concrete, resulting in the possible loss of the majority of the colour. Note that some trowelling marks should be expected from hand finishing.

The rate of application of a dry-shake topping for flatwork will typically be a minimum of 2 kg/m^2.

The procedure for using dry-shake toppings is as follows:

1 **Protect adjoining surfaces**. Before placing concrete, use plastic sheeting to protect adjoining surfaces from splashes of concrete and colour **Figure 14**. Pigments and cements are fine powders that can be easily carried by breezes and may be difficult to remove from adjacent finishes

2 **Place the concrete slab**. Place, screed and float the concrete to its finished level. During hot weather, the use of an evaporative retardant or surface set retarder prolongs the plastic (workable) state of the surface, which may otherwise harden prematurely and reduce the time available to finish the work.

3 **Apply dry-shake topping**. Evenly broadcast the dry-shake topping (coloured surface hardener) over the surface in two stages to ensure uniform colour and thickness. Usually two thirds is applied in the first 'coat', and one third in the second, which should be applied in a direction perpendicular to the first. For dark colours such as charcoal (black), it may be advisable to apply a third 'coat' to ensure a uniform colour **Figure 15**. Each 'coat' is thoroughly worked into the surface by trowelling and all edges and joints should be tooled before and after each application.

   A second colour (and third) can be added while the surface is still plastic, to produce colour flecks or mottling.

4 **Finish the surface**. Common techniques can be used to finish the surface including brooming, steel trowelling, sponging, woodfloating, or dragging with hessian. Stencilled and stamped patterns may also be used (see **Section 3**).

   If a smooth finish is required, additional steel trowelling of the surface will increase the hardness (advisable in commercial or industrial applications).

5 **Cure the surface**. Take particular care with curing to ensure strength and colour consistency. Coloured surface hardeners will not produce high surface strengths unless the concrete is cured adequately. Plastic sheeting and curing compounds provide the most practical methods but for some special finishes the use of same-day sealers may provide adequate curing. Methods such as hessian coverings, damp sand and ponding are generally not recommended for decorative concrete finishes. The method of curing may also result in colour variations (see **Section 4.17**).

6 **Seal the surface**. The main reason for sealing the surface is to minimise surface staining **Figure 16**. Cleaning stains from an unsealed surface, with cleaning compounds or solvents, may affect the colour. Sealing may also be used to highlight the colours by imparting a 'wet' appearance to the concrete surface.

   To assist curing an initial same-day sealer is often applied to coloured concrete surfaces immediately after finishing of the surface. This is followed by the application of the final sealer coat(s) following curing (see **Section 4.18**).

2.4 CHEMICAL STAINS

Chemical stains react with the excess calcium in the concrete to produce products that permanently colour the concrete. As the reactions between the stain and concrete constituents (which create the colour) depend on the stain penetrating into the concrete surface, a mottled finish rather than a uniform coloured surface is produced due to the

← BACK TO CONTENTS PAGE

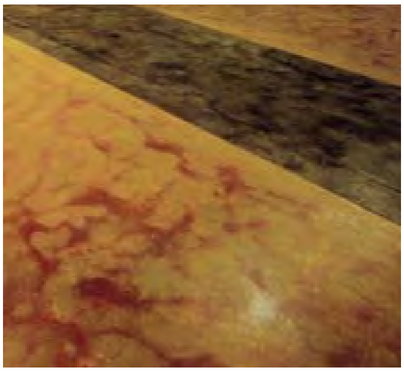


FIGURE 17
Mottled finish from chemical staining with dark lines resulting from application method

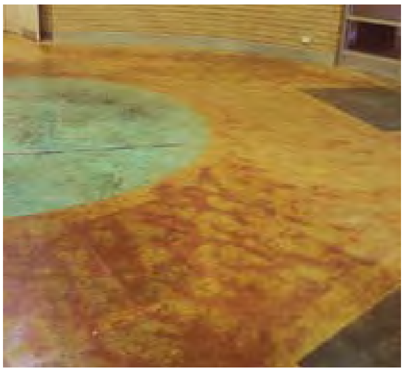


FIGURE 18
Stain penetration into the base slab can be variable depending on concrete consistency

FIGURE 19
Mottled finish typical of chemically stained concrete (pattern has been stamped into surface)

FIGURE 20
Surface coloured by chemical staining of thin topping layer used to provide more consistent colours over large areas

FIGURE 21
Examples of chemical stains applied to thin specialist toppings

FIGURE 22
Chemical staining by brush should be limited to small or other areas where brush marks are acceptable

FIGURE 23
Chemical stains can be ponded on flat surfaces to allow good penetration

← BACK TO CONTENTS PAGE

variable penetration (particularly when used on an existing slab that has been in service for some time) **Figures 17 and 18**. Two or more colours are often used to produce mottled finishes resembling stone, create patterns or provide an antique appearance to the concrete **Figure 19**.

Various colours are available and suppliers' samples should be inspected when selecting colours. For large areas, test panels should also be made to ensure the final appearance is acceptable. Often a non-critical area of the actual floor can be used and may provide a more representative sample of the work to be coloured.

Colouring concrete by the use of chemical stains may appear simple, but in fact requires careful planning and a level of experience and skill in its application to achieve a good result. Often it may be better to place a thin bonded topping (see **Section 4.20**) over the existing slab and apply the stain to this as the topping and hence coloured finish from the stain will be more consistent **Figure 20**. Specialist toppings generally accept stains well and therefore produce more intense colours **Figure 21**. The use of a topping also avoids having to protect the surface/finish during the course of normal construction activities.

Staining of small areas, particularly those containing patterns can be achieved by hand, using brushes or rollers **Figure 22**. Stains can be applied quickly enough to allow consistency over small areas without leaving brush or roller marks. Larger areas and those with flat or smooth finishes are best carried out using spray equipment to avoid brush or roller marks **Figure 17**. Note that coarser textured finishes such as stamped surfaces **Figure 21b** will tend to conceal brush and roller marks.

The use of chemical stains suits flatwork construction as the product can be ponded on the surface to allow good penetration into the concrete **Figure 23**.

Some further items to consider include:

- As chemical stains react with the concrete constituents, they should not be applied until the concrete has achieved its design strength.
- Concretes incorporating blended cements or with a low cement content (low-strength concretes) have lower calcium levels, resulting in less intense colours.
- Concrete strengths in excess of 32 MPa may prevent adequate penetration of the stains due to their lower permeability.
- Stains can be acrylic or solvent based. Solvent-based stains will dry faster, allowing a number of applications in a single day and earlier finishing of the surface.
- Surfaces should be free of contamination. Release agents and debonding compounds used when casting tilt-up concrete panels on floor slabs (to prevent them adhering to the floor slab) will affect the penetration of the stain into the concrete surface, and should not be used if the concrete is to be chemically stained. Curing compounds which are intended to form a film on the surface of the concrete may also affect the rate at which the stain will penetrate into the concrete surface and thus the end result.
- Chemical stains are mildly acidic to assist with penetration of the stain into the surface. Once stained, the pH of the surface must be neutralised.
- A sealer is usually applied to protect the finish and enhance the colour.

2.5 DYES AND TINTS

Dyes and tints are often grouped together by the decorative concrete industry and sometimes even confused with stains. However, dyes and tints differ from stains both in makeup and how they colour the concrete surface.

Dyes and tints both contain coloured particles in either a water or solvent solution and can produce colours that are not available with chemical stains, eg the red in **Figure 24**.

Dyes (or dye stuffs as they are often referred to) are extremely fine coloured particles in a powder form. While normally used to colour fibres such as hair and fabrics they can also be used to colour concrete. The variety of vivid colours possible extend the colour palette available for colouring concrete, providing a vast range of colouring solutions for both large and small projects. Note that unlike stains, dyes can be mixed to produce specific colours.

For most applications, dyes are made into liquids using either a water or solvent base. The water or solvent base transports the dye into the concrete by absorption, producing a translucent finish. Similar to chemical stains, they are dependent upon the material penetrating the concrete surface and therefore may produce a mottled finish. However, colours tend to be more consistent than those produced by chemical stains as the colour is not dependent on a chemical reaction and the extreme fineness of the dye stuff means that the water or solvent can transport the coloured particles more readily into the concrete surface. For this reason they are often used in conjunction with stains to correct areas where the colour from the stain is 'patchy' (darker or lighter) or the colour not as intense as expected.

← BACK TO CONTENTS PAGE

FIGURE 24

Dyes and tints produce strong vibrant colours not possible with stains – red, yellow and orange

[a] Chemical stain used for mottled green background and patterned border

[b] Original artwork by Christy Shaffer (courtesy of Dover Publications) and dyed image on floor by Gerald Taylor (www.imagesinconcrete.com)

[c] Artist: Dana Boyer of ConcretiZen

To ensure that the concrete surface is porous enough to allow penetration of the dye, the concrete strength should generally be no more than 32 MPa. Dyes generally do not work if the concrete strength is greater than 50 MPa. An alternative may be to add the dye to the plastic concrete prior to placement, ensuring that it is thoroughly dispersed through the concrete.

Solvent-based dyes have the advantage of spraying well, allowing better control of the work to be achieved. They are fast drying, allowing multiple coats to be applied and the floor to be coloured and sealed the same day. Water-based dyes take longer to dry and generally can not be recoated or sealed on the same day. With solvent- or water-based dyes, unlike chemical stains, no neutralisation of the pH is required, further reducing the time and labour costs.

Dyes are organic materials and as such typically have low UV resistance and hence tend to fade over time. For external applications, and even internal applications near window/door openings that allow sunlight on the floor, the dyed surface could be coated with a UV resistant sealer. The UV resistance, ability to use the product externally and precautions that need to be taken should be established with the supplier of the dye beforehand.

Tints are totally different products to dyes but because dyes and tints are often used together, they tend to be treated as similar products. Tints are pigmented coatings generally in a water base. The pigments used in tints are mineral oxides (see **Section 2.3**) rather than dye stuffs. Tints are applied to the surface rather than mixed into the concrete. As the pigment particles are much larger than dye particles, they tend to remain on the surface of the concrete and form opaque rather than translucent colours; the flowers in **Figure 24** are an example of the opaque finish achieved. Also, because mineral oxide type pigments are UV resistant, tints can be used externally.

Tints do not react with the concrete, and because they do not rely on penetrating the concrete surface, the colours and results are more predictable and less dependent on the consistency of the concrete or the weather conditions. They must be protected by a surface sealer to prevent removal by wear or abrasion.

If products are referred to by a combination of terms such as 'dye stains' the supplier should be contacted to determine the exact nature of the product and hence properties such as UV resistance and requirements for sealers.

2.6 APPLIED COATINGS

Coatings range from various paint systems and concrete 'sealers' to formulated coloured cementitious materials that provide similar results to integrally coloured concrete but with improved colour uniformity. Cementitious coatings which are usually applied thicker than normal paving paints are often referred to as micro-screeds/toppings and may be applied by brush, roller or trowel depending on the thickness required **Figure 25**.

Compared with the variable colour inherent with the use of 'dry-shake' toppings or the use of stains and dyes, coatings provide a uniform colour over the entire surface. However, as with any product applied to a trafficked surface, they are subject to wear and will therefore need to be re-applied from time to time.

FIGURE 25

[a] Dark blue areas are a coloured cement-based micro-topping approximately 1 mm thick trowelled onto the surface (light blue colour is from dye washed over surface)

[b] Coloured cementitious paint coating used to create designs *Photo courtesy of Ability Building Chemicals*

FIGURE 26

Coatings can serve multiple functions – provide uniform colour, delineate areas, protect surface and facilitate cleaning

FIGURE 27

Worn areas apparent on surface coating

Reasons for their use may include colour variations being unacceptable, to simplify the creation of patterns, provide duo or multi-coloured effects **Figure 25b**, achieve particular colours, protect the surface from abrasion and/or staining and assist with cleaning **Figure 26**. With adequate thickness they will conceal the substrate and, depending on the type of product used, may provide a moisture and/or degrading chemical-solution barrier to the concrete. According to their properties and the number of coats or layers applied, this may extend the design life of the concrete element.

If a combination of coats of different paints/coatings and/or sealer are required, manufacturers should be consulted to ensure that a compatible paint or coating/sealer system is specified.

Applied to the surface of a concrete pavement any coating/paint product will be subject to UV radiation, weathering and abrasive wear. Some coatings, especially those bound with the organic resins derived from crude oil, will need to be re-applied at regular intervals to reinstate their original appearance **Figure 27**.

3 Surface finishes

3.1 GENERAL

After the concrete has been placed and compacted (see **Section 4**), finishing of the surface is undertaken. The initial stage in achieving any finish is to screed the surface to the required level/profile and flatness **Figure 28**. A bullfloat **Figure 29** is then typically used to close and fill any holes in the surface and eliminate lines from the screeding operation, leaving the surface relatively smooth. Also, hand floating the edges, corners and around penetrations may be carried out to level off screed marks and to consolidate loose material **Figure 30**. The concrete is then left until all the bleedwater has evaporated. The final stage of finishing generally involves trowelling the surface **Figure 31** and, if required, applying one of a large variety of treatments to create different textures and patterns, and maybe colouring.

Factors to be considered when selecting and specifying a surface finish include:

- Grade of pavement. Steep pavements generally require a coarse surface texture to provide skid and slip resistance, especially if a surface sealer is applied. Depending on the grade, steel trowelled, polished, stamped and smooth aggregate type finishes may be unsuitable. Coarse broomed, tined, dragged and stencilled finishes would be more suitable. Also, exposed aggregate finishes may require an angular (crushed) stone rather than a smooth rounded stone.
- Slip resistance. Some surface texture is generally required to provide slip resistance, particularly in wet conditions and for steep grades. Note that if the pavement is subject to barefoot traffic (ie around a pool) the texture should not be too coarse. Suitable finishes for these applications include honed, wood float, light broom and pebblecrete (see **Section 4.23**).
- Skid resistance. Where pavements are to be used by vehicular traffic, adequate skid resistance must also be provided. Caution should be exercised in using generic products such as stamped and stencilled finishes since their heterogeneous nature could lead to wide variations in skid resistance properties. The skid resistance of 'smooth' finishes may improve with trafficking due to wearing of the surface causing increased roughness. (See **Section 4.23**).
- Environmental factors. The procedure for achieving some finishes may impact on the surrounding environment, eg water-washed finishes may require silt traps to filter runoff prior to entering the stormwater system.
- Cleaning. For pavements subject to spills (eg barbeque, outdoor kitchen and eating areas), the ability to adequately clean the surface may be a factor. Smooth finishes are the most appropriate since they are easy to clean and maintain. Use of a surface sealer can prevent staining of the concrete and facilitate cleaning.
- Glare. Adding a pigment to the concrete to darken the colour will reduce the amount of glare and improve the appearance **Figure 1**.

Surfaces finishes for concrete flatwork can be divided into two general categories: smooth and textured finishes.

3.2 SMOOTH FINISHES

3.2.1 General

Smooth concrete finishes are often referred to as polished concrete finishes. Polished concrete is a generic term covering a range of options which leave the concrete surface exposed as the final floor finish. Often, some form of surface sealer or coating is applied which may impart a gloss appearance to the surface. There are three basic methods of producing smooth finishes on either a concrete floor or on a topping over an existing concrete floor: steel trowelling, burnishing and honing.

3.2.2 Trowelled

This is the most basic flat, smooth finish possible and achieved by simply steel trowelling the concrete surface either by hand or with a power trowelling machine **Figure 32**.

Hand trowelling might be considered for confined or small areas or where adjacent finishes must be protected from possible damage caused by the use of trowelling machines. Pointed trowels **Figure 33a** with a flat, broad steel blade are generally used for slabs as the curve of the blade end reduces trowel marks. Square edged trowels **Figure 33b** are used for smaller areas such as stairs and kerb-and-gutter work for which pointed trowels are not suitable. Special tools for forming grooves in steps and ramps are also available to improve slip resistance **Figure 34** or allow insertion of slip-resistant materials.

FIGURE 28
Screeding concrete surface to level/profile

FIGURE 29
Bullfloating concrete surface

FIGURE 30
Hand floating edges to match levels, fill hollows, compact concrete and round edges to reduce spalling

FIGURE 31
Power trowelling concrete surface

FIGURE 32
Power trowelling used for large areas and hand trowelling for corners and edges

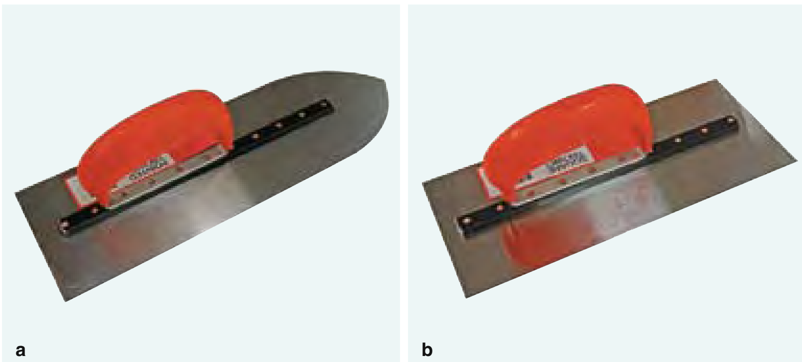


FIGURE 33
Common steel trowels
[a] Pointed steel trowel
[b] Square steel trowel

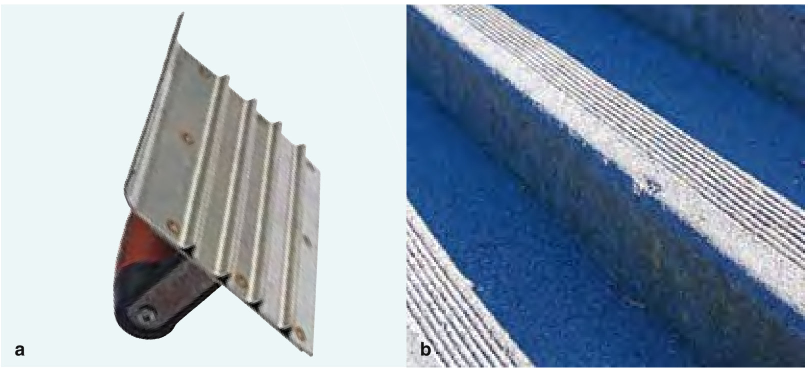


FIGURE 34
Special steel trowels
[a] Non-slip, groove-forming tool
[b] Grooves trowelled into stair tread

FIGURE 35
Hand steel trowelled floor free of trowelling marks

While hand trowelling can produce finishes free of trowel marks **Figure 35**, it is easier to achieve such a finish by using a power trowelling machine due to the ease with which additional trowelling can be provided, especially for larger areas.

Machine trowelling (power trowel or 'helicopter') is a common method for all applications. The machine generally consists of four steel blades rotated by a motor and guided by a handle **Figures 31 and 32**. Double- and triple-head ride-on trowelling machines **Figure 36** are also available to enable larger areas such as factory floors to be trowelled.

Some minor trowel marks may still be present after machine trowelling depending on the duration of trowelling or finish required **Figure 37**. The extra work required to ensure no trowelling marks remain will necessitate a near burnished finish **Figure 38**. Late and repeated steel trowelling of the surface with a trowelling machine can produce a burnished finish **Figure 39** (see **Section 3.2.3**).

The reflective nature of steel trowelled surfaces tends to highlight any undulations in the surface **Figures 38 and 40**. As the flatness of the surface may be critical to the overall appearance of these types of finishes, an appropriate tolerance for the surface should be specified (see **Section 4.22**).

Some sections of the floor may dry more rapidly than others resulting in the trowel having to be passed over previously completed areas in order to reach those that still need to be finished. This can affect surface tolerances as 'wet' material can be trowelled over previously-completed work. Also, to assist with moving the trowel over completed areas, water is sometimes sprinkled over the surface (known as 'wet wiping'). This practice should be avoided as the abrasion resistance of the surface can be affected and dusting problems result. The preferred solution is to ensure that the concrete and finishing conditions (sun/shade, doors allowing draft/winds over certain areas, etc) are as consistent as possible.

3.2.3 Burnished

Burnishing is the term applied to the finishing of concrete surfaces to provide a smooth, hard-wearing, durable finish having a surface lustre. It is usually produced by steel trowelling the surface until the concrete surface takes on a polished or glossy appearance of its own **Figure 41**. Alternatively, products such as floor waxes, liquid polishes and resin-based coatings can be applied to the surface and burnished using polishing equipment **Figures 38 and 42**. In this case, a minimum steel trowelled finish free of trowelling marks should be specified to ensure a good appearance.

A burnished concrete finish achieved by trowelling is often specified where a surface free of trowelling marks is required. However, the additional time and expense involved in achieving such a high level of surface finish may not be necessary if all that is required is the absence of trowelling marks. The specification should state what surface appearance is required.

Steel trowel burnishing can be achieved by either hand or machine trowelling. The additional trowelling for large areas is best achieved with a team of power trowelling machines which may be single-, dual- or triple-head devices **Figure 36 and 41**. Hand burnished floors on the other hand (depending on the area) may require either an increased number of workers, or the floor being divided into sections of a manageable area. Note the difference in gloss levels between the hand-burnished floor in **Figure 35** and the machine-burnished floor in **Figure 41**. This is mainly due to the ease with which additional trowelling can be provided by machine. For toppings placed after the walls are built, the inability to machine finish up against walls may mean that a uniform finish is not possible over the entire floor area. Trowelling is best carried out prior to the walls being constructed as the entire floor area is accessible for power trowelling. Note that this will necessitate the protection of the finish during subsequent construction (see **Section 4.25.3**).

Extended machine trowelling of the surface may cause some 'burning' or darkening of the surface as the trowel must be passed over the surface while the concrete is quite 'dry'. The resulting friction generates heat which in turn can affect the colour by causing dark areas or 'burn' marks. The concrete strength would typically be at least 32 MPa for burnished finishes and stringent control of slump, compaction, finishing techniques and curing are needed.

A similar burnished finish may also be achieved by applying products such as floor waxes, liquid polishes or resin-based coatings to the concrete surface and burnishing with polishing equipment. The degree of lustre achieved is dependent on the quality of the concrete finish, product used and burnishing technique.

Products can vary from those that penetrate into the concrete surface and result in a matt appearance, to those that form a film on the surface and provide higher gloss levels. With some products all that may be required to achieve a gloss finish is the correct method of application to ensure a finish free of brush/roller marks. With polishes and waxes, buffing after application will be required to produce a gloss finish, with perhaps a number of coats needed to fill any fine surface texture and give a consistent finish over the entire floor.

If a good gloss appearance is required using coatings, the concrete surface should be specified as being free of trowelling marks as thin surface coatings are generally incapable of concealing them.

Because burnished finishes are highly reflective and will therefore highlight any undulations in the surface, stringent control of tolerances will be required.

Utilised primarily in industrial buildings, carparks and warehouses, burnished finishes are increasingly being used in residential and commercial buildings **Figures 37 to 42**. Further information can be found in *The Specification of Burnished Concrete Finish*[2].

3.2.4 Honed (and polished)

Honed finishes are achieved by grinding the concrete surface using abrasive grit heads/pads to produce a smooth surface that may vary from a matt finish **Figure 43a** to a highly polished finish where the surface takes on a glossiness/lustre of its own **Figure 43b**. Honed finishes are generally used to expose the aggregates within the concrete **Figure 44**, but may also be used to expose decorative inserts within the concrete **Figures 45 and 46** or improve the surface of existing slabs by removing high spots, slight surface imperfections and marks, plus traces of adhesives from previous floor coverings **Figure 47**.

Depending on the reason for grinding, the depth of grinding should be specified; commonly by the outcome required, eg to remove the top third (or other depth) of the coarse aggregate particles and achieve a uniform exposure of the aggregates

Removing the surface layer of concrete by grinding to expose the aggregates produces one of the most durable, low-maintenance finishes available. The hard aggregates normally used in concrete mixes provide a surface finish with excellent abrasion resistance.

The initial grinding is carried out with coarse abrasives typically in the range of 60 to 100 grit. Some marks or scratches from these coarse abrasives will generally be visible on the surface, particularly on the cut face of aggregates. If glass aggregates are incorporated to provide a surface feature, finer abrasives (eg 200 grit) should be used for the initial grinding as the glass is more brittle than other aggregates.

'Polished' finishes are achieved by grinding with progressively finer abrasives until the surface takes on a lustre of its own. Abrasives as fine as 1600 grit are required to produce the type of finish shown in **Figure 43b**.

For most flatwork applications, to reduce the cost of grinding and because sealers are generally applied to minimise staining, polished appearances are achieved by a combination of honing to about a 300 grit and applying a surface sealer to provide the lustre or required gloss level.

The equipment used for grinding and polishing the surface is essentially the same as that used for terrazzo (the name traditionally used for honed concrete incorporating marble aggregate but now often used to cover that containing other aggregates). Both wet and dry grinding processes are available with typical equipment shown in **Figures 48 and 49**. The wet process uses water to control the dust while dry processes typically have vacuum systems connected to extract the dust produced. If there is a risk that existing finishes could be damaged by

← BACK TO CONTENTS PAGE

FIGURE 36
Double head ride-on trowelling machine

FIGURE 37
Power trowelled floor finish with some trowelling marks (surface sealer applied)

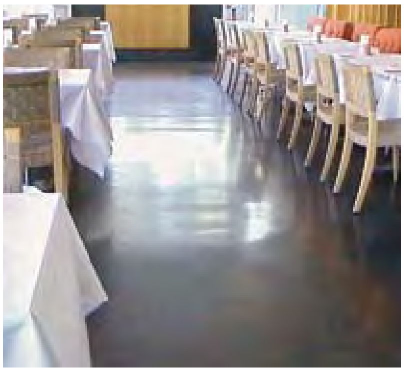


FIGURE 38
Steel trowelled finish free of trowelling marks

FIGURE 39
Burnished finish with no trowelling marks

FIGURE 40
Undulations in steel trowelled surface

FIGURE 41
Burnishing the concrete by extended trowelling (areas with gloss appearance completed)

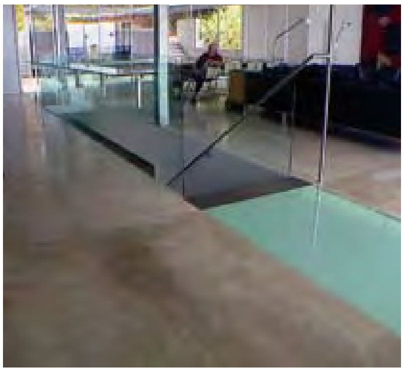


FIGURE 42
Burnished finish achieved through application of bees wax to the surface of the slab

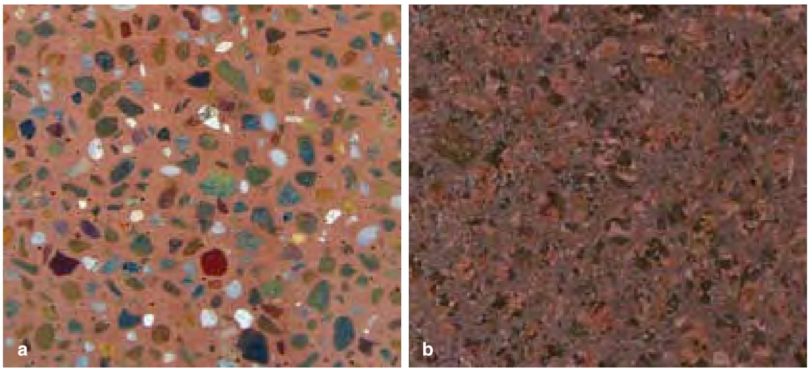


FIGURE 43
Comparison of matt and gloss finishes
[a] Typical matt finish from honing at 80 to 100 grit
[b] Highly polished finish with surface lustre (300+ grit)

← BACK TO CONTENTS PAGE

FIGURE 44

Honed finish exposing white quartz aggregate (concrete coloured with 'cherry red' pigment which dominates colour as more matrix than stone exposed)

[a] Honed finish

[b] More cement matrix than aggregate exposed

FIGURE 45

Stainless steel inserts exposed by grinding the concrete surface

FIGURE 46

Various finishes in Bourke Street Mall, Melbourne (Artist: David Humphries)

[a] Coloured aggregates seeded onto surface

[b] Honed finish

[c] Sea shell inserts

FIGURE 47

Surface lightly honed to improve finish (aggregates in some areas exposed – high spots)

FIGURE 48

Wet process grinding machines

[a] Typically used for terrazzo work

[b] Honing small areas/correcting tolerances

BACK TO CONTENTS PAGE

FIGURE 49

Dry process grinding machines/tools

[a] Grinding large areas

[b] Hand tools for edges, corners, steps

FIGURE 50

Honed stair risers to match floor finish

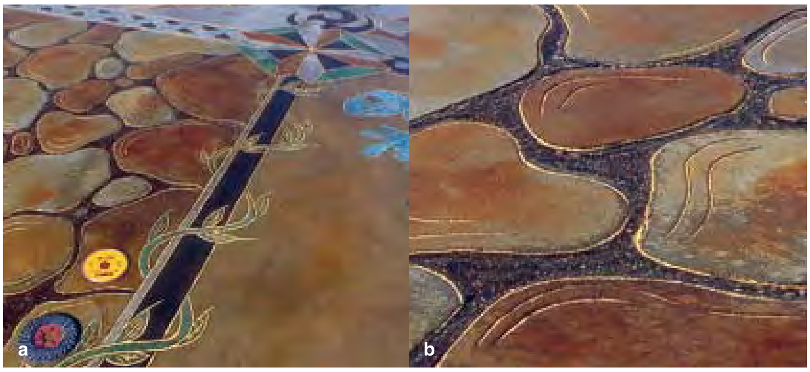


FIGURE 51

Stone pattern cut into concrete surface and areas between 'stones' ground with hand tools to recess 'joints' and expose concrete colour/aggregates below for contrast (surface coloured by chemical staining)

[a] Diamond cutting disc (yellow) used to cut pattern and abrasive disc to grind areas between stones and [b] Close-up of stone pattern

FIGURE 52

Patterns formed in honed surface with various aggregate colours and pigments

FIGURE 53

Seeded aggregates

[a] Seeding the surface with white quartz aggregate

[b] Finish after honing with 1% green pigment added to concrete

[c] Honed surface seeded with larger decorative aggregate.

the slurry produced with the wet process, then a dry grinding process should be specified. Smaller hand tools **Figure 49b** allow areas such as stairs and other vertical surfaces to be ground **Figure 50**.

With the range of grinding equipment available, a honed finish can be applied to almost any concrete element. For example, the stone pattern in **Figure 51** was achieved by first scribing the pattern into the concrete surface using a 100-mm-diameter diamond cutting blade and then grinding the areas between the stone shapes with small abrasive disks to recess the 'joints' and expose the colour of the concrete mortar/aggregates below the stained surface. Both the cutting wheel and abrasive disc are shown at the bottom left of **Figure 51a**.

Patterns can be formed in the surface by using different aggregate colours and also pigments to colour the cement paste between the stones. Brass, zinc or timber strips, tiles, pavers and construction joints are some of the things that can be used to separate the different colours **Figure 52**.

Some points to consider concerning honed finishes include:

- The aggregates used in terrazzo work are generally marble chips, glass or plastic, all of which are far easier to grind than the hard, durable aggregates used in decorative concrete mixes. While the increased wear-and-tear on the grinding pads will generally increase the cost of pads required, fewer grades of pads (coarse to fine) are required to produce a polished finish on a concrete slab. Combined with the contribution of sealers to the final appearance, grinding should still produce an economical finish.
- Grinding a new concrete floor (as opposed to an existing) is easier before the walls are built, when the grinding machine can pass over the edges and corners. This will avoid the need for smaller specialised equipment and/or hand grinding. However, the surface will need to be protected during construction (see **Section 4.25**) to avoid damage and staining. A comparison of the cost to protect the surface versus the cost of grinding the edges with smaller hand-held equipment may determine when the process is undertaken.
- Honing may expose small blow holes (air holes) in the surface. A subsequent light grind with a cement slurry applied to the surface may be required to fill these. The colour of the cement slurry should match the original concrete used. Note that adequate compaction (or removal of entrapped air) of concrete to be honed/polished is an important consideration to ensure that no large blow holes are present (see **Section 4.15**).
- A minimum concrete grade of S32 is typically used to ensure sufficient bond strength to retain the aggregate during the grinding process.
- While normal concrete mixes can be used, if the aggregates are to be exposed they will have a more significant influence on the final colour and appearance than the matrix. It is the aggregate rather than the matrix which holds the polish. Hard aggregates such as quartz and igneous rocks (eg granite) are preferred as they polish well and provide excellent wear characteristics.
- Aggregate colours, types (round or crushed), sizes, mineral content, etc can all be selected and blended to produce a variety of finishes including polished granite-type (reconstituted stone) finishes. The cost of special aggregates for large areas can be reduced by using them in a thinner topping or by seeding them into the surface of the structural slab or topping **Figure 53**. For smaller areas, it may be more economical and/or better to simply use the selected aggregate throughout the concrete or topping mix.
- A uniformly distributed aggregate is important, particularly with seeded surfaces, because if the aggregate density is not uniform, a patchy appearance to the final finish will result, due to some areas having more stone exposed than others.
- The colours of the coarse aggregate and the matrix are generally perceived in equal measure. This is because there is usually a high proportion of aggregate in the mix and the matrix is coloured with only 1 to 2% of pigment in order to blend with the aggregate colour (see **Section 2.3**). However, depending on the proportion, either may provide the dominant colour **Figure 44**.
- Glass aggregates can be used to give a translucent appearance to the honed surface, but some precautions should be taken to ensure that adverse reactions between the silica in the glass and the alkalies in the concrete do not affect the finish (see *Exposed Aggregate Finishes for Flatwork*[3]).
- With so many variables, it is recommended that either one of the specialist concrete mixes developed for this type of finish be used (test samples or examples are already available) or that test samples be produced to allow the finish to be assessed prior to work commencing.
- Further information on honed and polished finishes can be found in *The Specification of Honed Concrete Finish*[4] and *Polished Concrete Floors*[5].

FIGURE 54
Hand floating to embed aggregates or other special items into the surface
[a] Decorative aggregates
[a] Sea shells

FIGURE 55
Minor indentation indicates surface is ready for final floating

FIGURE 56
Hand tools for floating
[a] Wood float
[b] Magnesium float with curved blade
[c] Steel (coving) trowel

FIGURE 57
Rotary finishing machine fitted with floats

FIGURE 58
Wide bullfloat or 'bump cutter' used to level out any longer undulations in the surface from screeding and produce flatter finishes (vibrating beam screed plus two hand screed beams also shown)
Photo courtesy of Taylor Thomson Whitting

3.3 TEXTURED FINISHES

3.3.1 General

Textured finishes have traditionally been used to create a decorative surface or to provide slip and/or skid resistance. Finishes may vary from light textures such as those from nylon brooms or wood floats to heavier textures produced using tools such as hard bristle brooms, hessian drags over the surface or metal rakes. Providing texture by exposing the aggregate or creating voids in the surface can also deliver a decorative as well as functional finish. Similar to other types of finishes, pigments can be used to reduce glare and further enhance the appearance.

The coarseness of the texture should suit the application. For example, if the foot traffic in public areas includes people wearing stiletto heals, coarse textures such as exposed aggregate and deeply grooved surfaces may not be appropriate. Around swimming pools or other areas intended for barefoot use, coarse textures are generally inappropriate and finer textured finishes providing a compromise between slip resistance and comfort should be specified.

3.3.2 Floated

The purpose of floating a concrete surface is to produce a relatively even but still open texture. Floating may be used to:

- embed large aggregate particles or special items that have been seeded into the surface of the plastic concrete **Figure 54**;
- remove slight imperfections and produce a surface closer to the true plane;
- compact the concrete and consolidate the mortar at the surface in preparation for other finishing operations;
- close minor surface cracks which might appear as the surface dries

Floating is a two-stage process. Once concrete has been placed and screeded to level, a wide bullfloat is typically used to smooth and close any holes in the concrete surface.

Final floating by hand or machine should not commence until all bleedwater has evaporated from the surface (or has been removed with a hessian drag) and the concrete has begun to harden to the point where walking on it will leave only minor indentations in the surface **Figure 55**. Such indentations will, in fact, be removed by the floating operation.

Final floating is carried out by working the surface of the concrete with hand floats **Figure 56**, or by rotary finishing machines **Figure 57** fitted with appropriate floats or shoes.

Bullfloating involves working a large float on a long handle back and forth on the concrete in a direction parallel to the ridges formed by screeding **Figure 29**. The blade is typically aluminium or magnesium but may also be wood. The blade and handle are usually pivoted so that the angle of the blade can be changed depending on whether the stroke is forward or backward. Bullfloating should be completed before bleedwater appears on the surface. To minimise the number of ridge marks left at the edge of the blade, bullfloat passes should not overlap by more than 50 mm. Care should be taken not to overwork the surface if bullfloating is required more than once.

To improve the flatness of the surface, a wide bullfloat (sometimes referred to as 'bump cutter') can be used to remove not only the transverse ridges from screeding, but also the longer transverse undulations in the surface that may be present following the screeding operation **Figure 58**.

Floating by hand normally involves the use of a wooden, magnesium, resin or steel float **Figure 56**. Hand floats are held flat on the surface and moved in a sweeping arc to embed the aggregate, compact the concrete, and remove minor imperfections and cracks. Wooden floats require skilled operators and timing is important. If used too early, they stick, dig in, and can tear the surface. Used too late, they roll the coarser particles of fine aggregate out of the surface.

Magnesium floats require less effort and will not roll coarse particles out of the surface. They can be used after wood or power floating to give a more uniform swirl finish, which is not quite so rough in texture as that produced by a wooden float. Well-worn magnesium floats should be discarded. They develop an edge almost as sharp as that of a steel trowel, and use of them risks closing the surface too soon.

Resin floats have resin-impregnated canvas surfaces. They last longer than wooden floats, produce a finish smoother than wooden but rougher than magnesium floats and can also be used after wood or power floating.

Sometimes, the surface may be floated a second time to impart the final desired texture to the concrete, eg wood float finish. After the initial wood floating the surface is allowed to harden further and then should be worked over several times with hand or machine steel trowelling to adequately compact the surface layer. The use of a wooden, composite or sponge float will have the tendency to open the surface matrix if adequate compaction has not been provided. Floating to provide texture should in fact only score the surface.

FIGURE 59

Pattern formed by hand floating with a steel float

FIGURE 60

Wood float finish

FIGURE 61

Floated finish used for stencilled driveway and path

[a] Coloured surface hardener worked into concrete surface by floating/trowelling

[b] Fine aggregate floated into surface of driveway to increase texture and improve skid resistance

FIGURE 62
Light broom texture can provide a functional and attractive finish

FIGURE 63
Broomed finish to provide slip and skid resistance

FIGURE 64
Medium to coarse broomed texture suited to industrial applications

FIGURE 65
Tined finish on roadway – note set pattern in spacing of grooves
[a] Tining operation
[a] Tined finish

FIGURE 66
Grooves formed in steep ramps for drainage

As well as providing texture, patterns can be created by systematically floating the surface in a particular direction or manner **Figures 59 and 60**. Work should be broken up into small, manageable areas by the use of joints. Floating is typically used for stencilled and stamped finishes as it allows the final texture to be controlled **Figure 61**.

Steel floats (often called coving trowels because of the curved edges) produce a textured finish smoother than wooden floats and are suited to most outdoor paving applications **Figure 59**. They have a long life and the curved edges make these floats suited to working in the coloured surface hardeners used for stencilled and stamped finishes.

To achieve a consistent texture with any method (eg float, broom, stippled, hessian) the surface should be uniform. In situations where parts of the surface are shaded and therefore often cooler, the evaporation of bleedwater and possibly setting/ hardening of the concrete will be slower. This can make it difficult to achieve consistent finishes; planning should allow for such factors.

Floating by machine uses normal trowelling machines fitted with 'floating' blades **Figure 57**. These are wider than trowel blades and turned up along the edges to prevent them digging into the surfaces whilst in the flat position. For this reason, floating with a trowelling machine equipped with normal trowel blades should not be attempted. Note that combination blades which can be used for both floating and trowelling are available.

The power float should be operated over the concrete in a regular pattern to produce a matt finish. Concrete close to obstructions, or in slab corners, that cannot be reached with a power float should be manually floated before power trowelling is commenced.

The use of water sprays or other means of wetting the surface to facilitate the movement of the trowelling machine over the surface should not be allowed as such practices may reduce abrasion resistance and cause dusting of the slab at a later date.

3.3.3 Broomed

Brooms of varying degrees of stiffness can produce finishes that are both functional and attractive **Figure 62**. Polypropylene and horsehair bristles will produce light textures, poly fibre bristles are used for medium and coarse textures, while special long soft plastic bristles are used for texturing over long distances to reduce the risk of mortar being dragged across the surface or clogging the bristles.

As for wood float finishes, the surface should be adequately compacted by steel trowelling and the broom used only to provide texture by scoring the surface.

Although typically used to provide a straight pattern, curved lines, wavy finishes and sawtooth patterns are also possible. Finishes such as checkerboard are achieved by brooming at 90° to adjacent panels. Intricate textures or graphic brushing to incorporate borders or variegated textures are best achieved using small brushes. Achieving broomed finishes that include border tessellation are specialist applications and should be undertaken only by experienced contractors. These may require hand brooming with specific brushes to achieve the desired texture.

The timing of brooming, angle at which the broom is held and pressure applied will all affect the appearance, and should therefore be consistent. An extension handle is usually fitted so that the broom can be pulled right across the surface in one motion. After each traverse of the concrete, the broom head should be tapped or cleaned to prevent an accumulation of mortar in the bristles **Figure 63**.

Surfaces to be broomed should be uniform in order to achieve consistent finishes. Where parts of the surface are shaded during finishing, brooming of these moister sections may cause 'balling' of loose matrix material which will crust or wear away under traffic loads.

Where a broomed texture is used and traffic is heavier than domestic or light commercial traffic, the texture should be deeper. Lightly broomed textures look attractive when first done but wear quickly in industrial situations, whereas a medium or coarse broom texture should provide a good, skid-resistance surface over the design life of the floor or pavement **Figure 64**.

To improve slip and skid resistance (see **Section 4.23**) for applications such as driveway and sidewalk construction, the surface should be broomed at 90° to the intended direction of the traffic.

3.3.4 Tined/grooved

Tined finishes **Figure 65b** provide a coarse texture by forming a series of grooves that are achieved by dragging steel tines across the concrete surface **Figure 65a**. They are typically used on road surfaces to provide the required macro texture for skid resistance at higher speeds and to assist with drainage of the surface. They may also be used to improve skid resistance on steep grades.

While tined finishes are typically used for major road projects, smaller hand-held tools (known as flat wire brooms) are available for smaller projects. The main difference between the equipment used for roads and hand-held tools is the spacing of the tines. For roads, the spacing varies in a set pattern to reduce vibration and noise, whereas the hand tools have the tines at a uniform spacing: typically 13, 16, 19, 22 or 25 mm.

An alternative for ramps (as well as steps) may be to use a non-slip groove-forming tool/trowel to provide corrugations in the surface of the plastic concrete. These small hand tools should be considered only for small areas as access over the concrete surface and the required time to finish large areas may prohibit their use **Figure 66**.

No minimum concrete strength is required for tined finishes, with strength governed by the application. Concrete should be placed and compacted with the surface floated or steel trowelled prior to tining.

3.3.5 Hessian drag

Hessian drag finishes involve dragging hessian across the surface to create a textured finish **Figure 67**. Used mainly for road surfaces, it is applied following compaction, screeding and finishing (steel trowelling) of the surface. Applying the finish after trowelling of the surface also assists in preventing the hessian from clogging with otherwise loose/wet material from the concrete surface.

3.3.6 Textured rollers

An assortment of rollers can be used to texture the surface of concrete. Larger rollers with specially textured surfaces for imprinting concrete are often used for stamped concrete work (see **Section 3.4.3**). However, a range of smaller rollers are also available for producing finishes such as stippled surfaces **Figure 68**.

The common fault with this texturing method is its use on surfaces which have been only lightly trowelled, typically by 'stick trowelling'. Stick trowelling with a telescopic pole reduces the direct pressure on the surface and can dramatically reduce the surface compaction achieved.

Indications of insufficient surface compaction include leaving a trailing edge line when the roller is passed over the surface and wave caps produced in the uncompacted and plastic surface layer. An inadequately compacted surface layer will generally be subject to excessive wear.

3.3.7 Exposed aggregate

General

Exposed-aggregate finishes by definition, have the aggregates (the stones and/or sands) within the concrete which would normally be concealed by a thin surface layer of cement mortar, exposed at the surface. There are a number of techniques for producing exposed-aggregate finishes including water washing, abrasive blasting, acid etching and honing: each creating a different and distinctive appearance.

Concrete mixes are often 'modified' for exposed aggregate finishes by increasing the proportion and the size of aggregates which are to be featured. Because the predominant colour comes from the aggregates, these types of finishes tend to conceal staining of the surface and generally do not require a surface sealer to be applied. The cement mortar can also be coloured, usually to complement the colour of the selected aggregates.

Sample panels (see **Section 4.3**) are recommended to assess techniques, surface finish, distribution of stones and, if applicable, consistency of colour. These finishes should be done under the supervision of a paviour experienced in these techniques.

This section considers some issues relating to the aggregates and a number of techniques used to expose the aggregate for flatwork applications. Further information on exposed aggregate finishes can be found in *Exposed Aggregate Finishes for Flatwork*[3].

Selecting aggregates

Aggregates come in a variety of colours, sizes, shapes, textures and materials. Because the majority of the surface characteristics of exposed aggregate finishes come from the aggregates themselves, an understanding of some of these properties is beneficial when making selections.

Colour Both fine and coarse aggregates come in a wide range of colours **Figure 69**, although the choice may be limited by the availability at any particular location. For lightly abraded surfaces the predominant colour will be that of the fine aggregates; where the coarse aggregates are exposed, these will usually provide the dominant colour to the finish **Figure 70**. For large projects, sufficient quantities of both the coarse and fine aggregates should be stockpiled if consistency of colour is important.

Size Aggregates can range from 3- and 6-mm 'pebbles' to large stones placed into the surface of the concrete: often referred to as 'plumbs' **Figure 71**. For water-washed finishes, the size of the aggregate should be appropriate for the application. For barefoot use, 3- and 6-mm pebbles are ideal with 10 mm about the maximum size recommended **Figure 72**. Public areas generally do not have aggregates larger than about 20 mm.

Fine aggregates for concrete are defined in AS 2758.1[6] as less than 5 mm in size and coarse aggregates as 5 mm or larger.

Grading Grading refers to the distribution of particle sizes in a batch of aggregates. Typical concrete mixes have an even distribution of sizes ranging from fine through to coarse to balance the demands for workability, cohesiveness, strength and durability. Continuously graded aggregates will generally result in less of the coarse aggregates being exposed at the surface **Figure 73**. To achieve a greater density of coarse aggregate at the surface the intermediate aggregate sizes are often omitted in what is called a gap-graded mix **Figure 69**. With gap grading, a larger percentage of coarse aggregate and a small percentage of fine aggregate (sufficient of workability) are combined.

Shape Flat and elongated aggregates, referred to as misshapen particles **Figure 74**, reduce workability and may also have an adverse effect on strength because of their tendency to selective orientation and bridging, resulting in air pockets. A good mix design will limit the percentage of these particles. If a flaky, elongated aggregate has been selected, consideration should be given to using a topping mix or seeding the surface with the aggregate, see *Adding aggregates* below.

For barefoot applications the use of rounded river gravel instead of a crushed and angular aggregate is recommended. Where the surface is honed to expose the aggregate, the shape (and size) is irrelevant in terms of usage as a smooth surface is produced.

Surface texture Surface texture can be classified as glassy, smooth, granular, rough, crystalline or honeycombed. For exposed aggregate surfaces, the surface texture or micro-texture of the aggregates will influence the slip and skid resistance of the surface. Glassy and smooth aggregates may not be suitable for sloping paths and driveways, or those in exterior environments that can be contaminated by water, thereby increasing the risk of slipping and skidding **Figure 75** (see **Section 4.23**).

Glass aggregates Glass aggregates provide a translucent appearance to the finish and are available in a wide range of colours **Figure 76**. They may be exposed in the same way as other aggregates; however, for most applications, honing the surface will be necessary to ensure that sharp edges are not exposed.

Glass is generally seeded onto the surface to reduce material usage and cost. Minimising the usage is also beneficial in reducing the possibility of an alkali-silica reaction between the alkalis in the concrete and silica in the glass. For internal, dry applications the reaction can be minimised, if not prevented by keeping the concrete dry. Thus it is important to maintain the surface sealer to prevent the ingress of any moisture. Further information on glass aggregates and precautions concerning their use can be found in *Exposed Aggregate Finishes for Flatwork*[3].

Adding aggregates

Selected aggregates can be added to the concrete in a number of ways: they can be incorporated integrally throughout the entire concrete mix, contained in a topping mix, seeded onto and then embedded into the surface of the concrete, or set into the surface at particular positions.

Incorporating into the mix Special mixes (for either the whole slab or for a topping) can be ordered from premixed concrete suppliers. Most suppliers carry a range of aggregates that can be selected and used in varying proportions to achieve the desired colour or appearance.

Alternatively concrete for toppings can be mixed on-site in the typical proportions (by volume) of 1 cement:1.5 sand:3 parts aggregate (and pigments if required) and just enough water for workability. Bagged topping mixes are also available. However, these incorporate standard aggregates (usually dark grey) the colour of which may not be suitable. Test panels are recommended to ensure the finished result meets expectations.

Seeding onto the surface Hand-casting or seeding selected aggregates onto the surface is an economical way to incorporate decorative (and typically more costly) stones into the concrete surface. This technique is also adopted when the concrete is to be pumped and the size of the selected aggregate unsuitable for this method of placement **Figures 46, 53 and 77**.

Specifying the appropriate coverage rate to achieve the desired outcome could be difficult without the construction of test panels or prior experience. In most cases, uniformity of coverage will be at least as important as the actual rate of coverage, particularly when two or more aggregates are used. This can be assessed only visually.

Concrete is placed and screeded generally to the finished level, although depending on the size and

FIGURE 67
Hessian being dragged across the concrete surface

FIGURE 68
Stippled surface finish produced by using a textured roller

FIGURE 69
A variety of coloured aggregates are available (note that the predominant colour comes from the aggregates)

FIGURE 70
White quartz aggregate provides predominant colour to finish (white titanium oxide pigment added to the cement matrix to lighten the colour)

FIGURE 71

Aggregates may vary considerably in size

[a] 6-mm pebblecrete

[b] 20-mm aggregate

[c] Large stones or 'plumbs'

FIGURE 72

Exposed aggregates for barefoot use

[a] 6 mm pebblecrete

[b] Exposed aggregate with 10 mm stones

FIGURE 73

Abrasive blasted finish to 'normal' concrete mix – fine aggregates and mortar colour can be more critical to the final appearance than the coarse aggregate

← BACK TO CONTENTS PAGE

FIGURE 74

[a] Large river gravel (nominal 50 mm) containing misshapen particles seeded onto surface

[b] 10-mm crushed aggregate mix

FIGURE 75

The exposed aggregates should provide slip and skid resistance appropriate for the application

[a] Local roads

[b] Residential streets and public areas

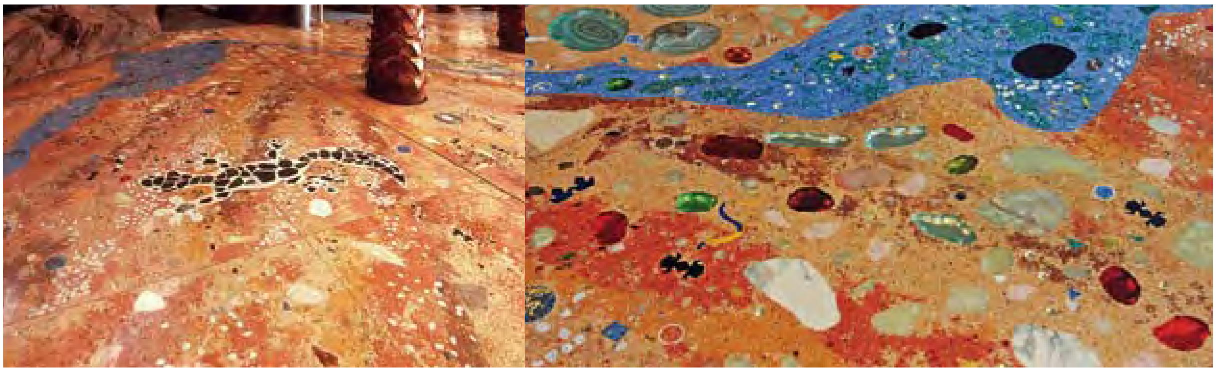


FIGURE 76

Glass aggregates provide translucent feature in artistic terrazzo design

Star City Casino, Sydney

Artist: David Humphries

FIGURE 77
Surface seeded with large decorative white quartz aggregate as a feature within concrete mix containing smaller dark grey aggregates
Mt Keira Summit Park, NSW

FIGURE 78
Hand-casting selected aggregates over the surface and bullfloating into the concrete prior to bleeding

FIGURE 79
Embedding aggregates by rolling

FIGURE 80
Coloured aggregates set into surface to form patterns
[a] Aggregates set into cement mortar topping
[b] Aggregates set into concrete path to create spiral design

FIGURE 81
Pebble mosaic formed from setting aggregates into smaller precast elements and assembling these on site
[a] Completed work
[b] Installing precast sections
[c] Individual precast section
Parterre Garden, Queens Park, Toowoomba. Artist: Naomi Hatt

FIGURE 82
Freeform patterns can be incorporated by placing in sections

FIGURE 83
Examples of patterns formed using exposed aggregate segmental pavers

FIGURE 84
Surface mortar is removed with a stiff-bristled broom followed by brushing and flushing with a water spray
[a] Typical water-wash method
[b] Specialist tools
[c] Hand washing of smaller areas using a sponge may be more practical than using a broom

BACK TO CONTENTS PAGE

quantity to be added, the initial surface level may need to be slightly lower than the finished level. **Table 1** provides some guidance on the depth to be allowed for the addition of aggregate. Selected aggregate(s) can be hand-cast or seeded onto the surface immediately after screeding and then bullfloated into the surface prior to bleedwater appearing **Figure 78**, or applied to the surface once all the bleedwater has evaporated **Figure 46** and fully embedded by either tamping and repeatedly working the surface with wood floats **Figure 54** or rollers **Figure 79**.

An aggregate size of 8–12 mm is recommended for ease of application, although sizes up to 20 mm can be embedded without difficulty.

TABLE 1 Recommended depth allowance for seeded aggregates

Aggregate size (mm)	**Depth allowance** (mm)
9.5	3
12	5
19	6
25	8
>25	10

Setting into the surface To have aggregates orientated in a specific direction and/or at particular locations within the concrete/topping to create patterns **Figures 80 and 81**, they are generally hand set into the surface of the concrete or topping.

The aggregate size must be appropriate to define the pattern, details and different colours **Figure 80**. To allow sufficient time to place aggregates over large areas, they may be placed into a dry mortar bed which is then watered. Alternatively, set retarders can be added to the concrete to allow more time to embed the stones. Large areas can also be divided into smaller, more manageable sections.

Large areas can also be constructed by setting aggregates into smaller precast sections which can be assembled on site **Figure 81**. This method has the advantage of highly controlled off-site fabrication and reduced installation time.

Larger stones can be set into the surface **Figure 71c**, but, strictly speaking, this process falls outside the definition of exposed aggregate.

Exposing aggregates

A number of methods are available to expose the aggregates including removal of the cement mortar from the surface layer by water washing (most common), abrasive/water blasting, acid etching, and removal of the surface layer of concrete by honing. Work should be done under the supervision of experienced contractors. Test panels are recommended to assess techniques, surface finish, distribution of aggregates and, if applicable, consistency of colour.

Note that rounded aggregates such as river gravels will generally give a better exposed aggregate finish than crushed aggregates having a cubical or irregular shape. This is because crushed aggregates tend to roll in the plastic mix during screeding and leave edges and corners exposed when the mortar is removed rather than the flat faces of the stones. This may result in a greater proportion of the mortar between the stones being exposed and affect the colour, uniform appearance of the surface and comfort for barefoot use.

Water wash-off technique The water wash-off technique is the most common method of removing the cement mortar at the surface of the slab and involves brushing and flushing the surface with water soon after the concrete has stiffened. Examples of the finish are shown in **Figures 69 to 72, 74, 75, 77, 82 and 83**.

The process is shown in **Figure 84** for various aggregate sizes; it can be started when the surface can bear the weight of the paviour without making surface impressions deeper than 2–3 mm and it can be broomed without dislodging the aggregates. A medium-bristle broom, together with a continuous fine water spray, is used to wash away some of the cement mortar. Brushing and washing continues only until the water runs clear and there is no noticeable cement film on the aggregate. Note that excessive brooming may dislodge aggregates. Trowelling the surface to ensure stones are embedded adequately and to improve the aggregate density is often carried out between periods of washing. If washing large areas, water runoff should not be allowed to build to the point where stones are either washed out or exposed more than one third of their depth.

For large areas the use of water-based surface set-retarders could also be considered. Those developed especially for this technique slow the setting time of the surface of the slab to a predetermined depth without affecting the set of the mass of the concrete. A consistent depth of exposure will be obtained with uniform application of the product. They are very useful when drying weather conditions would otherwise limit the time available for aggregate exposure. Careful compaction (vibration) is necessary to provide a consistent depth of penetration of the retarder, and hence exposure of the aggregates.

The shape and surface texture of the aggregates are unaffected by the water wash-off process, unlike abrasive blasting and honing (grinding) which affect the texture and, in the case of honing, the shape of the aggregates.

Following curing (7 days recommended) an acid-wash treatment (1 hydrochloric acid : 10–20 parts water) is usually necessary to brighten up the stones by removing the fine cement film from the surface. The surface should first be thoroughly wetted to prevent acid soaking into the concrete and weakening the bond to the exposed aggregates. The surface should afterwards be rinsed with clean water to remove all residual acid. A surface sealer may be applied if desired.

The water wash-off technique is also commonly used for many precast products including pavers for flatwork. The process is the same, but the smaller units allow exposed aggregate patterns to be readily achieved and reduce concerns with slurry runoff and acid washing in environmentally sensitive areas **Figure 83**.

Abrasive blasting Abrasive blasting (commonly called sand blasting or grit blasting) is used to expose the aggregates within hardened concrete by eroding the cement matrix in the surface layer. Typical equipment is shown in **Figure 85a** but variations that allow for recycling of the sand/grit are available **Figure 85c** as well as smaller hand-held equipment **Figure 85d** for detailed work. As the process is applied to hardened concrete the opportunity to trowel the aggregates to improve the appearance is not available and typically a mixture of fine and coarse aggregates will be exposed **Figure 73b**.

Abrasive mediums (air borne or water borne) include materials such as sand, slag, silicon carbide, glass beads and crushed glass. The choice of medium and equipment will be based on the specified finish, availability of the medium, site location and sometimes occupational health issues. The choice is generally best left to the contractor. Water blasting (with or without grit added to the water **Figure 86**) eliminates dust problems **Figure 85a**, can make cleanup easier in some situations or may be preferred for the location and environmental reasons.

There are four general grades of abrasion. Each one produces a matt finish, with textures varying from those resembling sandpaper where no coarse aggregate is exposed (brush blasting) to more coarse textures ranging from exposure of the sand particles with occasional exposure of coarse aggregate (light blasting), through coarse aggregates being exposed by up to 6 mm (medium blasting) up to a rugged and uneven surface where the maximum of one-third of the coarse aggregate is exposed (heavy blasting) **Figure 87**. For this reason it is important that the depth of removal be specified. Where the removal of a considerable depth is required, the use of a surface set retarder may reduce the work involved.

The greater the aggregate exposure, the more the colour will be dominated by the aggregate colour. Initially the colour of the cement matrix will dominate (brush blasting), then the sand colour (light blasting) and then progressively more by the coarse aggregates for medium and heavy blasting. Note that medium and heavy blast applications generally require a higher proportion of coarse aggregate in the concrete mix to achieve uniformity, while the aggregate should be hard enough to resist extended blasting without significant erosion. Aggregate particles maintain their general shape but the surfaces may be dulled by the abrasion.

The timing of the abrasive blasting roughly relates to how much material is to be removed. Brush blasting can be done any time after seven days, light blasting between 7 and 45 days, medium blasting within 7 days, while heavy blasting should be done within 24 hours (ie prior to any significant strength gain) to reduce the work involved. Water blasting is typically commenced when the concrete strength has reached about 10 MPa, but caution must be exercised to obtain the desired amount of exposure without loosening the aggregate.

Abrasive blasting can be used to produce highly decorative finishes **Figures 88 and 89**. Stencils to protect the surface during the blasting operation can be cut from plate steel **Figure 85a** or, more recently, from vinyl and rubber materials **Figure 88** which enable intricate patterns to be cut.

Acid etching The acid-etching process for removing the surface cement matrix and exposing the aggregates is typically carried out under factory controlled conditions **Figure 90a**, but may also be used on site, albeit that compliance with OH&S and environmental requirements may be difficult. As with abrasive blasting, the depth of

← BACK TO CONTENTS PAGE

FIGURE 85

Abrasive blasting techniques and finished surface – stencils in [a] are specially cut thin steel plates

[a] Air-borne grit blasting

[b] Finished surface seen in [a]

[c] Equipment allowing recycling of grit

[d] Small equipment for detailed work *(shown below)*

FIGURE 85d

FIGURE 86

Water blasting (with or without grit)

FIGURE 87

Grades of abrasive blasting

[a] Light abrasive blast with larger particles of fine aggregate and some coarse aggregate exposed

[b] Medium abrasive blast with top of coarse aggregate exposed

[c] Heavy abrasive blast exposing coarse aggregate

FIGURE 88

Patterns/pictures can be formed by either masking the object and [a] abrading the surrounding surface or masking the surrounding area and abrasive blasting the actual object/pattern [b] and [c]

FIGURE 89

Shell pattern formed by abrasive blasting over a specially cut stencil – stencil material was a vinyl sheet with a thin rubber backing

FIGURE 90

[a] Acid etching of precast paving panels and

[b] Installed panels

← BACK TO CONTENTS PAGE

FIGURE 91

Levels of acid etching

[a] Light acid etch with fine aggregate and some coarse aggregate exposed

[b] Medium acid etch with top of coarse aggregate exposed

[c] Heavy acid etch exposing honed top of coarse aggregate

FIGURE 92

Rock salt texture resembling travertine finish to foreshore walkway – note expansion joints are sealed to exclude incompressible material (sand) which may render these joints ineffective

FIGURE 93

Fine rock salt texture produced using small granules of rock salt

FIGURE 94

Coarse rock salt texture to walkway provides texture that blends with surroundings

Taronga Park Zoo, Sydney

← BACK TO CONTENTS PAGE

FIGURE 95
Examples of rock salt finishes in commercial applications
[a] Shopping centre
[b] Plaza area
[c] Public entertainment area

FIGURE 96
Rock salt texture produced using special rollers

etching should be specified as this may vary from light to heavy **Figure 91**. Acid etching (or light abrasive blasting) is commonly used to slightly roughen the surface to improve slip resistance, rather than expose the coarse aggregates as shown in **Figure 91c**.

The procedure is the same as for the water-wash treatment (see *Water Wash-off Technique* above). The use of concentrations higher than 1 hydrochloric acid : 10 water should be avoided as secondary reactions with the concrete constituents may result in the formation of insoluble white compounds on the surface which are difficult to remove.

For environmental reasons, if the surface of hardened concrete must be removed on site, water wash-off, abrasive blasting or honing are the preferred methods. However, etching gels which can be neutralised with water offer an alternative. Because the acid is contained within a gel it can be controlled far more successfully than liquid acid; it is therefore suitable for highly detailed work or patterns. Gels are left in place for 5 to 15 minutes and generally do not react with the stencils used to form patterns.

3.3.8 Rock Salt

Rock salt finishes produce a decorative texture characterised by holes in the surface. Depending on the size and quantity of rock salt applied to the surface, the appearance may range from travertine type textures **Figure 92** to a slightly pitted surface **Figure 93**.

They are ideal for a wide range of footwear and commercial applications where shopping trolleys and strollers are used **Figures 94 and 95**. They are also

BACK TO CONTENTS PAGE

suitable for barefoot use as the texture is formed by depressions rather than by projections.

Rock salt finishes are typically produced by placing and finishing the concrete slab to the desired base texture and colour (for appearance and factors such as slip resistance), uniformly seeding the surface with granular salt particles, trowelling these into the surface so that the top of the salt is exposed, curing the surface and then washing to remove the salt particles. These textures can also be formed by using rollers **Figure 96** and special stamping mats.

Matters to consider include:

The rock salt is readily available as coarse sodium chloride. Typically the particles would permit 100% to pass a standard 9.5-mm sieve and 85% to be retained on a 2.8-mm sieve. A coarser grading may be specified to obtain a higher percentage of larger holes. However, holes larger than 6 mm are not recommended for foot traffic.

Application rates vary from about 0.2 kg/m^2 (typical) to 0.6 kg/m^2. The higher rates produce heavy textures that resemble travertine **Figure 92**.

Salt particles are applied after finishing of the concrete surface, when the concrete has stiffened sufficiently to prevent particles from being completely embedded into the concrete, but still plastic enough to allow them to be pressed into the surface. If they are covered by cement mortar, the salt is difficult to remove at a later stage and the required texture will not be obtained.

Salt particles are normally pressed into the surface using a 20- to 40-kg roller **Figure 79**, but smaller hand tools such as trowels may be used for smaller jobs.

The surface should be cured for 7 days, generally with plastic sheeting or other impermeable membrane (see **Section 4.17**). Curing compounds will make later removal of salt difficult, while moist curing will prematurely dissolve the salt.

If reinforcement is present, sufficient additional cover to the reinforcement/mesh should be provided to allow for the depth of texture (and effects of the salt if rock salt is used to achieve the texture).

Rock salt finishes are not recommended for use in locations where freezing conditions may occur; water trapped in the holes may freeze and cause deterioration/spalling of the surface.

Further information on rock salt finishes can be found in *Rock Salt Texturing*[7].

3.4 PATTERNED FINISHES

3.4.1 General

Stiff-bristle brooms, wood floats and sponges have been used for many years to create surface textures and patterns. More recently, cardboard stencils and purpose-made rubber moulds and metal dies have been developed to provide patterns in the concrete surface. Colouring by the use of coloured surface hardeners is typically undertaken in conjunction with such patterning.

The techniques are simple, but must be well planned to take advantage of the short period for which concrete is workable. Good curing practice is crucial to the appearance, and to the service of the slab or pavement.

Patterns can also be provided by the use of spray-on toppings and by sawcutting.

3.4.2 Stencilled

Stencilled patterns are made by manipulating the surface of the concrete pavement after the concrete has stiffened, but before it has hardened. Using standard stencils, patterns resembling tiles, pavers, brickwork, stone or random paving can be produced **Figure 97**. Special stencils can also be made to allow motifs, pictures and custom designs to be incorporated into the surface **Figure 98**. The surface texture can also be varied, eg by brooming, to produce coarser textures for improved slip resistance on steep grades.

Stencilled finishes involve laying cardboard stencils on the surface of the pre-hardened concrete **Figure 99** to mask the surface from the subsequent application of the coloured surface hardener **Figure 100**. When the concrete stiffens the stencil is removed **Figure 101** producing a coloured pattern with grey joints (the colour of the base concrete).

The process for stencilling is relatively simple. However, the timing of each stage is critical to the success and durability of the finish. The procedure is as follows:

1. Protect adjoining surfaces. Stains caused by fine oxides and cement are difficult to remove. Use protective plastic sheeting to stop splashing of adjoining surfaces, glass, aluminium or timber joinery during placement **Figure 99b**.
2. Place the concrete slab. Place, screed, bullfloat and trowel concrete to its final level.
3. Lay the stencils. Points to note include:
   - Wait until all bleedwater has evaporated before placing stencils.
   - Features such as rosettes or motifs are normally placed first, followed by borders and

finally the main stencilled area is placed and cut in around other items **Figure 99a**.

- → Carefully work the stencil into the surface with a suitable roller or a trowel **Figure 99b**.
- → Stencils placed on concrete that is too wet may become embedded too deeply and will be difficult to remove, resulting in uneven 'joint' depths.
- → Stencils that have not been adequately embedded or are not well bonded to concrete will tend to adhere to the applied colour, leaving ragged outlines when removed. The colour may also creep underneath the stencil and stain the 'joint' lines. Evaporative retarders such as aliphatic alcohols can be used to help keep the surface of the concrete plastic during drying conditions and thereby increase the working time available.
- → When placing and aligning stencils it is good practice to lift them, rather than drag them into position.
- → Shrinkage control joints (see **Section 4.19**) in stencilled concrete can be 'wet-formed' such as tooled joints (grooves) or 'hard-formed' such as sawn joints. Wet-formed joints are best placed under a stencil 'joint' line so that they are not repeatedly trowelled over; hard-formed joints should be located to suit the pattern where possible. Note that the stencil is generally laid to suit the location of joints that have already been formed in the pavement.

4. Apply coloured surface hardener. Evenly broadcast the coloured surface hardener over the surface in two stages **Figure 100**. Highlight or flecking colours must be applied while the surface is still plastic to ensure bonding. For dark colours such as charcoal it is advisable to apply a third coat for more even colour distribution and to avoid mottling (see **Section 2.3.3**).
5. Apply surface texture. While the surface is still plastic it can be lightly textured by brooming, wood floating, sponging, or by use of a hessian-drag to give a more slip resistant finish **Figure 101**.
6. Remove the stencils. The stencil can be removed once the concrete surface has stiffened sufficiently **Figure 102**. Note that this phase of stiffening or setting is 'drying', rather than curing. The appropriate time for lifting the stencil is very dependent on the weather conditions.

   After the stencil has been removed, clean off any debris with a leaf blower rather than with high pressure air and avoid walking on the concrete with heavy or industrial footwear. If necessary the leaf blower can be attached to a long pole for greater reach.
7. Cure and seal the concrete surface. Curing (see **Section 4.17**) is required to ensure that the potential strength and performance of the coloured surface hardener is achieved and the risk of cracking is minimised. Sealers (see **Section 4.18**) are applied mainly to protect the surface from contaminants such as oil spills and thereby reduce staining. Stains may be difficult to remove and some of the cleaning compounds and solvents required could affect the colour.

3.4.3 Stamped

Many of the available stamped finishes resemble natural stone paving, from relatively smooth slate-like patterns having shallow impressions to coarser cobblestone and rock textures having deep impressions **Figure 103**. Special features can also be stamped into the surface of the concrete **Figure 104**. Where very fine details are required to be reproduced in the surface, stamping into a mortar topping may be necessary to avoid coarse aggregates interfering with the profiling of the surface **Figure 105**.

After the application of colour, the pattern is stamped into the surface with metal moulds or rubber mats. To better resemble natural stone, patterned concrete produced by stamping often combines two or more colours.

The procedure for stamping is similar to that for stencilling. After placing and screeding the concrete it is left to stiffen, and the bleedwater is allowed to evaporate before the application of any dry-shake toppings.

The procedure for stamping concrete is as follows:

1. Protect adjoining surfaces. Similar to stencilling, adjoining surfaces should be protected as the stains caused by fine oxides and cement are difficult to remove.
2. Place the concrete slab. Place, screed, bull float and trowel concrete to its final level. Note that the thickness of a stamped concrete slab is measured from the bottom of the impression to the underside of the slab. This is important as the strength or load-carrying capability of the paving depends on the minimum concrete thickness and not the average thickness. For example, if the slab thickness needs to be 100 mm, and a 15-mm deep stamp is used, the formwork will need to be set at 115 mm to ensure the minimum thickness is achieved. This will also ensure sufficient cover and protection for any reinforcement.

FIGURE 97

Some of the many standard stencilled patterns

[a] European fan pattern *Photo courtesy of Concrete Colour Systems*

[b] Flanders weave pattern

[c] Flagstone pattern *Photo courtesy of Concrete Technologies*

[d] Mediterranean tile pattern *Photo courtesy of Concrete Technologies*

FIGURE 98

Examples of special motifs/stencils

FIGURE 99

Placing and embedding the stencil into the 'wet' concrete

[a] Border placed first

[b] Trowel/roll stencil into surface – note plastic sheeting to protect adjoining surfaces

FIGURE 100

Broadcasting coloured surface hardener over stencil

FIGURE 101
Various surface textures can be applied to improve slip/skid resistance

FIGURE 102
Stencil being removed
Photo (left) courtesy of Concrete Technologies

FIGURE 103
Some of the many stamped patterns and textures available
[a] Random blue stone (stamped) *Photo courtesy of Concrete Colour Systems*
[b] Flagstone *Photo courtesy of Concrete Technologies*
[c] Large diamond tile *Photo courtesy of Concrete Technologies*
[d] Seamless *Photo courtesy of Concrete Technologies*
[e] Rock texture [f] Slate texture

Points to consider in relation to joints (see **Section 4.19**) within the pavement include:

- Wherever possible, joints should coincide with the grooves in the pattern **Figure 103a**. The sawn joint in the foreground of **Figure 105a** should have been aligned with the pattern, similar to the joint in the background.
- Wet-formed control joints can be tooled after stamping is finished, while the surface is still plastic; although this is difficult if the stamping makes deep impressions.
- Form key joints before placement. Key joints may interfere with stamping of deeper patterns.
- Install isolation joints against abutting structures before placement. Installing them after will probably damage the finish.

3 Apply coloured surface hardener. Similar to stencilling, after all bleedwater has evaporated, evenly broadcast the coloured surface hardener over the surface in two stages as described under *Dry-shake Toppings* **Section 2.3.3**.

The use of integrally-coloured concrete may give the paviour more time to apply highlight colours, and stamp the surface, which is helpful in conditions that cause rapid drying.

Concrete mixes for stamped finishes contain a finer grade of sand than those for stencilling in order to better reflect the texture of the stamping moulds. Consequently, the coloured powders need to be carefully worked into the surface, with trowels, for even application.

Some items to note include:

- When two or more colours need to be applied, a low-bleed mix may be necessary to reduce the time required for bleeding and hence commencement of application of the coloured surface hardener. Being able to apply the colour sooner allows more working time to place subsequent colours and trowel them into the surface prior to the concrete hardening.
- In hot, dry or windy conditions evaporative retarders should be applied to the surface to increase the working time. Without their use the surface may dry prematurely causing a 'crust' to develop on the surface of the slab. When deforming the surface of the concrete during the stamping operation, such a crust may result in cracking around the edges, particularly with deep profiles, this is known as crusting **Figure 106**.
- Evaporative retarders have an added benefit of reducing the incidence of plastic shrinkage cracking. They should be re-applied each time the surface is worked and during conditions causing extreme drying, see **Section 4.14.2**. They should not affect the colour, and will generally aid in the finishing operation.
- When large areas are to be finished, access to the areas beyond reach should be provided by laying planks over the work **Figure 107**. It is important that the entire surface is able to be given the same attention with respect to the application of colour hardener and release agent.
- Where slip resistance is required (eg a steep driveway) a surface can be textured at this stage with special rollers or stiff bristle brooms **Figure 108**.

4 Apply surface release agent. After the application of the base colours, a coloured release coat is applied **Figure 109**. The surface release agent has two purposes:

- It prevents concrete adhering to the stamping mould and ruining the appearance of the pattern.
- It serves as a highlight colour, creating a variety of two-tone effects.

Release agents come in a range of colours to match the surface hardener colour. Stamping with sufficient pressure will ensure an adequate bond of the colour release agent to the base coats, which is why the highlight effect generally occurs in deeper joints and impressions. Note that the surface release agent is not a curing agent.

A thin film of clear polythene plastic can be used as an alternative bond breaker but may interfere with the stamping of some textures. It is placed over the prepared concrete before stamping, preventing the concrete sticking to the moulds **Figure 110**.

A further alternative is the use of liquid release agents which are generally sprayed onto the surface of both the concrete and mould. These may be coloured and obviate the need to remove a powdered release agent from the surface prior to sealing. Sealing must be delayed (a few days) until the solvents in the release agent have evaporated.

5 Stamp the surface. It is always necessary to plan the stamping sequence to produce a good result where the pattern meets walls and fixtures and extends over joints **Figure 111**. In many cases hand pads and hand-held jointing or ironing tools will be required to complete the edges.

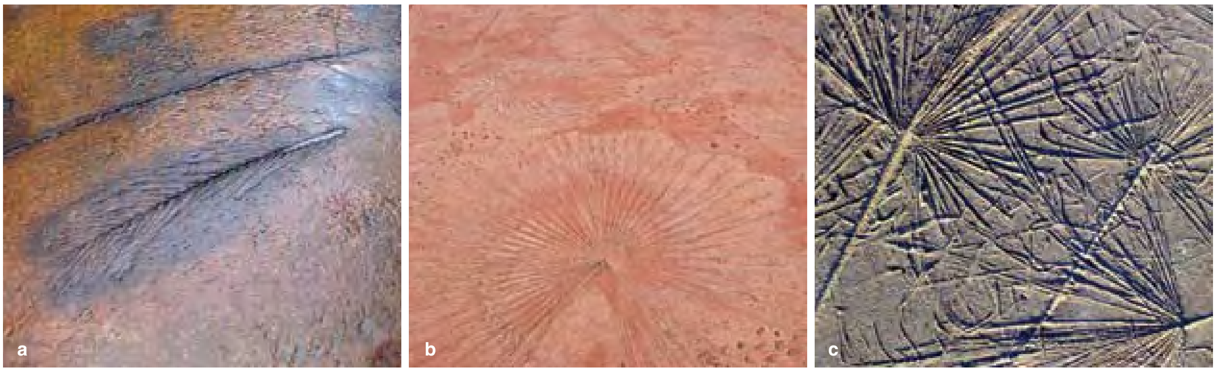


FIGURE 104

Many other objects can be used to stamp patterns into the surface

[a] Chemically stained surface

[b] Integrally coloured with pigment

[c] Integrally coloured with pigment

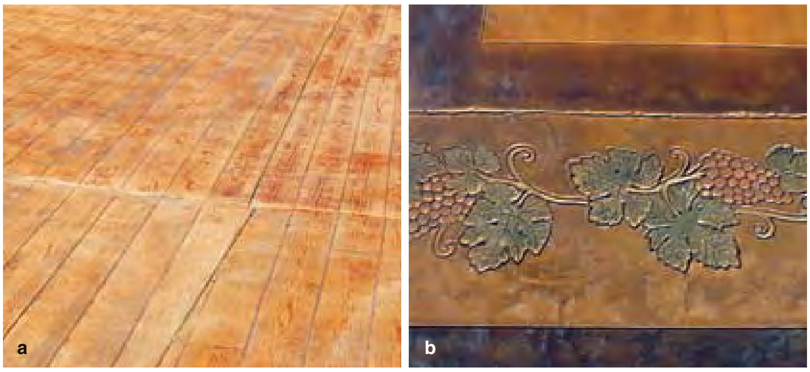


FIGURE 105

Finishes requiring reproduction of fine details stamped into a mortar topping

[a] Timber pattern

[b] Artistic pattern – colour from chemical staining

FIGURE 106

Crusting around edges of stamped pattern due to drying of the surface prior to stamping

FIGURE 107

Plank used to ensure uniform application and trowelling of dry-shake topping *Photo courtesy of Concrete Technologies*

FIGURE 108

Surface textured prior to stamping to provide slip resistance

FIGURE 109

Applying release agent to surface

Textures can vary from shallow **Figures 103 and 111** to coarse **Figures 106, 110 and 112**, and can be formed by a variety of methods including mats, rollers **Figure 113** and open-grid metal moulds **Figure 114**. 'Seamless' stamping mats that provide a continuous textured surface without a defined pattern are also available **Figure 103d**.

6 Cure the concrete. Curing (see **Section 4.17**) is required to ensure that the potential strength and performance of the coloured surface hardener is achieved and the risk of cracking is minimised.

7 Remove the release agent. If powdered release agents have been used, these must be removed prior to sealing. They are normally removed using high-pressure water or by scrubbing with a detergent-based wash as soon as the concrete is hard enough to allow removal without damage to the surface finish **Figure 115**. If left to the end of the curing period they may become partially bonded to the surface and difficult to remove.

8 Seal the surface. Sealers (see **Section 4.18**) are applied mainly to protect the surface from contaminants such as oil spills and thereby reduce staining. Stains may be difficult to remove and some of the cleaning compounds and solvents required could affect the colour.

3.4.4 Spray-on toppings

Patterned finishes can be provided to existing slabs by spraying the surface with coloured and textured finishes which vary in thickness from 3–5 mm **Figure 116**. Spray-on toppings are available as cementitious or acrylic-based materials. They can look similar but their life expectancy may vary. The supplier should be consulted about suitability and performance of these toppings for a particular application.

The procedure for applying spray-on concrete toppings is as follows:

1 Prepare the surface of the substrate. The success of any topping depends on the bond to the substrate. Clean the existing slab to remove grit, paint, oil, and other substances that will affect the bond and finish. Use high-pressure water cleaning or acid etching (a mild solution of 1 part hydrochloric acid to 25 parts water). Where severe surface deterioration has occurred, grinding or dustless shot blasting may be necessary to produce a clean, even and sound substrate.

   Take care when preparing acid solutions. Use appropriate safety equipment and always add the acid to the water, never the reverse.

2 Repair the substrate. Most sprayed finishes are applied to existing concrete surfaces to improve the appearance. Any defects within the existing slab that may detract from the appearance should either be repaired or if satisfactory repairs are not possible, they should be incorporated into the new pattern or design. As a last resort, some sections of the existing pavement may need to be replaced to achieve a satisfactory outcome. Note that matching finishes and colours between replaced sections and the existing slab is generally not an issue as the spray-on topping normally includes a base coat that will conceal the entire substrate. For patterned finishes where joint/grout lines are left exposed and no base coat is applied, the colour consistency of the concrete substrate may be more important.

   Defects that may need to be repaired prior to spraying a topping include cracks, differences in level, broken corners, joints, spalling and minor surface defects. Information on appropriate procedures can be found in **Section 6**.

3 Provide joints. As a general rule, joints in a new topping or coating should correspond with existing joints (see **Section 4.19**). This is because joints are used to allow or control movement in the slab. If they are filled and sealed over, continued movement of the pavement could cause the joint to rupture and the topping to spall.

   The location of existing joints may govern the direction of any surface patterns. If any new joints are cut into the existing pavement (existing joints too far apart or not able to adequately control movement) these should, if possible, be located to suit the new pattern.

   In certain situations, isolation joints may need to be provided or re-established around structures (posts and walls) adjoining the slab to relieve stresses.

4 Protect adjoining structures. Protect adjoining surfaces from over spray or splatter. Staining by fine oxides and topping powders stain is difficult to remove.

5 Apply bonding products. Bonding products can be used to increase the strength of the bond of the topping to the existing substrate. They are usually supplied with the application kit or incorporated into the spray material. Products should be applied in strict accordance with the manufacturer's recommendations as incorrectly used bonding agents can have a de-bonding effect.

FIGURE 110
Plastic sheeting used to prevent concrete sticking to the mould – cobblestone texture

FIGURE 111
Stamping with textured rubber mats – slate texture aligned with joints

FIGURE 112
Coarse textured rock finish

FIGURE 113
Stamping with a purpose-made roller

FIGURE 114
Stamping with open-grid metal moulds
(a) Large grid
(b) Small grid

FIGURE 115
Removing the release agent with high-pressure water – note that adjacent finishes should be protected

FIGURE 116

Examples of sprayed-on toppings over existing concrete slabs

[a] Random blue stone (stencilled) *Photo courtesy of Concrete Technologies*

[b] Tile *Photo courtesy of Concrete Colour Systems* [c] Large flag *Photo courtesy of Concrete Colour Systems*

[d] Special designs are easily achieved *Photo courtesy of Concrete Colour Systems*

[e] Large flag pattern to existing balcony

FIGURE 117

Scale provided by saw cutting insitu paving to resemble large format pavers

FIGURE 118

Guides should be used to ensure lines are straight or uniformly curved

FIGURE 119

Brass and zinc strips used to create lines and define areas

FIGURE 120

Joints used to delineate different finishes and colours

[a] Alternate panels of exposed aggregate and broom finish

[b] Sections of exposed aggregate with different matrix colours

[c] Exposed aggregate contrasting with grey concrete broom finish

6 Apply base coats. A base (or primary) colour coat is applied over the bonding agent (where required); this becomes the colour of the 'joints' in stencilled patterns.

Base coats are fairly workable and can be levelled with trowels, broad floats or squeegees. The condition of the slab, existing falls and depths of any depressions will, however, influence the choice of slump.

After the base coat has dried (a period specified by the manufacturer) smooth the surface with fine sanding, light grinding or rubbing over with open-mesh rubbing blocks to remove minor imperfections. Fill any minor holes. Remove dust and grindings from the immediate area so it is not walked onto, or blown back onto, the pavement.

7 Apply stencil to the surface. If required, stencils are placed over the base coat. They are usually self-adhesive for fixing directly to the base coat or prepared surface. They are available in a wide range of patterns, similar to those available for standard stencil applications. Stencils with special patterns can be made to order.

8 Apply topping coats. The final coloured coat is mixed according to the manufacturer's recommendations. This may include additives sold with the application kit. Varying the slump and viscosity of the topping can produce different textures. A more fluid topping (with a high slump) will produce a smooth finish; a drier mix (lower slump) is used to produce rough textures. Increase the slump by adding both fluid and binding materials; not only fluid. Watering down of any product will weaken the mix.

The colour can be applied through a dual-line feeder or hand-held hopper with a gravity feeder. An even application is crucial. A number of coats, including highlight coats (with an iron-oxide fleck for example) can be applied and allowed to dry in accordance with the manufacturer's recommendations.

After the surface is set, the stencils are removed and the residue is blown off.

9 Cure the concrete. As with any cementitious product, curing is essential in order to produce optimum results see (**Section 4.17**).

10 Sealing. A same-day sealer can be applied for immediate protection. Once the surface has achieved its design strength, two coats of a high-quality sealer are recommended to ensure the lasting serviceability of spray-on surface finishes (see **Section 4.18**).

3.4.5 Sawcuts, inserts and joints

Patterns can be created in both smooth and textured surfaces by methods such as:

- Sawcutting 'pattern' lines into the surface after hardening of the concrete **Figures 117.** Sawcutting can be carried out with tools ranging from hand-held and guided angle grinders **Figure 118** to larger concrete saws. Shallow sawcuts (about 5 mm deep) are often used with patterned, chemically stained surfaces to prevent the stain from spreading to adjacent differently coloured areas **Figures 20 and 21**. If sawcuts are being relied on to provide crack control they must be installed at an appropriate time and be of the correct depth (see **Section 4.19.3**). Sawcuts can also range in width (depending on the appearance required) and be grouted to provide contrasting coloured strips between sections.
- Providing inserts in the plastic concrete to define areas **Figure 119**. Inserts are typically brass or zinc strips and may be full depth similar to those used in terrazzo finishes or partial depth and act as crack inducers. Alternate materials may include rigid plastics/PVC.
- Use of joints. Because of the normal spacing of joints they are generally used to define areas and create patterns on a larger scale **Figure 120**, although they can be incorporated into more-detailed patterns **Figure 21b**.

3.5 TOOLED FINISHES

Mechanical tooling removes the surface by fracturing both the concrete and aggregates. For stained/coloured decorative finishes, fine details and features can be incorporated by using needle-point scabbling equipment **Figure 121** to remove only the surface layer of cement mortar to reveal the contrasting colour of the concrete below. Templates are generally cut into a rubber or vinyl sheet to define the pattern and control the area scabbled.

Coarser textures can be achieved by bush hammering or point tooling the surface but these are labour intensive and generally unsuitable for surfaces used by pedestrians.

Tooling of the surface should be kept 25 to 50 mm clear of edges and corners to avoid them being fractured and/or broken off.

3.6 SPONGE FINISHES

Sponges can be used to provide a good slip-resistant finish to flatwork. The surface is either dabbed with a sponge or sponge float to roughen the surface and provide a fine even texture. Alternatively the sponge can be wiped over the surface to provide textures resembling more-traditional wood float finishes **Figure 122**.

Similar to float finishes, the surface should be compacted by several passes with a steel trowel and the sponge used to impart texture only to the surface. Used on an uncompacted surface the sponge may draw up the cement and sand matrix which, once exposed, is easily worn away under traffic. Note that finishes similar to render may not be possible on flatwork due to the coarser sand used in concrete mixes. For fine sand-like textures a dry-shake or other form of topping containing finer materials may be required.

3.7 COMBINED FINISHES

Many surface treatments can be combined to further increase the range of decorative finishes available. Some combinations include the following:

- Stamping and exposed aggregate Exposed-aggregate surfaces can also be stamped with an impressed pattern **Figure 123**. The finish can provide the appearance of segmental paving but with reduced risk of step-faulting from variations in level. The finish is often provided on road surfaces to provide an audible warning to drivers of a change of surface, thus alerting them to the need for caution in residential areas and at pedestrian crossings.

  After the surface mortar has been washed away, a thin film of clear plastic is placed over the surface to prevent the concrete adhering to the mould, and the surface is stamped with metal moulds usually consisting of an open grid in a metal frame with a driving shaft **Figures 110 and 114**.

  Stamping must be done while the surface is still plastic. To avoid premature setting, the concrete should be placed and finished in manageable sections. If conditions are hot, dry or windy, applying an evaporation retarder and/or surface set-retarders to the surface will extend the time available to stamp the surface and avoid crusting problems **Figure 106**.

  Surface set retarders can also be used to retard certain areas within stamped patterns, enabling the selective exposure of aggregates to provide a feature within the pattern **Figure 124**.

  The concrete should be cured for a minimum of 3 or 7 days (7 days is preferred) with polythene sheeting (clear or light coloured for external applications) or other curing method. A two-coat sealer can be applied after curing to brighten the finish and prevent staining.

- Stamping and rock salt The success of this combination depends on the stamping operation. If stamping with rubber mats or metal grills, if salt is used, it must be applied to the surface after stamping to avoid being completely embedded into the surface of the concrete. At this stage, it may be difficult to embed the salt into the surface with rollers without affecting the stamped pattern. However, where special features are placed on the surface and can be rolled into the surface along with the salt particles allowing control over the embedment, a successful outcome is possible **Figure 125**.

- Stamping and tooling the surface An example of this can be seen in **Figure 121b** where the surface has first been stamped and chemically stained to provide colour, the border has then been scabbled using needle point scabbling equipment. This method can be used to produce very fine details in the surface of the concrete **Figure 126**.

- Honing and acid etching The typical smooth surface resulting from honing can be textured by removing the mortar from between the stones. This leaves the aggregates with a flat surface having a dull to polished finish depending on the fineness of the abrasives used, but also provides some texture for slip resistance.

  One method of achieving this is to acid etch the surface **Figure 127**. As for acid etched finishes, it is important to specify the depth of removal of the mortar.

- Honing and setting aggregates into surface Similar to setting aggregates into the surface, in this case the pieces of aggregate have been polished to highlight the colour and provide a flat surface that is easy to walk over **Figure 128**.

- Chemical staining and abrasive blasting Once colour and texture have been added to the concrete surface, the surface can be lightly blasted to retain some of the colour but change the texture in order to produce subtle decorative features **Figure 129a** or blasted to remove all the colour in specific areas to provide greater contrast and hence form a decorative pattern/feature **Figure 129b**. The latter eliminates the need to sawcut the borders in order to prevent spreading of the stain and achieve clearly defined edges/lines. Machine-cut rubber or vinyl stencils (to mask areas not to be abraded) can be used to produce a higher quality and more consistent finish for repetitive items such as borders.

FIGURE 121

Fine details can be produced by tooling the surface through stencils using needle point scabbling equipment

FIGURE 122

Sponge finish textures

[a] Foam/sponge float

[b] Fine even texture

[c] Texture similar to wood float

FIGURE 123

Stamped and exposed-aggregate finish combined

FIGURE 124
Pattern is stamped and set retarder applied to surface to allow selective exposure of aggregates

FIGURE 125
Rock salt texture with stamped pattern

FIGURE 126
Fine details can be tooled into the coloured concrete surface

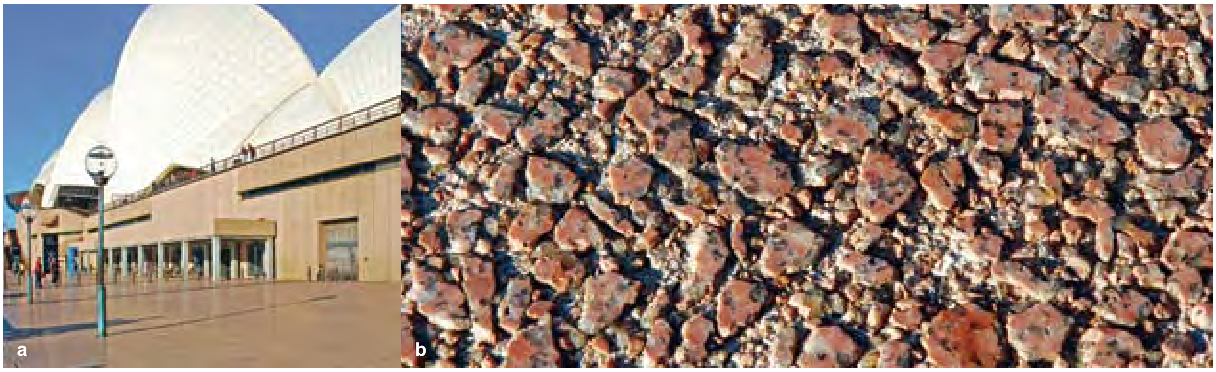


FIGURE 127
Sydney Opera House precast concrete paving panels
[a] General view
[b] Closeup showing flat surface of aggregates from honing/polishing and texture from subsequent acid etching

FIGURE 128
Granite pieces with polished surface set in coloured mortar pavement
Parliament House forecourt

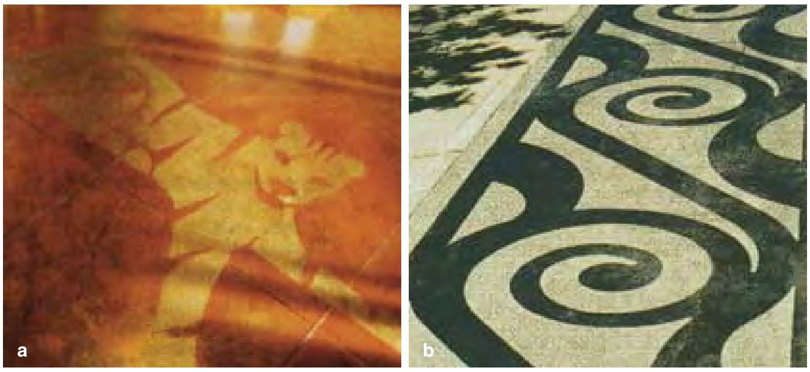


FIGURE 129
[a] Light abrasive blasting to alter texture and
[b] All surface colour removed by blasting

4 Construction

To ensure that the specified surface finish is achieved and that it performs satisfactorily many aspects of the concrete and related construction practices must be considered. This section gives guidance on the aspects of concrete construction that relate specifically to flatwork.

The elements of a typical concrete floor or pavement are shown in **Figure 130**. Note that some elements may not be present depending on the application and whether the floor is on the ground or suspended. In this guide the key terms are defined as follows:

- Wearing surface. The trafficked surface or top surface of the floor or pavement.
- Concrete floor or pavement. The main structural element of concrete flatwork.
- Reinforcement. If required, reinforcing bars or mesh complying with AS/NZS 4671 *Steel Reinforcing Materials*[8].
- Subbase. If required, the layer of selected material placed on the subgrade.
- Subgrade. The natural or prepared formation on which the floor or pavement is constructed.

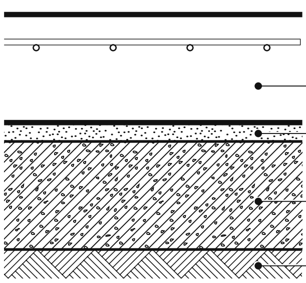


FIGURE 130

Cross section of typical floor or pavement

4.1 REQUIREMENTS OF STATE AND LOCAL AUTHORITIES

Concrete flatwork between the kerb-and-gutter and a property boundary will generally have to comply with the requirements of the Local Authority in respect of levels, grades and specification (thickness, reinforcement and concrete strength). Special requirements in these areas are often imposed to provide safe access for pedestrians and to allow use by occasional maintenance vehicles, equipment for repair/replacement of in-ground services and delivery vehicles. Requirements should be determined initially, as they may affect the grades of adjacent paving on the property. For driveway pavements requiring steep slopes, maximum grades and the need for possible transition zones may also be affected by the requirements outside the property boundary.

Where Government authorities have produced guides for the standards and tolerances required for building works, the provisions within such guides relating to the finished floor levels, levelness of concrete floors, cracking and other related items should be checked. For example, *Guide to Standards and Tolerances*[9] states that 'Except where documented otherwise, new floors are defective if within the first 24 months they differ in level by more than 10 mm in any room or area, or more than 4 mm in any 2-m length. The overall deviation of floor level to entire building footprint shall not exceed 20 mm.' This highlights the importance of specifying in the project documentation items such as the acceptable tolerances for the finished concrete surface (see **Section 4.22**). Also, depending on the reactivity of the soil, ground movements (long-term and seasonal) following the construction of a floor or pavement could easily cause the concrete surface to fail to meet the tolerances stated above. Thus the cause of any deviations must be determined in assessing compliance with requirements.

Finishes such as water washed, acid etched and abrasive blasted may result in contaminants that affect the surrounding environment, particularly if runoff is allowed to enter the stormwater drainage system without the appropriate precautions being taken. Most State Government Environmental Protection Authorities have specific requirements relating to the collection, filtration and disposal of a range of waste materials from building sites. One example from the Environmental Protection Authority in NSW is *Environmental Best Management Practice Guideline for Concreting Contractors*[10].

BACK TO CONTENTS PAGE

While each State has its own requirements, preventative measures that can be taken to contain waste products (runoff) include:

- Sand barriers can be used as filters to contain sediment from runoff which is then removed from site.
- Hessian wraps or excavated channels can be used to divert runoff to surface catchment areas or into excavated silt traps. Overflow from silt traps (if clean) can be diverted back into the stormwater system or contained within a secondary trap to allow further settlement of particles. Any acidic solutions should be neutralised prior to discharge from the silt trap.
- Drainage inlets can be temporarily capped.
- Raised formwork can be used to control sediment run-off.
- Where practicable, the residue from one section of pavement can be washed onto an adjacent area that is to be subsequently covered by an adjoining section of paving.
- Runoff can be recovered by using wet vacuum systems.

4.2 CODES AND STANDARDS

A number of Codes and Standards cover construction of concrete flatwork. It is important to understand what aspects of flatwork are covered in order to know what information should be incorporated into the project documentation and what can be specified by reference to these documents. The main ones are:

- Building Code of Australia[11] The BCA contains performance requirements and a number of deemed-to-satisfy provisions for building structures. For house slabs and footings, these include deemed-to-satisfy provisions for general items such as excavation of footings, foundations, filling under slabs, support, membranes under slabs, concrete strength and shrinkage control. In terms of the actual construction of the floor slab, no requirements are included for the formwork (edges of slabs) or the surface finishes and tolerances. These should therefore be included in the project documentation.

  If Australian Standards are referenced in the BCA, the requirements contained within those Standards become deemed-to-satisfy requirements as though they were contained in the BCA itself. The formwork standard AS 3610[12] (see below) is not cited in either Volume 1 or 2 of the BCA but is indirectly cited by virtue of its citing in AS 3600. Thus the class of formwork finish for formed surfaces needs to be specified if this aspect of the flatwork construction is critical to the finish.

  Volume 2 *Housing Provisions* contains performance requirements for ramps (eg 'have slip-resistant walking surfaces on ramps') but unlike Volume 1 does not directly or indirectly cite AS/NZS 2890.1[13] (see below) or give any deemed-to-satisfy provisions in this regard. The grades and details of pavements (eg driveways) for Class 1 and 10 buildings should therefore be specified to ensure compliance with the performance requirements.

  Note that AS 2890.1 is a secondary reference from within AS 1428 *Design for access and mobility* but applies only to buildings covered by Volume 1.
- AS 3610 The formwork code contains requirements only for the formed surfaces of concrete elements (ie formed edges of floors and pavements). If the finish of formed surfaces is critical to the appearance, then a suitable Class of finish (Class 1 to 5) should be specified. Unformed surfaces such as the tops of concrete floors and pavements are not covered by AS 3610; the finishes and tolerances should therefore also be specified in the project documentation.
- AS 3600[14] The concrete structures code contains concrete durability requirements (ie strength and cover) for a range of situations such as exposure environment (location), abrasion (from traffic loading) and freezing and thawing. While tolerances for concrete surfaces are given, these are for structural performance criteria and should not be used to specificy the quality of an unformed surface, ie top of a floor or pavement.
- AS 2870[15] The residential slabs and footings code provides deemed-to-satisfy provisions for the construction of house slabs/footings. It does not nominate a class (from AS 3610) for formed surfaces and does not include tolerances for unformed surfaces. Specifications for these should be included in the project documentation.
- AS/NZS 2890.1 The parking facilities code (Part 1 *Off-street car parking*) provides deemed-to-satisfy solutions for the width and grades of domestic driveways and general circulation roadways and ramps. While not cited in BCA Volume 2 *Housing provisions*, it does contain information on domestic driveways. If problems with access to residential buildings does occur and the details do not comply with the provisions of AS 2890.1, then even though the provisions have no legal standing for housing, it could be difficult to demonstrate compliance with the performance requirements.

FIGURE 131
Coloured concrete test panel with various surface textures and sealers awaiting slip-resistance testing

FIGURE 132
1000 x 1000 mm test panels to trial colours/designs and the finished floor

FIGURE 133
Precast paving units range from small segmental units to large panels

4.3 TEST PANELS

Test panels are typically used to assess the contractor's ability to produce the specified finish and quality of workmanship on site using the same techniques and materials intended to be used in the actual work. They are also used to trial colours, combinations of products and to test properties such as slip resistance prior to the construction of large areas. Depending on the results, materials and/or methods of construction can be adjusted until the desired outcome is achieved. The approved test panels become the benchmark for the remainder of the project **Figure 131**.

The construction of test panels is generally not warranted for projects involving 'standard' finishes such as steel trowelled, floated and broomed or even stencilled/stamped finishes where patterns and colours are chosen from a manufacturer's range. There are usually enough examples of these finishes to allow comparison with existing work and for contractors to have demonstrated their ability to produce them. Suppliers of decorative products will often have a display from which finishes can be selected.

However, test panels are an essential component of paving projects incorporating specific requirements such as special features and surface treatments, more-stringent tolerances, higher-quality finishes and colour control.

To minimise the expense of providing test panels, there will sometimes be non-critical parts of a project that can be placed first and treated as test panels. The first section of concrete placed on any project is often viewed as a form of test panel.

Preparation of test panels

The size of test panels is largely determined by what needs to be tested. A reasonable minimum size to allow the proper evaluation of finishes, surface textures and surface characteristics would be 1000 x 1000 mm **Figure 132**. For some patterns and designs, larger areas may be necessary; the maximum size is usually 2400 x 2400 mm. To evaluate the ability to achieve stringent tolerances over large areas, large test panels may be uneconomical and the first concrete placement would generally be regarded as a test panel. Larger test panels may also be required if other aspects of the pavement such as penetrations, joint details and ability to incorporate reinforcement, dowels, spacers and other fixings, edge angles and hardware need to be assessed.

When specifying a textured surface, it is beneficial to nominate a reference or sample finish. Alternatively, high resolution images could be incorporated into the specification to assist in achieving the desired finish.

Small laboratory-prepared samples of finishes (say 300 x 300 mm) should not be confused with test panels as they are unable to replicate the placement and finishing of concrete pavements under actual site conditions. They may, however, provide some initial guidance regarding a number of aspects of a proposed finish (eg colour, special aggregates, surface treatments and texture) and give an indication of the finished effect of applied sealers and/or coatings. They may also be used to assess properties such as slip resistance. This may assist in developing a realistic specification and to reduce the costs of producing larger test panels and full-scale sample pavements that do not meet the specified criteria, and which may therefore require rectification or demolition.

Assessment and rejection criteria

Test panels should be assessed on the same basis as the actual work as they are representative of what is to be achieved.

Repairs

If repairs should be necessary, procedures should first be carried out on test panels to allow an assessment of the contractor's ability to undertake the repair work and, more importantly, to match existing finishes. Repair procedures should be approved on test panels prior to any actual repairs on finished sections of the pavement.

4.4 PRECAST

Insitu flatwork is constructed on site and generally allows large areas to be placed as continuous elements (incorporating joints), whereas precast elements for flatwork are constructed remote from their final location and placed or set into position. Precast elements may vary from small segmental type units to large paving panels and may be placed side by side to form a larger area or separated by other materials to form 'stepping stone' type pavements **Figure 133**. Depending on the application and design requirements, either one may provide an appropriate cost-effective solution.

Precast elements provide a practical solution over water where forming up for insitu work is difficult and may create OH&S issues **Figure 134**. Some other advantages of precast include:

- Off-site construction reduces congestion on site.
- Manufacture is in a quality-controlled factory environment.

FIGURE 134
Precast paving units allow easier construction over water

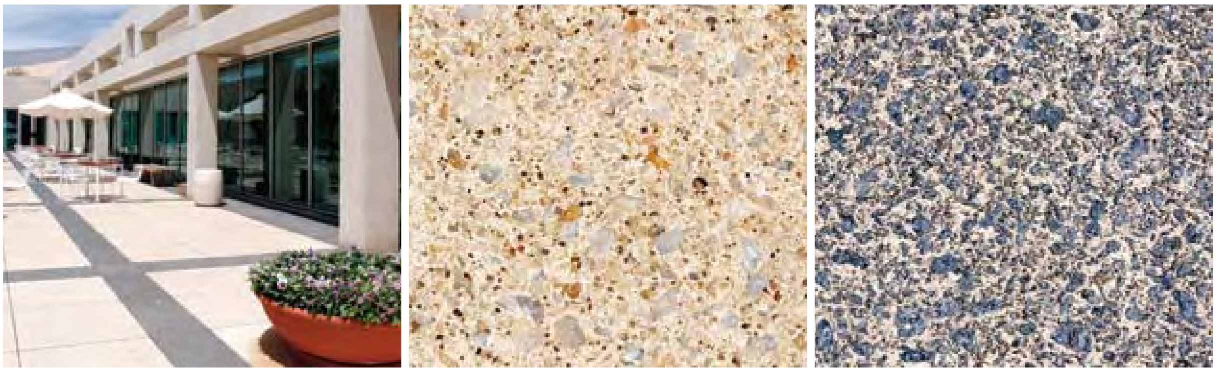
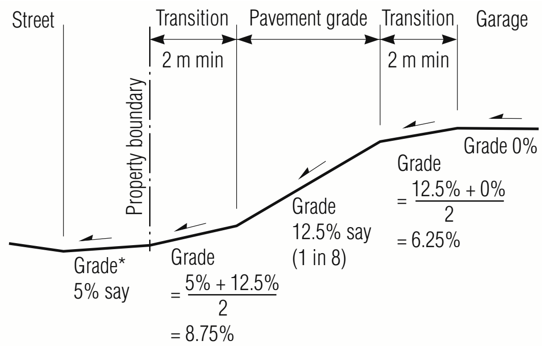


FIGURE 135
Precast paving units allow abrasive blast finish without risk of damage to surrounding Class 1 concrete finishes
Parliament House, Canberra



* The advice of the Local Authority should be sought to obtain grade requirements for the area between the street and property boundary.

FIGURE 136
Transition zones to prevent vehicles scraping on ramps

- The production of some finishes such as water washed, honed/polished, acid etched and abrasive blasted have less environmental impact due to the controlled conditions which allow recovery and reuse of materials such as acid, water and grit.
- May allow special finishes to be provided in situations where onsite construction would be difficult or would risk damage to surrounding finishes **Figure 135**.
- Approval of finishes prior to delivery.
- Allows tactile pavers to be easily incorporated.
- Pavers are cured prior to delivery and have gained sufficient strength to allow immediate use once installed. This may reduce disruption to businesses and access for pedestrians.
- No control or expansion joints need to be provided within the pavement.
- Access to in-ground services as pavers may be lifted and re-installed.
- The ease with which scale can be provided to large areas through the use of borders, patterns and changing textures/colours.

Further information on detailing and construction with segmental paving is available from the Concrete Masonry Association of Australia[16].

4.5 GRADES AND LEVELS

AS 2890.1 contains the requirements for acceptable pavement grades. Briefly, the minimum gradient or crossfall required for an exterior concrete pavement to allow adequate drainage of the surface is generally 1 in 100 (1%), or 10 mm per metre.

Pedestrian areas will generally have a slope between 1 in 100 and 1 in 40. Slopes steeper than 1 in 20 are classified as ramps, with the BCA allowing slopes up to 1 in 14 where disabled access is required and up to 1 in 8 in other cases.

The maximum grade should not exceed 1 in 20 (5%) in the footpath area or 1 in 4 (25%) within the property boundary. Note that as the actual requirements may vary from these limits, especially in hilly areas, it is always advisable to check with the relevant Local Authority.

Where grades at or near the maximum gradients are necessary for driveways, a transition zone at either end of the steep section may be required to prevent vehicles from scraping or 'bottoming' on the driveway **Figure 136**.

Where driveways and pavements are constructed adjacent to houses and other structures, a number of items may need to be considered:

- Termite barriers. It is important not to construct the pavement at a level that will obstruct any required visual termite inspection zone.
- Finished levels. The BCA requires paved areas that have a slope away from the building of at least 50 mm (25 mm in South Australia) over the first 1 m from the building to be at least 50 mm (75 mm in South Australia) below the finished surface of any adjacent slab-on-ground. This minimum height may need to be increased if: the required slope can not be provided; there is a possibility of flooding; local plumbing regulations require specific heights between the overflow relief gully and drainage fittings and ground/paving level.
- Flashings and damp-proofing courses. The BCA requires that the height of a damp-proofing course or flashing serving as a damp-proofing course be at least 75 mm above the finished surface level of the paving adjacent to the wall.
- Sub-floor ventilation openings. If any existing sub-floor ventilation openings are covered by the paving, the BCA requires new openings to be provided to reinstate the required ventilation area.
- Ground movement. In clay soils, the moisture content of the soil beneath large areas of paving may change over time, possibly causing movement of the soil and consequent changes to the paving and adjacent building levels. The possible effects of this movement on the drainage and adjacent walls should be considered.
- Drainage. Where a pavement can not be graded away from a building (eg driveways that slope towards the house), a suitable drain should be provided adjacent to the building to divert stormwater runoff.

4.6 SUBGRADE PREPARATION

Normal subgrade preparation involves removal of all topsoil and vegetable matter to remove weak and degradable material and avoid settlement of the paving, cutting or filling to required levels and compaction. The subgrade should provide a uniform layer on which to commence pavement construction. All soft material should be removed and replaced with suitable material from, or imported to, the site. A common misconception is that rigid concrete pavements can span over poor subgrades **Figure 137**.

For residential work, the pavement is often placed directly on the prepared subgrade with no compaction of the surface undertaken. If the pavement is to be used by vehicles heavier than 3 tonnes the subgrade should be compacted and, depending on the weight and frequency of use, a subbase may also be needed to distribute loads on to the lower-strength subgrade.

Regarding compaction, the fill can either be rolled or controlled. Rolled material is satisfactory for lightly loaded applications; AS 2870 defines this as consisting of 'material compacted in layers by repeated rolling with an excavator'. It goes on to state: 'Rolled fill shall not exceed 0.6 m compacted in layers not more than 0.3 m thick for sand material or 0.3 m compacted in layers not more than 0.15 m thick for other material.' For heavier loads and increased thicknesses, controlled fill is required. Controlled fill should be placed and compacted in accordance with AS 3798[17] which is cited directly in Volume 2 of the BCA and indirectly in Volume 1. The guidance given in AS 3798 concerning suitable and unsuitable material, compaction of soils, fill construction (layers, moisture control and compaction) and testing requirements should therefore be followed.

AS 3798 also covers the correct backfilling and compaction of trenches required for, say, services beneath the floor or pavement. It states that 'it is important that rapid lateral changes in the engineering properties of the ground in such areas (as service trenches) should not occur. Compaction of backfill to trenches to a comparable condition to that of the surrounding ground, therefore, is important and should be clearly specified in terms of the relative compaction and should be controlled. The practice of flooding sands to achieve compaction of backfill is insufficient and should only be used in conjunction with other compaction methods.' The inadequate backfilling and compaction of service trenches is a common problem that can result in failure of a pavement, safety issues and expensive repairs **Figure 138**.

4.7 SUBBASE

The subbase is the layer of selected material placed on the subgrade. Its functions include:

- providing uniform support to the concrete base;
- assisting with load transfer at joints;
- reducing deflection and stepping at joints **Figure 139**;
- assisting to control volume changes in moderately to highly expansive soils;
- eliminating erosion and pumping of the subgrade (especially at joints) as a potential failure mode (generally for heavily trafficked pavements);
- providing a stable working platform for pavement base construction.

Even for residential floors and lightly loaded pavements a subbase is recommended, particularly on highly expansive clay subgrades. The significant volume changes that can occur in these types of soils may result in non-uniform support of the slab, and subsequently lead to early slab failure. The subbase or cover layer of low-volume-change (non granular) soil minimises moisture migration under the pavement, and hence changes in the moisture content and volume of the underlying expansive soil. It also provides more-uniform slab support by reducing the impact of any minor subgrade defects. The appropriate thickness of the non-expansive subbase layer depends on the site conditions and local experience. In the majority of cases, a 100-mm thickness is recommended.

Alternatives to using a subbase material such as 'roadbase' include stabilising (generally with lime or cement) a layer of the subgrade soil to enhance its stability under conditions of alternate wetting and drying, or designing the floor/pavement to allow for such movement.

4.8 REDUCING FRICTION UNDER FLATWORK

Providing polyethylene sheeting or a 20-mm-thick layer of sand beneath the pavement is an effective way of reducing the friction between the slab and subgrade/subbase. Compared to placing the concrete directly on a plastic soil such as clay, the frictional force – and hence restraint of the slab – can be more than halved **Figure 140**. This allows the concrete slab to move more freely as a result of factors such as drying shrinkage and thermal volume changes, thereby reducing the risk of unplanned cracking.

If using sand, it is important that the percentage of fine material such as silt and clay be limited to about 5%, so that the material does not bind together, thereby restricting movement of the slab. Also, the sand layer should not be able to wash out from under the slab, nor act as a layer enabling water to gain access and/or pond under the slab and cause increased ground movements on reactive clay soils.

4.9 REINFORCEMENT AND FIXING

The main function of reinforcement in a pavement is to hold tightly closed any cracks that may form. Reinforcement or mesh does not increase the load capacity of a pavement, nor does it reduce the required thickness. In general, the amount of reinforcement required to provide the appropriate degree of crack control will depend on the thickness

FIGURE 137
Rigid concrete pavements are unable to span over areas of poor subgrade (eg softened by water saturation)

FIGURE 138
Subsidence of paving above inadequately backfilled and compacted service trench

FIGURE 139
Stepping at joint due to settlement of subgrade

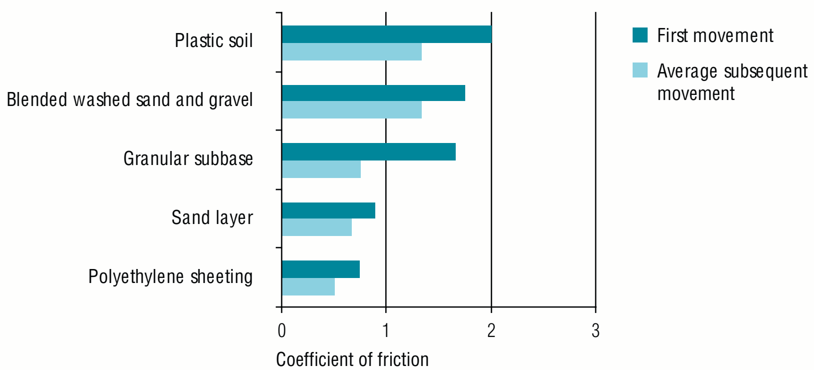


FIGURE 140
Variation in values of coefficient of friction for 125-mm-thick slabs constructed on different materials (from Timms[18])

FIGURE 141
SL81 mesh used to control cracking where the surface of the slab will be exposed (polished concrete finish)

of the slab and the joint spacing **Table 2**. Calculating the reinforcement required is not necessary for the types of applications covered by this table.

Where the concrete surface provides the final finish, minimising the risk of cracking and (if cracking does occur) controlling crack widths is critical to the success of any floor or pavement. Methods to reduce/control cracking include appropriate joint spacing (see **Section 4.19.7**), increasing the amount of reinforcement or reducing the friction under the slab (see **Section 4.8**). Depending on the application, a combination of all of these measures may be warranted.

For example, in residential slabs where reliance is placed on the reinforcement for crack control (ie no joints), AS 2870 requires that the mesh size be increased by two sizes where brittle floor finishes are to be installed, and that heavier meshes be used for longer slabs. The same reasoning applies to polished concrete floors **Figure 141** or decorative paving finishes where wide cracks may detract from the appearance. Note that for stiffened raft floor slabs the reinforcement also contributes to the structural performance of the footing system.

Where step-faulting of the footpath or pavement is likely to occur (this may be due to nearby large trees or shrubs) **Figure 142**, reinforcing mesh may help maintain slab-to-slab alignment at control joints. However, with the likelihood of wires eventually rusting at the joint locations, alternatives such as proprietary key joints and other shear-connection forming devices may provide better long-term solutions. Dowels should be provided at expansion joints. The method used will determine the minimum slab thicknesses.

Steel fibres are an alternative type of reinforcement that can be substituted for mesh in flatwork **Figure 143**. They will generally also improve the abrasion resistance of the surface, minimise plastic shrinkage and settlement cracking and are ideal for odd shaped slabs that may be difficult to reinforce using mesh. Note that polypropylene fibres provide some tensile strength to the concrete in its plastic state to assist in minimising plastic shrinkage and settlement cracking but should not be used as a substitute for mesh. Further information can be found in Current Practice Note 35[19]. As fibres vary in length, thickness and end details, the manufacturer's recommendations for specific applications should be followed.

Concrete reinforced with steel fibres can be placed, screeded and finished in the same way as normal concrete. For some finishes and applications, particularly those for barefoot use, the possibility of fine steel fibres protruding from the surface must be considered. For example, broomed and most exposed aggregate finishes will be unsuitable for barefoot use as they can leave the ends of the fibres exposed. Generally, only finishes such as steel trowelled that embed fibres into the concrete are suitable for these applications. Some corrosion of the fibres may also occur at the surface of the concrete and affect the appearance **Figure 144**.

Reinforcement for pavements (usually mesh) should be located within the top half of the pavement, and have a minimum 30 mm of concrete cover to the top of the slab and 40 mm to the sides and any joints. It should be fixed in position using suitable supports or bar chairs to prevent movement during concrete

TABLE 2 Typical concrete pavement specification for residential applications

			Alternative 1 Unreinforced		**Alternative 2 Reinforced**	
Traffic	**Minimum slab thickness** (mm)	**Minimum concrete grade** (MPa)	Maximum control joint spacing (m)	Minimum reinforcing mesh	Maximum control joint spacing (m)	Minimum reinforcing mesh
Foot and bicycle	75	20	2	–	2	SL52
Light – Gross mass not exceeding 3 tonnes	100	20	3	–	3	SL62
Medium – Gross mass not exceeding 10 tonnes	150	25	3	–	4.5	SL82

*Note: For decorative finishes mesh sizes should be increased (see **Section 4.19.7**)* placement. Typically, a maximum spacing of 800-mm centres should be sufficient to prevent sagging of the mesh **Figure 145**. Note that for light meshes, the spacing may need to be reduced to prevent sagging. Mesh should not be walked into position or lifted to height using a hook during concrete placement. Nor should the concrete truck be driven over it to gain access for concrete discharge.

Bar chairs which could puncture vapour barriers or damp-proofing membranes (where provided) during placing operations should be avoided, or be supported on purpose-made bar chair bases or 'saucers' (flat galvanised metal plates).

Where sheets of mesh are joined, they should have a minimum overlap of two cross wires (ie the two outermost cross wires of each sheet are overlapped) and be secured by tying at, say, every third wire and with the tying off line staggered.

Trucks should not be allowed to drive over reinforcement and mud should be prevented from being walked onto the reinforcement. Materials should be stored on skids off the ground.

For toppings less than 40 mm thick no reinforcement is generally required. A light mesh may be considered for 50-mm-thick toppings. Unbonded toppings should be designed and reinforced as for new slabs.

4.10 FORMWORK

Formwork is the temporary structure which moulds concrete into the desired shape, and holds it in the correct position until it has hardened sufficiently and/or is able to support the loads imposed on it. Formwork should have sufficient:

- strength to resist the pressure of the fluid concrete without damage or excessive deflection (and the ability to support equipment such as vibrating screeds);
- stiffness to avoid bows, bulges and deflections outside the tolerances specified for the work;
- accuracy of construction to ensure correct surface levels and dimensions/shape;
- watertightness to prevent the loss of cement paste and/or matrix from the concrete (this can cause ragged edges, hydration staining and honeycombing, which in turn can affect strength, durability and result in poor off-form finishes);
- robustness to allow repeated stripping, storing and erection.

The requirements for formwork are provided in AS 3610. A Class 4 finish in accordance with AS 3610 will provide satisfactory alignment and finish for the majority of flatwork applications. Where edges are exposed or form joints for subsequent work, a Class 3 finish is generally adequate, but Class 2 may be specified if the edge can be viewed in detail, eg exposed slab edge for residential house slab used as part of the termite barrier system.

For specific applications such as warehousing, more-stringent tolerances on the formwork may be required to ensure that the unformed surface of the concrete can be constructed within tolerance (formwork is often used to control surface levels by supporting screeding and finishing equipment). Any specific requirements should be detailed in the project documentation.

Common formwork materials for flatwork include timber and steel. Timber is readily available, easily worked with conventional tools, has good load-carrying capacity and some species of timber are relatively light in weight, eg oregon. Steel sections are strong and robust and capable of multiple re-uses but require a measure of standardisation to warrant their additional cost. Steel and timber may be combined as shown in **Figure 146** to make use of the strength of steel and the workability of timber.

Further information on formwork materials and requirements can be found in *Guide to Concrete Construction*[20] and on basic ground forms, deep edge forms and edge forms with rebates for house slabs in *Guide to Concrete for Housing*[21].

Formwork should be coated with a form release agent to aid in the removal of the formwork and thus minimise possible damage to the concrete face from the stripping operation. There are two basic types of release agent: barrier products which simply separate the concrete from the formwork, and the more common reactive products which react with the concrete constituents to form soap-like products that prevent the concrete from adhering to the formwork. A release agent suitable for the type of formwork and finish required should be selected.

Formwork is left in place, primarily, to protect the edges of the slab from mechanical damage during site works (while the concrete is hardening), and to avoid damage from the premature removal of the formwork itself. Formwork is also an effective means of curing when it is left in place. If the formwork is stripped before 3 days have elapsed, it is advisable to continue curing exposed surfaces by one of the methods described in **Section 4.17**.

FIGURE 142
Step-faulting at joints due to movement caused by tree

FIGURE 143
Steel fibre reinforced concrete can be screeded and finished in the same way as normal concrete

FIGURE 144
Staining from corrosion of fibres at the surface may affect the appearance

FIGURE 145
Reinforcement supported on bar chairs

FIGURE 146
Formwork (steel with timber top rail) used to support screeding and finishing equipment and thus control surface levels – timber top rail allows fine adjustment of levels

FIGURE 147
Reinforcement must have increased cover to allow for removal of surface layer and exposure of aggregates

← BACK TO CONTENTS PAGE

4.11 CONCRETE

A number of items must be considered when determining the appropriate concrete to be specified for a flatwork application. These include:

Concrete strength

General issues relating to the strength of the concrete are crucial to the performance of all floors and pavements, but particularly for finished surfaces designed to be seen. A weak surface or one having an inappropriate concrete strength will be prone to dusting, abrasion and chipping. The requirements will vary depending on the application of the floor or pavement and may be dependent on various factors including:

- Loading. N20 concrete is generally acceptable for residential floor slabs as gross vehicle loads in garage areas are typically less than 3 t. Commercial floors, and particularly industrial floors and pavements that may be subject to non-traffic loading and loading from forklifts, must be designed to carry the imposed loads (see *Industrial Floors and Pavements*[22] and **Abrasion resistance** below).
- Special floor finishes. Burnished floor finishes require N32 minimum. The additional cement provided in the higher strength concrete allows the surface trowelling to produce a smooth, dense and lustrous finish. Honed finishes also require the use of a higher strength concrete (typically S32 minimum) to ensure aggregate particles are not dislodged during the grinding process and the matrix is able to be reasonably polished if required. For finishes where the cement matrix is removed from around the aggregate particles, a higher strength concrete will provide greater bond between the concrete and the aggregate, reducing the risk of aggregate particles being dislodged from the surface, either during initial surface treatments such as abrasive blasting or when the floor/pavement is in service. Pavements that are to have saw-cut joints installed at an early age will also benefit from higher strength concrete as higher early-age concrete strengths will improve the bond of the aggregate particles into the concrete and minimise dislodgement or fretting during the sawing operation.
- Abrasion resistance. The ability of the concrete surface to resist wear is directly related to the strength of the concrete and also strongly influenced by curing and the surface finish. AS 3600 stipulates minimum concrete strengths for abrasion depending on the member and/or traffic **Table 3**. An N20 concrete is satisfactory for most residential paving applications, including typical driveways. For use by heavier pneumatic-tyred vehicles up to 3 t, an N25 concrete is recommended and for vehicles over 3 t an N32 concrete is recommended.
- Freezing and thawing. AS 3600 requires a minimum N32 concrete if the pavement is subjected to occasional exposure to freezing, and an N40 concrete where 25 or more freezing cycles occur each year. Also, a percentage of entrained air (dependent on the aggregate size) is required in the concrete mix. Note that the concrete will be classified as a 'Special' class concrete (ie S32 or S40) if the entrained air percentage is above 5%.
- Salinity. If salts are present in the soil or groundwater, increasing the concrete strength to provide improved durability is advisable[23]. N25 concrete is recommended for moderately saline soils, N32 for very saline soils and N40 for highly saline soils. Also, a plastic membrane should be provided under the pavement to reduce the risk of a white deposit of salts (efflorescence) developing on the surface.

TABLE 3 Concrete strength requirements for abrasion (after AS 3600)

Member and/or traffic	Minimum concrete strength of the surface, f'_c (MPa)
Footpaths and residential driveways	20
Commercial and industrial floors not subject to vehicular traffic	25
Pavements or floors subject to:	
(a) Light pneumatic-tyred traffic/vehicles up to 3 t gross mass	25
(b) Medium or heavy pneumatic-tyred traffic/vehicles over 3 t gross mass	32
(c) Non-pneumatic-tyred traffic	40
(d) Steel-wheeled traffic	To be assessed but not less than 40

- Durability. AS 3600 provides combinations of minimum concrete strength and cover to reinforcement to ensure the achievement of the design life of concrete elements in various exposure classifications.

Concrete thickness

- The following concrete thicknesses are typically used:
  - 75 mm for foot and bicycle traffic
  - 100 mm for light traffic having a gross mass not exceeding 3 tonnes
  - 150 mm for medium traffic having a gross mass not exceeding 10 tonnes
- Residential slabs are generally 100 mm thick.
- The thickness of commercial floor slabs and industrial floors and pavements should be determined for the proposed loading and ground support conditions.
- For finishes such as abrasive blasted, acid etched, honed and water-washed exposed aggregate which involve the removal of the surface layer of concrete or mortar, the thickness should be increased to allow for the depth removed and thus ensure that the required minimum slab thickness and cover are provided **Figure 147**. For stamped finishes the depth is measured from the bottom of the impression to the underside of the slab. If a 100-mm-thick slab is required and a 15-mm-deep stamp is used the formwork will need to be set at 115 mm to ensure the minimum thickness is achieved.

Concrete mix

- Most concrete for decorative finishes will be a special class concrete due to requirements such as cement colour, aggregates used, gap grading, low bleed and pigments.
- Concrete should be manufactured and supplied in accordance with AS 1379[24].
- When products such as pigments or fibres are added on site, concrete should be adequately remixed.
- The water in the mix should be the minimum necessary for workability; no excess water should be added on site in an attempt to increase the workability. Excess water will increase the drying shrinkage and risk of cracking.
- Ordering 'low-bleed' concrete shortens the waiting time for bleedwater to rise to the surface and evaporate, in effect giving more time for finishing. This is important for finishes such as stencilled and stamped where time for subsequent processes is required. The addition of polypropylene fibres, which can help bind a mix and reduce bleeding could also be considered.
- Admixtures can be used to provide greater working time (set retarding) in hot weather conditions or allow finishing in a reasonable time in colder weather conditions (set accelerators). For stamped finishes caution should be used with set retarding admixtures to avoid crusting problems due to possible rapid drying of the surface during hot and windy conditions. Admixtures to improve workability (plasticisers) are also available; they eliminate the need for the addition of excess water on site. In freezing conditions, an air entraining admixture should be specified. By providing minute air pockets within the concrete, the concrete is able to accommodate some expansion of the water within the concrete as it freezes thereby reducing the risk of surface spalling.
- An alternative to the use of admixtures to improve workability is to order concrete with a slump that provides adequate workability; a 100-mm slump is generally suitable. This should eliminate the temptation to add excess water on site to increase the workability and thereby risk increasing the drying shrinkage and the possibility of cracking. Lower slump concretes can be ordered, but placing and finishing becomes progressively more difficult without the use of special admixtures to increase the workability.
- For exposed aggregate finishes, a gap-graded mix should be specified to provide a good aggregate density at the surface. Aggregate colours, shapes, textures and proportions should also be selected to achieve the desired result.
- Special concrete mixes are available to construct permeable (or porous) pavements (see below).
- If hand mixing concrete for slabs or toppings, adequate mixing and consistency between batches should be ensured.

No-fines concrete

No-fines concrete (also known as percolating concrete and porous paving) is a porous, open-texture concrete that contains little or no fine aggregate. It is suitable for parking lots, sporting facilities, residential streets and levelling courses **Figure 148**. Because it is characterised by uniformly distributed voids, it is not suitable for reinforced or prestressed concrete construction.

The coarse aggregate should preferably be a single-size material (nominal maximum sizes 10 and 20 mm being the most common). However, blended aggregates (10 and 7 mm; and 20 and 14 mm) have been found to perform satisfactorily.

For pavements, construction with portland or blended cement, 10-mm aggregate, a water-cement ratio of 0.3–0.4, and an aggregate to cement ratio of 4–4.5 results in compressive strengths of 5–13 MPa and required design thicknesses slightly greater than traditional concrete pavements. A small amount of sand (10–20% of total aggregate) improves strength characteristics. Strength increases with a rise in compaction energy and a decrease in aggregate-cement ratio. Shrinkage reinforcement is not required since the drying shrinkage is approximately 1/3 to 1/2 of conventional concrete (in the order of 200–300 microstrain).

Further information can be found in *Permeable Concrete Pavements*[25].

4.12 COLOUR CONTROL

Unlike off-form concrete finishes, colour control over large areas of 'grey' concrete flatwork is generally not specified. Horizontal surfaces can not generally be viewed as a 'whole' in the same way as elements such as building facades; colour variations are therefore less obvious. Surface weathering, wear and contamination will also impact on the colour, as will the provision of surface textures. Finishes such as wood float and brooming will change the perception of colour and tend to conceal any minor colour variations **Figures 149**.

Colour control or consistency is difficult to achieve, particularly with smooth finishes such as steel trowelled floor slabs where there is little or no surface texture to mask any slight variations in colour. The principle adopted in AS 3610 where acceptable colour variations are governed by a grey scale may provide some assistance in specifying the consistency of colour if required.

The key to colour consistency is to keep all aspects of the concrete and concreting as consistent as possible. In reality, each truckload of concrete that goes into a project will be slightly different due to factors such as batching tolerances, differences in mixing and supply times, changes in temperature and minor variations in how the concrete is placed, compacted, finished and cured on site.

Ways of minimising colour variations include:

- Keep materials consistent. The cement and source of cement and of any supplementary cementitious materials should not be changed. Changes in the sand will also affect the colour. For large projects on which work is carried out over an extended period of time, attention should be given to matters such as the effect of the different admixtures used under various climatic conditions (ie summer and winter admixtures) and changes in raw materials over time. One method of keeping materials consistent for exposed aggregate finishes (where the predominant colour comes from the aggregates) is to stockpile sufficient quantities of both the fine and coarse aggregate for the entire project.
- Ensure accurate mix proportions. The quantity of materials (including pigments) in each batch should be as consistent as possible. The water content in particular must be kept very consistent as variations can lead to significant colour variations. This may involve checking the moisture content of raw materials more frequently, while adding excess water on site should be avoided.
- Use off-white cement. Off-white cement is more consistent in colour than grey cement and will reduce the impact of colour variations.
- Use single batch of concrete. As the colour within each batch will be consistent, placing the entire area from a single batch will minimise colour variations **Figure 150**. Placing the concrete as a thinner topping will enable larger areas to be covered from the same batch of concrete. Trying to cover larger areas with a series of small hand-mixed batches is not recommended if colour consistency is important.
- Incorporate borders. For large areas, consider incorporating borders of different colours and/or materials such as concrete pavers to avoid side-by-side comparisons to be made. Borders also divide large areas into smaller, more-manageable sections which can be placed from a single batch. Any slight variations which do occur are usually seen as a pattern rather than a variation.
- Use proprietary topping mixes. Proprietary mixes provide a thin topping (less than 10 mm thick) over the entire area. Premixed and bagged products generally give good consistency and water for mixing can be accurately measured.
- Cure carefully. Concrete must be cured carefully to produce uniform colour; colour variations will result if different areas cure at different rates. The

curing method must maintain uniform moisture content across the surface (see **Section 4.17**).

- Avoid excessive trowelling. For burnished or highly trowelled concrete surfaces, the extended trowelling over drier surfaces may lead to 'burn' marks or darker areas on the surface due to the heat generated from the friction between the trowelling blades and the concrete surface. While the effects are less noticeable when off-white cement is used, it can still result in minor colour variations.

Since some colour variation is often unavoidable, acceptance criteria should be specified. Colour variations for off-form 'grey' concrete can be specified in accordance with AS 3610 as allowable tonal variations depending on the class of finish. For unformed surfaces, and in particular coloured finishes, colour variations can be assessed by reference to test panels (see **Section 4.3**).

4.13 TRANSPORTING

When water is added to cement it triggers hydration, setting begins and the concrete begins to lose workability. Delays in deliveries from the batching plant, on the road and on the site, should therefore be avoided. Delays reduce the amount of time to place concrete while it is still workable. Additional mixing of the concrete may be necessary on site, further delaying placement. Note that AS 1379 requires discharge of the concrete within 90 minutes from the commencement of mixing, or before proper placement and compaction of the concrete can no longer be achieved, whichever comes first.

The setting process is also accelerated in high temperatures. To avoid premature setting and difficult placement, the following procedures should be adopted:

- Select a premixed concrete supplier close to the site to reduce travelling time.
- Provide good access for trucks to enter, and clear space for turning and manoeuvring, to allow for the quick discharge of their loads.
- Ensure that adequate labour is on hand to minimise the unloading time.
- Complete the placement of reinforcement, erection of formwork and site inspections at least 24 hours before concrete deliveries are due.
- Check that all mechanical appliances (eg vibrators, screeds) are in working order the day before placement to allow time for replacement or repair if needed.
- Have all tools, equipment and materials at hand to avoid disruption.

Further information on transporting concrete can be found in *Guide to Concrete Construction*[20].

- When pumping concrete, plan delivery schedules with enough time between loads to avoid delaying trucks.
- Consider using a pump if the weather is unpredictable. Overnight rain can limit access to the site and reduce the amount of time for placement.
- When access through a neighbouring property is necessary, ensure authorised passage beforehand to prevent delays arising from misunderstandings.
- Check that all underground services have adequate loadbearing cover to prevent damage from trucks and the need for subsequent rectification work.
- Where trucks must be driven over trenches, provide strong bridging to carry a fully laden vehicle. A loaded concrete truck bogged in a trench will cause long delays.
- If the bearing capacity of the soil is in doubt, do not bring trucks onto the site; use pumps.

4.14 PLACING

4.14.1 General

Common placement methods for flatwork include by chute, pumping, barrowing the concrete into position and manual shovelling. If barrowing concrete over reinforcement, displacement of the reinforcement should be prevented by providing supported running boards on blocks above the reinforcement. If pumping, the maximum aggregate size will be limited. Thus for exposed-aggregate finishes requiring larger aggregates, seeding of the aggregates onto the surface may be necessary.

It is important not to over-handle the concrete as this can lead to segregation of materials (ie an uneven distribution of fine and coarse aggregates in the concrete) and result in poor finishes.

To minimise the risk of segregation, concrete should be placed vertically and as near as possible to its final position. When it must be moved, it should be shovelled into position and not be left to flow into position.

Other techniques for avoiding segregation during placement depend on the type of element being constructed and on the type of distribution equipment being used. For flatwork and slabs incorporating ribs and beams (shallow forms) the techniques shown in **Figure 151** should be adopted.

TABLE 4 Effect of weather conditions on concrete properties

Property	Weather conditions: Hot	Cold	Dry/windy
Slump	Decreased	Nil	Decreased
Setting time	Reduced	Increased	Nil
Strength gain			
Short term	Increased	Decreased	Nil
Long term	May be decreased	Increased	Nil
Workability	Decreased	Nil	Decreased
Risk of plastic shrinkage cracking	Increased	May be increased	Increased
Risk of drying shrinkage cracking	Increased	Nil	Increased
Risk of cold joints	Increased	Decreased	Increased
Period required prior to removal of formwork	Reduced	Increased	Nil

The subbase or subgrade will often be moistened prior to placement to minimise the initial water loss from the concrete, or it may be wet from earlier rainfall. Any ponded water should be removed and not mixed into the concrete as this may delay finishing of the slab and affect the concrete's water-cement ratio, and hence properties such as strength and permeability.

Further information on placing concrete can be found in *Guide to Concrete Construction*[20].

4.14.2 Placing in hot and cold weather conditions

In Australia, weather conditions can vary from freezing cold to very hot. Experienced paviours are always aware of the effects that ambient temperature can have on concrete. Low workability, early setting times or plastic shrinkage cracking are not symptomatic of hot weather conditions alone but can occur at any time of the year. Neither do low temperatures occur only during the winter months, but can be experienced throughout the year in some locations.

Water is very important for hydration of cement. Maintaining the correct amount of water and workability of concrete in all weather conditions is important to allow proper placement, compaction and finishing of the concrete and full hydration of the cement to achieve, ultimately, the properties of good concrete.

When the final finish does not meet expectations, the product (concrete) is often wrongly blamed; the most likely cause is a failure to adopt concreting practices suitable to the conditions. By considering appropriate concreting practices in both hot and cold weather, the risks involved with placing in these conditions should be reduced and the construction of good quality concrete made possible.

The effect of weather conditions on concrete properties is summarised in **Table 4**.

Placing in hot weather

Precautions to be taken when placing in hot weather conditions include:

- Plan the job to avoid delays once placement of the concrete has started. Delays reduce the time available for working and finishing the surface.
- Place concrete during the coolest time of the day.
- Provide sunshades and wind breaks to work areas **Figure 152**.
- For interior slabs, ensure that the building is enclosed
- Protect the surface of concrete slabs at all stages against excessive evaporation and premature drying by using an evaporation retarder such as aliphatic alcohol. These products reduce the rate of evaporation and control the premature drying of the surface, while allowing bleedwater to rise to the surface of the concrete. Note that these products are not curing compounds.

FIGURE 148

Permeable pavement constructed with no-fines concrete

Photos courtesy of Florida Concrete and Products Association

FIGURE 149

Surface texture can mask colour variations and staining

FIGURE 150

Floor placed from single batch of concrete for colour consistency

FIGURE 152

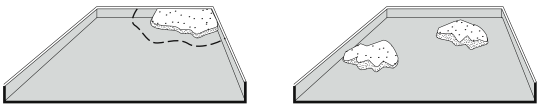
Examples of wind breaks for industrial projects

FIGURE 153

Inconsistent compaction may cause uneven exposure of the coarse aggregate

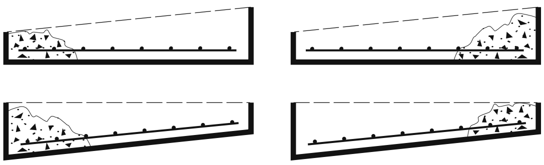
FIGURE 154

Streaks caused by tamping the surface during screeding



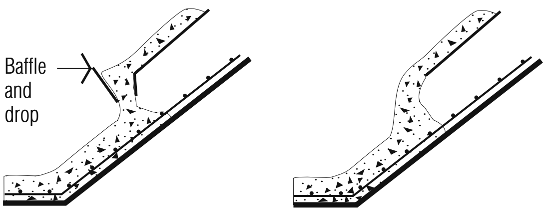
CORRECT
Commence placing at one corner of the formwork and progress away from the completed work

INCORRECT
Random placing can result in segregation and cold joints, and makes it more difficult to achieve correct levels



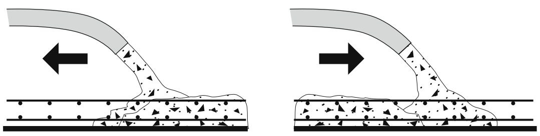
CORRECT
If either the final surface or the soffit is sloping, commence placing at the lowest point

INCORRECT
Placing commenced from the highest point makes it more difficult to achieve correct levels and can lead to segregation as the concrete tends to settle down the slope



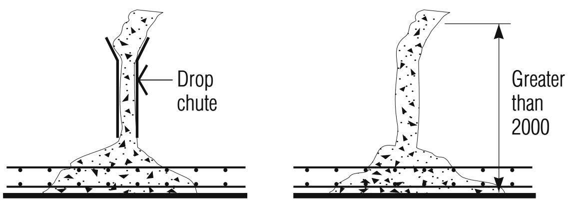
CORRECT
If placing on a sloping surface with a chute, always use a baffle and drop at the end of the chute

INCORRECT
The velocity from a free-end chute tends to carry the concrete down the slope, separating the aggregate, which goes to the bottom of the slope



CORRECT
Regardless of the distribution method, always deposit concrete into the face of that already placed

INCORRECT
Depositing concrete away from the face of that already placed can cause poor intermixing and segregation



CORRECT
Use a drop chute if concrete has to fall more than two metres

INCORRECT
Allowing concrete to free-fall more than two metres can displace reinforcement, damage formwork and cause concrete to segregate

FIGURE 151
Placing techniques for flatwork

- Dampen the subbase/subgrade before placement of concrete (but do not leave surface water). Also dampen side forms for slabs and walls.
- Use a set-retarding admixture.
- Commence curing as soon as possible and continue for a minimum of 3 days; 7 days is preferable. If plastic sheeting is used for curing, it should be clear or light coloured, not black.
- Note that the Building Code of Australia (Volume 2 Housing Provisions: Clause 3.2.3.1d) states that 'In hot (above 30°C) and windy conditions concrete must be cured by covering with plastic sheeting, spraying with a liquid membrane curing compound or ponding of water on the top surface'.

Further information on placing concrete in hot-weather conditions can be found in *Hot-weather Concreting*[26].

Placing in cold weather

Precautions to be taken when placing in cold weather include:

- Protect the concrete from the cold, including cold/frozen ground, winds and frosts. Concrete should never be placed on frozen ground.
- Insulate formwork and/or cover the surface with insulation for the first 24 hours. Hydrating cement generates a significant amount of heat which, if retained within the concrete, will protect it from freezing.
- Delay stripping of formwork as long as possible to protect concrete from frost.
- Use a suitable method of curing as moist or water curing is generally inappropriate during freezing conditions. The concrete should be kept warm during curing where this is practicable.
- The temperature of surfaces should always be allowed to fall slowly to avoid thermal cracking due to temperature differences between the cold exterior and warm interior of the concrete.

Further information on placing concrete in cold weather conditions can be found in *Cold-weather Concreting*[27].

4.14.3 Cold joints

Placing concrete in a continuous pour, if practicable, avoids the formation of cold joints. Cold joints are formed when fresh concrete is placed against the face of concrete that is about to set. The cracks resulting from cold joints will pass through the full depth of the slab.

Cold joints can be avoided by working new concrete into existing. When cold joints could occur (eg due to hot or windy weather, or delays) it is good practice to blend the faces by re-vibrating the concrete or to compact the joint with a shovel in a tossing motion to re-blend the faces.

4.15 COMPACTION

Compaction of concrete is undertaken to improve its overall performance. It is the process that expels entrapped air from freshly placed concrete thus increasing its density. As each 1% of entrapped air can reduce the strength by up to 5% it is important that compaction continue until no further air bubbles can be seen emerging from the surface of the concrete. Due to the transport, mixing and placing operations, concrete (excluding that with a very low or high slump) will typically contain between 5% and 20% by volume of entrapped air when first placed in the forms.

Adequate compaction of concrete will:

- significantly increase its strength and density and thus allow the design strength to be achieved;
- increase the abrasion resistance of the surface and thus reduce wear from vehicles, etc;
- increase the general durability and thus provide longer life;
- enhance the bond to mesh and bar reinforcement plus any cast-in features/inserts;
- decrease the permeability and thus limit penetration of water and other aggressive substances (both air-borne and contained in ground water);
- minimise the risk of plastic settlement cracking over mesh/bar reinforcement (plus other restraints within the concrete);
- reduce the incidence of drying shrinkage cracking;
- improve the quality of off-form finishes at edges by ensuring concrete completely fills the forms and blow holes in the surface are minimised.

The most common form of compaction for flatwork is vibration, undertaken with immersion (poker) vibrators or surface vibrators such as vibrating screeds. Note that for honed finishes care is required to compact consistently over the entire area to ensure uniform exposure of the aggregate **Figure 153**.

Tamping with the screed board on thin ground slabs is an effective method of compaction. In certain situations, tamping with wood floats and surface working closes up some types of cracking.

For honed finishes, tamping may locally settle the coarse aggregate resulting in 'sand' streaks or lines where less aggregate is exposed in the finished surface **Figure 154**. If this occurs, additional honing will normally be required to expose the coarse aggregate that has settled further from the surface.

Note that adequate compaction of slabs and toppings up to 100-mm-thick can generally be achieved through the placing, screeding and finishing operations. Further information on compaction can be found in *Compaction of Concrete*[28], *Guide to Concrete Construction*[20] and *Compaction of Concrete Road Pavements*[29].

4.16 FINISHING

The purpose of finishing concrete flatwork is to achieve the desired level or profile, flatness and surface density and texture. Finishing involves screeding the surface (levelling), floating, trowelling, edging and possibly applying other surface treatments.

Compacting and finishing are generally two separate operations, but for flatwork they can often be part of the one operation if a vibrating screed is used. In these cases it is essential that adequate compaction is achieved along with the surface finish.

Screeding is the operation of levelling the concrete after it is placed in the forms and roughly distributed with shovels. It is done by hand, vibrating-beam screeds or machine-mounted screeds and should be completed prior to bleedwater appearing on the surface.

Floating is a two-stage process that leaves the concrete surface even and open in texture, ready for the final stage of finishing. Immediately after screeding a bullfloat is used to smooth and close any holes in the concrete surface, with hand floats used along edges. After the bleedwater has evaporated and the concrete has stiffened sufficiently, the surface is floated again either with machines or hand floats. The floating process (when specified as the final finish) is covered in detail in **Section 3.3.2**.

Trowelling is carried out some time after floating. The delay is to allow some stiffening to take place so that aggregate particles are not torn out of the surface. Generally, compaction of the surface by trowelling is required prior to the application of surface textures such as wood float and broomed finishes.

Further information on finishing can be found in *Guide to Concrete Construction*[20].

4.17 CURING

Curing is the retention of moisture within the concrete to allow cement hydration which occurs when water and cement are combined to form cement paste.

The most common methods are the use of curing compounds or plastic sheeting. Since the hydration of cement takes some time (days, and even weeks rather than hours) curing must be undertaken for a reasonable period of time if the concrete is to achieve its potential strength and durability. Curing will:

- improve compressive strength;
- reduce the incidence of drying shrinkage cracking;
- reduce surface dusting;
- improve durability and hence the protection of reinforcement;
- improve the hardness of the surface, and consequently its resistance to abrasion;
- improve the bonding of aggregates into the surface for exposed aggregate finishes.

The minimum curing period required for concrete by AS 3600 is 3 days unless curing is by accelerated methods such as steam curing. Depending on the environmental exposure (eg near the coast and/or exposed to salts), continuous curing for a minimum of 7 days may be required.

For decorative finishes such as exposed aggregate, a minimum of 7 days curing is recommended to ensure good surface strength, bonding of aggregates into the surface and durability. Fourteen days for polished concrete work is preferable, to minimise the potential for cracking and produce a hard surface that can be honed and polished.

Curing should begin as soon as possible but no more than 3 hours after finishing, or the benefits will be markedly reduced.

Without any curing regime the concrete surface strength achieved could be as much as 30% below its potential strength.

Decorative (and coloured) finishes must be cured carefully as colour variations will result if uniform moisture conditions are not maintained over of the surface. Some points to note include:

- Curing compounds are generally not used as they are designed to degrade over time and may interfere with the adhesion of the surface sealer which is typically applied to these finishes to prevent staining. If no sealer is proposed, curing compounds provide the best solution.

  For exposed-aggregate finishes, curing compounds can interfere with the acid washing process and this should either be delayed until the curing compound has degraded/worn off or carried out prior to the curing compound being applied. If the later is chosen, curing by plastic sheeting should be provided until the curing compound is applied. Note that any colour variations in the cement mortar caused by the uneven contact of the plastic sheeting are usually acceptable in exposed aggregate finishes as the aggregate colour is unaffected and generally dominates the finish.

  Curing compounds can not be used on stamped finishes having a release agent on the surface as this will prevent the curing compound from bonding to the concrete surface.
- Covering the surface with plastic sheeting is not generally recommended where a uniformly coloured surface is required, regardless of the finish. Uneven contact caused by wrinkles and folds can result in colour variations. If using plastic, the sheeting should either be lifted each day after placement and the surface saturated with water to reduce variations in moisture, or the sheeting should be suspended just above the surface (while ensuring that supports do not stain the surface).
- The use of a same-day sealer which is applied immediately after the surface has been finished may provide an acceptable solution. They are not as effective as curing compounds or other conventional curing methods but they generally provide a satisfactory solution for decorative and coloured concrete finishes and allow the application of the final sealer coat without adhesion problems.
- For stamped concrete finishes where surface release agents have been applied to prevent the moulds from adhering to the concrete surface, the application of same-day sealers is not an option. Powdered release agents are usually removed the next day, the surface is allowed to dry, and a sealer then applied. Note that some loss of strength at the surface will occur due to the lack of initial curing. With liquid release agents, a few days may be necessary to allow the solvents to evaporate prior to applying the sealer. The surface should be cured until the sealer is applied.

  With two-tone finishes, minor variations in colour resulting from the use of plastic sheeting are less noticeable and the surface could be cured for a minimum of three days (seven days is preferred) using plastic sheeting. Note that to prevent powder type release agents bonding to the concrete surface during the curing process, they should be removed as soon as the surface is sufficiently hard to avoid damage from the removal process, ie from high-pressure water blasting.

- The majority of decorative concrete product suppliers have a range of curing products and same-day sealers and/or final sealers that are specifically intended for these types of finishes and ensure compatibility between products. Advice from manufacturers/suppliers should be sought regarding available products, performance, compatibility between products and suitability for subsequent finishes.
- Duration and temperature of curing. To minimise colour variations, the duration of curing and curing temperature should be consistent. Higher temperatures generally produce a surface having a lighter appearance. The difference between summer and winter curing temperatures (for larger projects) may be sufficient to cause slight colour variations.

Further information on curing and its affect on concrete properties can be found in *Curing of Concrete*[30] and *Guide to Concrete Construction*[20].

4.18 SURFACE SEALERS

On decorative finishes, sealers are used to protect the surface from staining by contaminants such as oil because such staining is difficult to remove without the cleaning compounds or solvents affecting the colour. They can also facilitate cleaning of the surface and prevent microbial contamination (especially in food-preparation areas), reduce the occurrence of efflorescence and provide water resistance. They can also contribute to the finish/colour through highlighting colours or tinting, improve the durability of the concrete by protecting it from aggressive/corrosive substances and provide a wearing layer on the surface.

Sealers work by sealing the pores within the concrete near the surface that allow the movement of substances either into or out of the concrete. Thus materials that could potentially stain the concrete are either prevented from penetrating the surface, or find it more difficult to become entrapped within the pores/texture of the concrete surface layer. This also enables easier cleaning of the surface. Reducing or preventing the movement of water through the concrete surface also assists in controlling efflorescence (the deposition of lime/salts on the surface) and the growth of moss.

Further information on sealers can be found in *Sealers for Exposed Concrete Flatwork*[31].

4.19 JOINTS

Joints are typically used in flatwork to divide large areas into smaller more manageable sections, and to reduce the risk and minimise the impact of random long-term drying-shrinkage cracks by controlling the locations at which they occur. Joints fall into two broad categories:

- Those that allow movement (isolation and expansion joints).
- Those that control cracking of the concrete (control or contraction joints).

A further type, construction joints, are used when there is a break in the concrete placement for reasons such as plant breakdowns, to divide large areas (having no expansion or control joints) into smaller more manageable ones and to allow more efficient programming of work on large projects. They are rarely required in residential work because of the smaller slab sizes and/or distances between formed joints, but are often used in larger commercial/industrial floors.

For residential slab-on-ground footings, joints of any type are rarely needed and generally not recommended as the slab is typically designed as one structural element to resist movement from reactive soils. Reinforcement is added both for structural reasons and to control cracking, with provision for heavier reinforcement in areas where random cracking is unacceptable, or for longer slab lengths. The longer the slab (up to 30 m), the more reinforcement is required in order to control the tensile stresses caused by the drying shrinkage of the concrete. The standard designs in AS 2870 are intended to control shrinkage cracking so that the majority of slabs will have either no cracking or only very fine hairline cracks (<0.3 mm in width – see **Section 4.19.7**).

Joints are not appropriate in some slab types; indeed, providing joints in a house slab without expert advice can cause structural problems that may be expensive to fix. If joints are provided in house slabs, both the slab and other elements should be designed to allow movement at these locations.

4.19.1 Isolation joints

Isolation joints are used to separate the concrete slab from any abutting buildings, existing slabs, or rigid structures such as drainage pits, access holes and columns which may cause restraint of the slab and thereby increase the risk of cracking **Figure 155**. They should allow the slab to move vertically, horizontally and to rotate. While movement from concrete drying shrinkage will normally cause the joint to open with time, temperature changes may cause the joint to close.

Compressible, cellular materials are commonly used to fill these joints and they must be sealed to prevent dirt entering the joint and reducing its effectiveness. Silicone and polyurethane sealants are commonly used for isolation and expansion joints.

The filler materials should be installed before concrete placement to allow edges to be finished correctly and avoid damaging surface finishes.

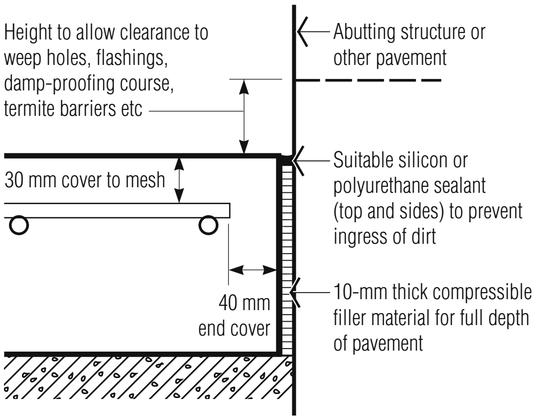


FIGURE 155

Typical isolation joint detail

4.19.2 Expansion joints

Expansion joints **Figure 156** are used in large areas of paving to allow concrete to expand without damaging adjacent sections of paving, mainly due to high temperatures in hot weather, but also changes in the moisture content. They should be provided at maximum 15-m centres. For narrow sections of paving such as footpaths the spacing is generally reduced to minimise joint peaking: a common problem if joints are not adequately constructed or maintained **Figure 156**.

Expansion joints typically have dowel bars connecting the slabs to provide load transfer across the joint and avoid changes in the levels from one slab to another (known as stepping). As a guide, for 100-mm-thick slabs intended for vehicles less than 3 t gross mass (eg typical cars) 12-mm-diameter dowels at maximum 400-mm centres would be satisfactory. For more heavily loaded pavements, research[32] suggesting that dowels transfer only between 15% and 30% of the load across a joint (because of the differential movement that occurs across joints) may provide some guidance for their design. There are many proprietary jointing systems **Figure 157** that allow easy installation and continuous concrete placement across these types of joints. Proper placement and alignment of dowels is critical to allow the joint to move and prevent cracking near the joint **Figures 158 and 159**.

As for isolation joints, expansion joints need to be sealed to prevent dirt entering and problems such as edge spalling **Figure 160**, slabs riding up and joint peaking, all of which are detrimental to performance and appearance. Preformed strips at the top of joints should not be relied on to provide an adequate seal as shrinkage can open up a gap which can then fill with dirt and cause problems **Figure 161**. Any gaps that do occur should be sealed.

Bitumen impregnated fibreboard fillers in joints are common but may not have sufficient compression and can detract from the appearance if squeezed out of the joint **Figure 162**. Self-expanding cork and high-density foam materials generally provide a better solution and are recommended.

4.19.3 Control joints

Control joints **Figure 163** typically form a weakened plane at which concrete will crack. Without them, drying shrinkage would result in random cracking. They should be provided at maximum 3-m centres, at any changes in shape (eg a narrow path attached to a driveway), at any changes in direction (eg around corners), and at any rigid structures that may prevent movement and increase the risk of cracking **Figure 164**.

Control joints can be made by:

- inserting a pre-moulded (plastic or metal) strip into the concrete as it is being placed;
- use of a grooving tool immediately after the concrete has been placed;
- sawing a groove when the concrete has hardened sufficiently to prevent ravelling;
- using a proprietary pressed-metal key joint.

Note that:

- Both isolation and expansion joints can be used as control joints.
- If joints are saw cut, this should be done before shrinkage cracking occurs **Figure 165**. Once cracking has occurred, saw cutting will generally not induce another crack at the saw cut location or prevent the initial drying shrinkage crack from widening with time. As a guide, saw cuts should be made not more than 12 hours after finishing of the slab if temperatures exceed 25°C, and not more than 16 to 18 hours after finishing of the slab for lower temperatures. The surface is hard enough for sawing when it does not chip, spall and collapse on the cutting blade (sometimes referred to as ravelling). To avoid delays, early-age saw cutting is possible with specialised equipment. The surface should be thoroughly cleaned after cutting to remove cement paste from the surface, especially for decorative work.

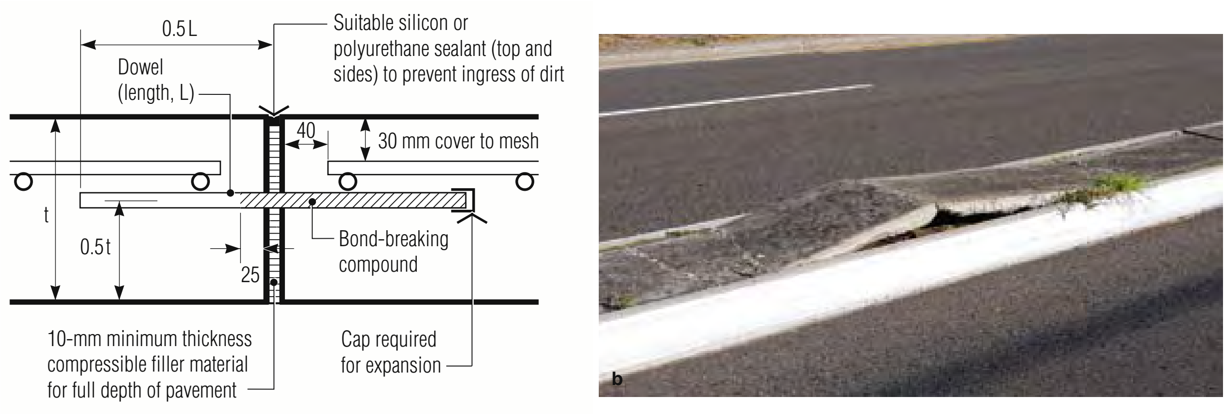


FIGURE 156

Typical expansion joint detail

[b] Joint peaking in narrow section of paving

FIGURE 157

Example of proprietary expansion joint to allow accurate dowel placement, continuity of concrete placement and minimisation of problems

FIGURE 158

Dowels bars must be positioned and aligned to prevent lockup of joint and cracking

FIGURE 159

Dowels should be accurately located, especially in thin pavements

FIGURE 160

All movement joints should be sealed to prevent ingress of debris causing spalling of edges

← BACK TO CONTENTS PAGE

FIGURE 161

Preformed cover strips along tops of joints provide a neat joint but do not guarantee the exclusion of dirt and edge spalling problems

FIGURE 162

Bitumen impregnated fibreboard fillers can detract from the appearance

FIGURE 164

Access pit creates a weak point by reducing width of pavement

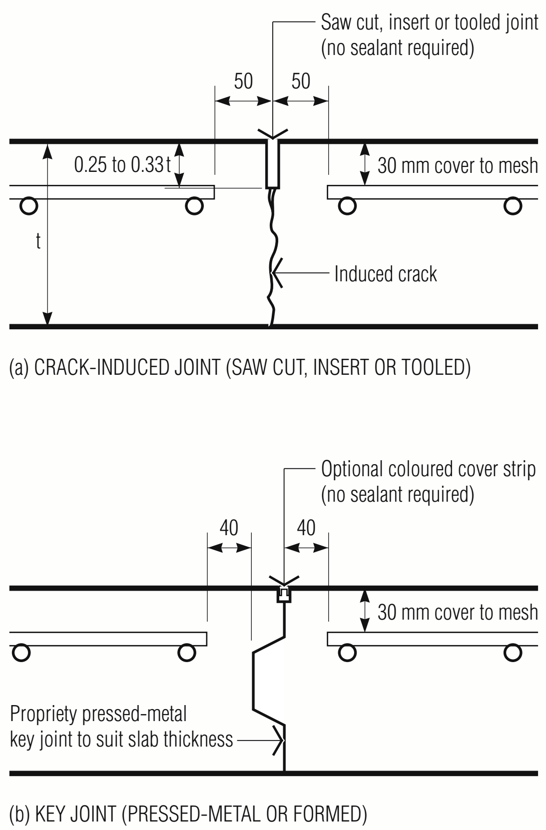


FIGURE 163

Typical control joint details

With water wash-off exposed aggregate finishes the aggregate particles are not bonded into the concrete for their full depth and at such an early age may tend to dislodge during cutting **Figure 166**. The use of other types of control joints such as crack inducers and pre-formed metal joints should be considered **Figure 167**.

- If joints are wet-formed by scoring the plastic concrete with an edging tool, care should be taken to ensure that the joint does not fill with cement slurry/mortar, making the joint less effective.

  For stamped finishes, wet-formed control joints can be tooled after stamping is completed, while the surface is still plastic, although this is difficult if the stamping makes deep impressions.

- If joints are formed with pressed-metal keys, the keys should be fixed in position to maintain straight lines. Note that key joints may interfere with stamping of deeper patterns. Also, pressed metal key joints (and other crack inducing strips) should be flush with the surface to avoid an irregular crack that allows sections to break off **Figure 168**.

- While reinforcing mesh will normally stop 50 mm from control joints, it may extend across the joint to provide better control of movement on, say, highly expansive clays. In this case, 50% of the mesh should be cut to assist in the formation of a plane of weakness at the joint location. To allow some tolerance in the location of the saw cut, crack inducer or tooled joint, the ends of the cut wires should be at least 50 mm clear of the proposed joint location. **Figure 169**.

- Joints can be incorporated into pavements with various materials that complement an exposed-aggregate finish **Figure 170**.

- Control joints do not need to be sealed, but often are to improve the appearance.

4.19.4 Construction joints

Construction joints **Figure 171** are concrete-to-concrete joints that prevent any relative movement across the joint. They are commonly used when there is discontinuous placement of concrete and successive placements are allowed to harden beyond the initial set; or at the end of the working day. They may also be necessary if unforseen circumstances (for example delays in delivery, pump breakdown or bad weather) interrupt a placement.

Most house slabs are placed and finished in the course of a day, obviating the need for construction joints.

4.19.5 Joints near trees

The presence of trees may cause considerable movement and cracking of adjacent concrete flatwork: either by causing ground movement in expansive soils, or more directly, by tree roots finding their way under the floor or pavement and lifting sections of the slab. Removal of trees can be just as damaging since the moisture content within expansive soils will generally increase causing them to swell and lift the slab. Further information can be found in BTF18[33].

If ground movement is likely, measures to prevent damage to floors and pavements, particularly stepping at joints in pavements needs to be considered. Expansion joints should be provided with dowels and if cracking at control joints could result in the loss of aggregate interlock at the joint, measures to control differential movement (stepping) of adjoining slabs should be considered. Some options to minimise stepping at joints include continuing reinforcement across the joint and the use of devices such as keyed joints that form an interlocking joint **Figure 172**.

← BACK TO CONTENTS PAGE

FIGURE 165
Saw cuts must be installed prior to the formation of drying shrinkage cracks

FIGURE 166
Aggregate particles in exposed aggregate finish dislodged during sawcutting

FIGURE 167
Crack inducer (zinc strip) used to avoid saw cutting exposed aggregate finish at an early age

FIGURE 168
Crack inducer or pressed metal joint not flush with surface resulting in random cracking and spalling at surface

FIGURE 169
Reinforcement fixed in position and mesh being cut at control joint locations – 200 mm length of wire removed to allow tolerance in joint location

FIGURE 170

Use of various materials to form/conceal joints

[a] timber, [b] and [c] tiles, [d] and [e] expansion joint at paved border

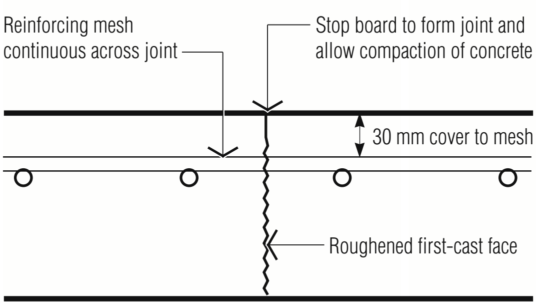


FIGURE 171

Typical construction joint detail

FIGURE 172

The use of mesh and proprietary jointing products will assist to minimise stepping at joints (note that mesh should be supported on bar chairs)

BACK TO CONTENTS PAGE

4.19.6 Slab proportions

Concrete slab sections bounded by joints should be as near to square as possible; the rule of thumb is that the length of the longer side should be no more than 1.5 times the length of the shorter side.

Acute angles should be avoided as these are difficult to reinforce and increase the risk of cracking and/or of the tapered section of concrete breaking off, even under light loads. With all joint types, the angle formed at edges and intersections of joints should not be too acute. A good detail in these situations is to keep at least 500 mm of the joint at more than 75° (and preferably at right angles) to the slab edge **Figure 173**.

4.19.7 Joint spacing

The main issues that should be addressed in determining an appropriate joint spacing for flatwork applications are the acceptability of random cracking (ie cracking at other than joint locations) in the surface and whether it is a plain (unreinforced) or reinforced concrete slab.

Most standards around the world nominate a maximum 0.3-mm wide crack as being acceptable based on durability and aesthetic considerations. The new Euro code[34] states that where the crack width has no influence on durability, a 0.4-mm crack width is visually acceptable. Narrower widths may be required for durability depending on the exposure environment. Note that cracks wider than 0.3–0.4 mm may be acceptable aesthetically depending on the type of finish, eg water-washed exposed aggregate finishes which tend to conceal cracks between the aggregate particles.

To minimise cracking in unreinforced slabs and pavements, a rule of thumb is that joints should be spaced at no more than 30 times the slab thickness and, as mentioned above, so as to divide the slab into panels in which that the longer dimension is no more than 1.5 times the shorter dimension. For example: 75-mm-thick paths should have transverse control joints spaced no more than 30 x 75 = 2250 mm apart. However, if the path is only 900 mm wide, the spacing of control joints is limited to 900 x 1.5 = 1350 mm to control the shape and minimise the risk of cracking. Even if the slab was 100-mm-thick, the 1350 mm length would still govern the joint spacing.

For reinforced pavements where the joint spacing is greater than 30 times the slab thickness, the reinforcement is designed to control the width of any cracks that may form, not prevent them from occurring. Work by Miltenberger and Attiogbe[35] to develop a rational basis for determining the appropriate concrete performance characteristics for a given control joint spacing in a slab on grade, concludes that 'reinforcement provides only a marginal increase in control joint spacing if cracking cannot be tolerated.' Thus joints must be spaced as though the pavement was unreinforced in order to minimise cracking. This is consistent with observations that cracks in reinforced pavements generally occur only 0.5 to 1 m further apart than the recommended limit for unreinforced pavements.

Therefore, to minimise cracking in a plain or reinforced 100-mm-thick concrete pavement, joints should be spaced 3 m apart and in a 150-mm-thick pavement, 4.5 m apart. As the formation of cracks is not only dependent on the joint spacing, but on many other variables such as concrete strength, subgrade condition and preparation, provision of subbase, expansiveness of the soil, joint detailing, compaction and curing, it is recommended that reinforcement also be provided. Increasing the required mesh given in **Table 2** by two sizes for decorative finishes will further assist to ensure that any cracks that may form will be tightly held together and not become visually unacceptable.

For applications such as carparks and cycleways having basic finishes and not subject to close scrutiny, cracks tend not to detract from the finish or function. In these situations a wider joint spacing (up to 6 m) can be specified with reinforcement used to control crack widths. Concerning wider cracks, ACI 224.3R-21[36] recommends aggregate interlock is effective only for cracks less than about 0.9 mm in width.

For residential slabs and footings, joints are generally not recommended and the reinforcement required by the standard designs in AS 2870 is intended to control cracking so that the majority of slabs will have cracking within category 0, ie less than 0.3 mm (Table C1 in AS 2870). Research[37] confirming this indicates that about one third of house slabs have no cracking, one third have cracks no more than 0.3 mm in width and the majority of others do not have cracks exceeding 0.6 mm in width. Note that the Victorian Building Commission's *Guide to Standards and Tolerances 2007*[9] states that only cracks (shrinkage, flexural or a combination) greater than 2 mm in width are to be considered as defects.

4.19.8 Joint layout

The layout of joints is very important and should, wherever possible, be planned. While this is done for larger commercial and industrial projects, it is often overlooked for smaller projects. However, it is just as important to the success and performance of the pavement. An example of a typical joint layout for a residential driveway is given in *Residential Concrete Driveways and Paths*[38].

For decorative concrete finishes, the joint layout should be coordinated with the pattern to conceal the required joints wherever possible **Figure 174**.

Joints should be continuous across the pavement. As joints are intended to allow movement or control the location at which cracking occurs, if they are not continuous any cracking that develops at the joint will tend to continue into adjoining sections even though they may be separated by another joint **Figure 175**.

4.19.9 Joint sealants

The function of the joint sealant is to prevent the ingress of dirt (or other incompressible material) which will restrict the movement available and may render the joint ineffective or cause spalling of the slab edges **Figures 160 and 161**. If joints are used for drainage and therefore remain unsealed, they must be kept clean **Figure 176**.

There are many different types of sealants on the market. For pavements, high-performance sealants such as polyurethane or silicone should be used. They can be purchased in cartridges for easy use with a caulking gun, come in a range of colours to suit various decorative finishes **Figure 177** and are UV light resistant.

The performance of the sealant depends on a number of factors; attention to the following will allow the performance of the sealant to be optimised and the life of the joint prolonged:

- → Joint width. The joint spacing, drying shrinkage of concrete and temperature movement (expansion and contraction) of the pavement will determine the movement to be accommodated at the joint. As different sealants have different capacities for expansion and contraction, the width of sealant in the joint (and hence joint width) must be sufficient to allow for the expected movement **Figure 178**.
- → Application. The performance of joint sealants is often affected by the timing of their application. Sealing of joints when the pavement is new and at the point of maximum expansion of the paving (eg mid afternoon in summer) means that the sealant must have sufficient extension capacity to accommodate both the total concrete drying shrinkage as well as the maximum temperature movement (ie from hot summer conditions to cold winter mornings). The timing must reflect the design assumptions but as a general guide sealant application should be delayed until the majority of drying shrinkage has occurred and should not be carried out in high temperatures. This enables the sealant's ability to both extend and compress to be utilised and the joint width to be minimised.
- → Joint preparation. The faces of the joint should be clean, dry and primed if necessary. Applying sealants to 'green' concrete can result in bubbling and loss of adhesion between the sealant and concrete **Figure 179**. The surface temperature should be above 5°C.
- → Backing systems. To behave correctly when the pavement moves, sealants should adhere only to the sides of the joint. With a cork or foam compressible filler in the joint this requirement is normally satisfied.
- → Joint geometry. For typical joints, the cross-sectional depth of the sealant should be at least one half of the width, and never greater than the width **Figure 180**. This enables the sealant to expand and contract as designed with movement of the floor or paving. Greater sealant depths reduce the material's capacity to either expand or contract.
- → Setting time. The setting time of the sealant determines when it can be brought into service, or the pavement used. Polyurethane sealants will cure at a rate of about 2–3 mm of depth per day in temperatures over 5°C. Fast-curing and two-part products will be marginally faster. Silicones skin quickly but have a slower cure-through-depth rate.

If cover strips are used, the joints may still need to be sealed to prevent dirt entering and making the joint ineffective **Figure 181**.

4.20 TOPPINGS

4.20.1 General

Toppings can be divided broadly into two categories: those placed during construction of the slab (monolithic toppings) and those placed over an existing concrete slab (bonded or unbonded). To limit the need for protection from other building activities, the latter are the more common type when the finishes covered by this guide are to be provided.

It is crucial to consider the locations of joints in a topping to avoid cracking. Joint locations largely depend on whether it is a bonded or unbonded topping. If bonded, joints are placed to correspond with existing joints in the slab. If unbonded, joints should also correspond to existing joints supplemented if necessary to comply with the recommendations for maximum joint spacing in new concrete slabs (ie 30 times the topping thickness) to reduce the risk of cracking. Practically, the area enclosed by joints should be limited to 15 m^2 to allow time to place and finish the concrete.

FIGURE 173

Joint perpendicular to slab edge

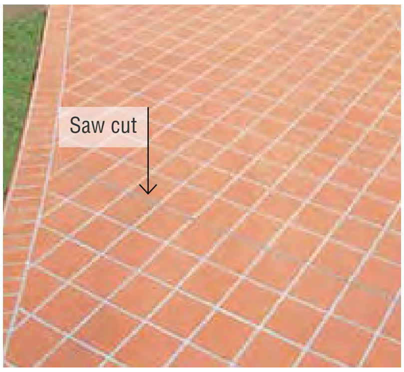


FIGURE 174

Control joints saw cut along pattern but leaving acute angles at edges

FIGURE 175

Joints should be continuous to avoid random cracking from the end of the joint or cracks initiating in adjoining section.

FIGURE 176

Open joints can be used for drainage but must be kept free of detritus

Sydney Opera House

FIGURE 177

Joints sealed to prevent ingress of dirt, sand and other non-compressible material (detritus) in colour to match the finish

FIGURE 178
Expansion capacity of sealant exceeded

FIGURE 179
Loss of adhesion due to inadequate preparation

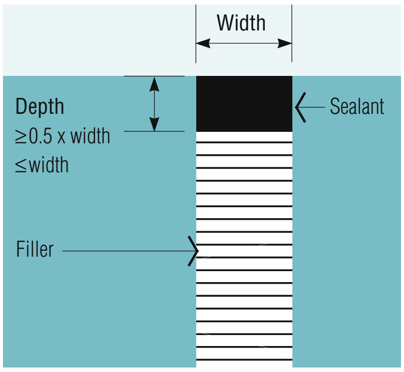


FIGURE 180
Joint geometry is critical to allow sealant to expand and contract within the manufacturer's limits

FIGURE 181
Bronze strip, sealed both sides to prevent dirt entry

FIGURE 182
Patterned 10-mm-thick topping designed to conceal cracking in substrate

FIGURE 183
Coloured mortar topping (about 5-mm-thick) applied as monolithic topping to structural suspended slab
St Mary's Cathedral, Sydney

The maximum aggregate size should not exceed one third of the topping thickness – one quarter is recommended, particularly where reinforcement is present.

For monolithic and bonded toppings, consideration should be given to increasing the reinforcing mesh in the slab by at least two sizes to control any cracking that may occur and possibly reflect through the topping. It may sometimes be possible to provide a pattern in the topping to conceal existing crack locations in the base slab **Figure 182**.

New concrete toppings may show fine surface cracks because of drying at the surface of the topping, and the bond of the topping to the existing base.

After curing, the topping can be used by foot traffic. However, heavier loads should be deferred for 28 days.

4.20.2 Toppings placed during construction (monolithic toppings)

Monolithic toppings are surface layers which are applied after the base or structural concrete slab has been placed, and while the concrete is still in its 'plastic' or workable state. This allows bonding of the two layers as they set and harden together, effectively producing a single or monolithic element.

Dry shake toppings are the most common type of monolithic topping used to provide a coloured surface (see **Section 2.3.3**). An alternative to casting dry powder over the surface is to apply a thin layer of mortar to the surface **Figure 183**, either be trowelled or sprayed on.

A surface layer of coloured concrete can also be placed as a monolithic topping. Because concrete surface layers/toppings have similar properties to the concrete below, there is no limit to the thickness of a concrete surface layer. Practically, the thickness is kept to a minimum to reduce pigment costs, with the minimum thickness usually governed by the maximum aggregate size used.

For exposed aggregate finishes where expensive aggregates are required, placing the mix as a topping will usually be more economical than using it for the whole slab. The procedure for placing such a 20- to 40-mm exposed-aggregate topping that allows a water-washed finish is as follows:

- Place the base slab and screed it to a level 20- to 40-mm below the finished level.
- Prepare a topping mix in the proportions (by volume) 1 part cement: 1.5 parts sand: 3 parts aggregate (and pigments if required) and just enough water for workability. Alternatively, order a special premixed concrete.
- Use a surface set retarder on large jobs (or in drying conditions) to allow more time to place and finish the topping.
- Wait until the surface bleedwater has evaporated from the base slab before placing the topping.
- Screed and float to ensure consolidation and complete bonding.
- Follow the steps for exposing the aggregate and curing in **Section 3.3.7**.

4.20.3 Toppings placed over existing concrete slabs

There are two types of toppings that can be placed over existing concrete slabs: bonded and unbonded. Bonded toppings are relatively thin layers of material that are bonded to, and rely on, the existing slab for their integrity, eg resistance to drying shrinkage and cracking. Unbonded toppings are separated from the existing slab, contain reinforcement and act as individual thin slabs.

Bonded toppings

Bonded toppings can be classified according to their thickness. Ultra-thin toppings up to a few millimetres in thickness (eg spray-on toppings) and thin toppings up to about 10 mm in thickness (eg trowel-on toppings) consist of mortar-type mixes, generally incorporating polymers and bonding agents. Pigments can also be added, or the surface chemically stained after hardening similar to any other cementitious material.

Thicker toppings in the range of 20 to 40 mm consist of concrete mixes containing coarse aggregates to better control drying shrinkage – the thickness being a function of the aggregate size used. Typical hand mixes range from 1:1:2 (heavy duty) to 1:2:4 (lightly trafficked) cement:sand:aggregate. These are mixed with a minimal quantity of water necessary for workability.

The usual maximum thickness for unreinforced bonded toppings is about 50 mm. Beyond this, the topping will behave more like a thin slab and achieving an adequate bond to the existing slab becomes even more important to guard against delamination due to factors such as shrinkage and curling.

Toppings are placed on a rough surface, which is clean and sound. Old concrete surfaces, which are dusting or spalling, should have all loose material removed until a sound surface is obtained. Smooth concrete should have the surface roughened to provide a key for the new topping. Water blasting or captive shot blasting is preferable to scabbling, because scabbling tends to produce a weak base layer. On a prepared surface the coarse aggregate should be visible. Note that any paint on the surface should also be removed as this could affect the bond.

The surface should be hosed and scrubbed with a stiff broom to remove all dust and foreign matter (eg grease, oil) before placing the new concrete. A suitable bonding compound should be used. These range from cement slurries, acrylic latex products, styrene-butadiene products to epoxy bonding agents. Common PVA- or water-based bonding products should not be used externally as they may break down over time with exposure to moisture.

Generally, reinforcement is not used when the topping thickness does not exceed 50 mm. However, depending on the thickness, SL42 mesh can be positioned 20 mm from the top of the slab (supported on bar chairs) to help control shrinkage cracking. Polypropylene or steel fibre reinforcement may also be used.

Levelling compounds are a form of bonded topping typically less than 10 mm in thickness. They are mixed with water and screeded onto the concrete surface. They can be applied in thicknesses as little as 1 mm. Some self-levelling products require little finishing. It is essential to follow the manufacturer's recommendations about the product's application.

All joints in the original slab should be duplicated in the topping slab to maintain movement control.

The topping should be cured for a minimum of 3 days, preferably 7 days.

Unbonded toppings

If toppings greater than 50 mm in thickness are required, then a separate unbonded reinforced topping should be considered. In reality, unbonded toppings are essentially thin new slabs but referred to as toppings because they are placed over existing concrete.

While these toppings are typically used for waterproofing applications by allowing the installation of a polythene sheet or other waterproof membrane, they also provide a useful means of topping existing timber or concrete floors. The greater thickness allows the use of up to 14-mm aggregate.

A plastic membrane is typically used as a bond-breaker to separate or 'unbond' the new topping from the old or existing concrete. To allow cover to the reinforcement and minimise curling problems a thickness of about 70 to 75 mm is recommended. Toppings that exceed 75 mm in thickness should be regarded as new concrete slabs and designed and reinforced accordingly.

Because unbonded toppings do not rely on the substrate to control shrinkage and hence cracking, a layer of reinforcing mesh (typically SL62) should be provided for crack control. Note that durability requirements may govern the concrete strength (minimum N32 with a 100-mm slump recommended) and minimum topping thickness. The topping should be cured for a minimum of 3 days, preferably 7 days.

Joints should be provided as recommended in **Section 4.19**.

4.21 DRYING OF CONCRETE SLABS

An important but often overlooked aspect of flatwork construction where moisture-sensitive sealers and coatings are to be applied to the concrete surface, is allowing the concrete to dry sufficiently prior to their application. Adequate drying may take months not weeks, and the construction schedule must allow for this.

Depending on the type of sealer or coating and its permeability, the timing of the application may be critical to its performance. This is because the moisture level within the concrete may affect the initial bond to the concrete and result in blistering either initially or over the longer term.

Further information on moisture within concrete slabs including sources, the drying process and time required, reducing drying times, various test methods and the effects of moisture on various floor finishes and coatings can be found in *Moisture in Concrete*[39].

4.22 TOLERANCES

A common misconception is that specifying the flatwork to be in accordance with AS 3610 and AS 3600 guarantees that reasonable tolerances will be achieved for the surface of the slab. However, since neither of these standards covers the quality of unformed surfaces, if surface levels and flatness are important, tolerances for these must be specified in the project documentation.

Flatwork can not be constructed perfectly flat or level. Neither can the formwork used for edges and steps be located exactly in the required position or at the exact level required. The tolerances specified define the acceptable variations from the specified values or performance levels. They are provided to ensure that the finished concrete surface is suitable for the application and/or intended function while acknowledging that some degree of variation is inherent in all building work. Tolerances must be specific for the application and be reasonable, ie both achievable and able to be checked in the field using the available techniques and at an acceptable cost.

← BACK TO CONTENTS PAGE

The method of specifying and assessing tolerances for a concrete surface will depend on whether it is a formed or unformed surface.

Formed surfaces are those which use formwork to provide shape and texture/finish to the concrete. For flatwork, formed surfaces are typically vertical edges required to retain the plastic concrete. Examples include slab edges, joints, setdowns, upstands, steps between levels and openings/penetrations for services, stairs, lifts, etc.

The required quality of a formed surface can be easily specified by nominating one of five classes of formwork finish detailed in AS 3610. For each class tolerances are given for a range of physical and aesthetic surface finish properties. The appropriate class depends on the application. For exposed edges a Class 3 surface finish would generally be specified, with the higher Class 2 specified only for more aesthetically demanding situations. Class 1 finishes (the highest quality) are typically never specified in relation to flatwork construction because of the difficulty in achieving them with this form of construction. If the edge is concealed (eg by soil or finishes) a Class 4 surface finish may suffice. Class 5 should not be specified for slab edges as AS 3610 contains no minimum requirements for the quality of the surface. Further information on the various classes of surface finish, the applications for which each apply, required tolerances and checking the off-form concrete surface finish for compliance can be found in AS 3610.

Unformed surfaces are those that do not require formwork to provide either shape or finish to the surface, eg the top surface of slabs or pavements. The two properties that should be specified are the flatness and levelness of the surface.

The flatness is the deviation of the surface from a straight line joining two points on the surface. It is commonly measured using a 3-m straightedge which can be placed anywhere on the slab in any direction. The deviation is the maximum gap between the straightedge and the concrete surface **Figure 184**. For larger areas specialist measuring equipment such as F-Meters **Figure 185** can be used to reduce the time and cost of compliance checking.

Levelness (elevation tolerance) is the permitted vertical variation of the surface from a fixed external reference point or datum. It is normally checked with an optical 'level', but equipment such as F-Meters can also be used for larger areas.

Note that the tolerances within AS 3600 are to ensure only structural performance and will not ensure the quality or appearance of the concrete surface.

Compliance with flatness and levelness tolerances should be checked within 72 hours and prior to activities such as stressing, formwork stripping and application of surface finishes such as abrasive blasting that may affect the levels and/or flatness achieved.

A performance approach, where the class of surface finish for formed surfaces and actual acceptable variations for flatness and levelness are stated should be adopted for the specification of tolerances. How these are achieved is a matter for the contractor. However, the more stringent the tolerances specified, the more critical will be good communication between all parties so that suitable construction methods and procedures can be adopted to achieve the outcome required.

Realistic tolerances for the majority of flatwork are:

- Formed surfaces. Class 3 finish in accordance with AS 3610.
- Flatness. Maximum deviation from a 3-m straight-edge placed anywhere on the surface: 12 mm.
- Levelness. Surface level to be within ±10 mm of the specified level.

More-stringent tolerances may be required for some applications such as polished concrete floors where the reflection from the surface may highlight undulations in the finish, and warehouse slabs for high-bay storage where flatter finishes may be required for efficient operation of special fork lift trucks.

Note that more stringent tolerances may be recom-mended within some industry guides. In the *Guide to Standards and Tolerances*[9] the following guidance is given: '***Except where documented otherwise***, new floors are defective if within the first 24 months they differ in level by more than 10 mm in any room or area, or more than 4 mm in any 2-m length. The overall deviation of floor level to entire building footprint shall not exceed 20 mm.' Further, that; 'Finished Floor Levels (FFL) or Reduced Levels (RL) are defective where they depart from the documented RL or FFL by more than 40 mm.' This highlights the need to specify what tolerances are acceptable within the project documents, and if not documented, ensuring that those responsible for achieving the finish are aware of the assessment criteria.

Further information on tolerances including recommendations for reasonable tolerance limits, measurement, specification, achievement and rectification can be found in *Tolerances for Concrete Surfaces*[40].

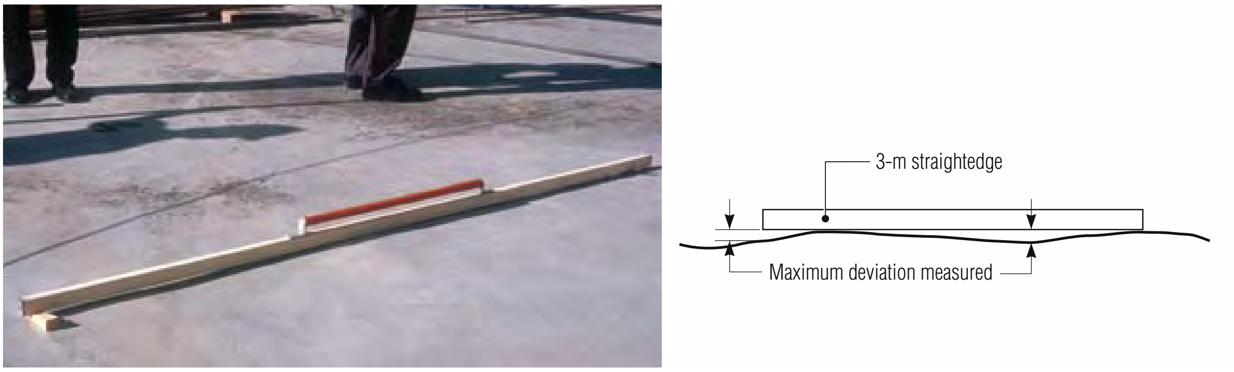


FIGURE 184

Testing of surface for compliance using a straightedge

FIGURE 185

F-Meter in use to check levelness

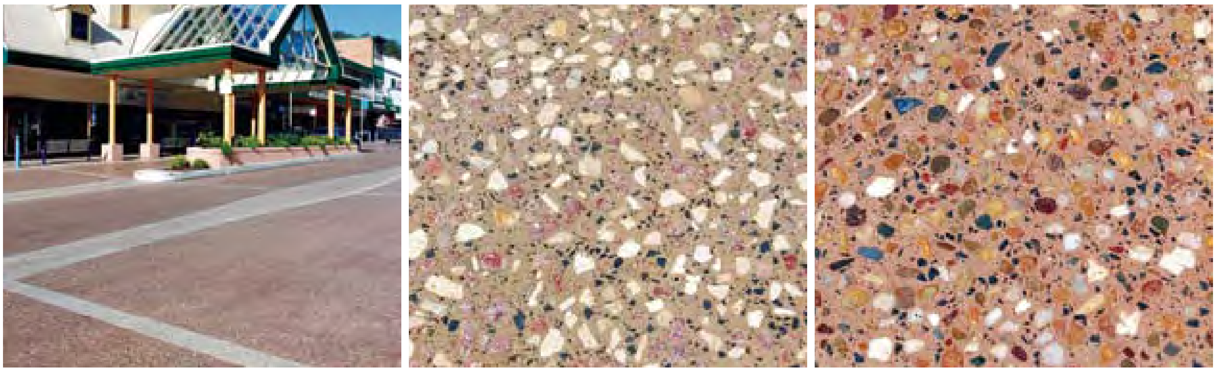


FIGURE 186

Honed and sealed concrete road pavement provides sufficient micro-texture for adequate skid resistance at low speeds

← BACK TO CONTENTS PAGE

FIGURE 187

Stencilled finish with fine aggregate trowelled into surface for skid and slip resistance

FIGURE 188

Stamped finish provided with sufficient surface texture to prevent skidding and slipping on steep driveway

FIGURE 189

Honed concrete at 300 grit with penetrating type sealer applied.
Mean BPN achieved of 52 complied with Class W finish (required BPN of 45–54)

4.23 SKID AND SLIP RESISTANCE

4.23.1 General

Concrete flatwork is generally constructed for vehicle and/or pedestrian use and must provide a surface that is safe for the intended application. For vehicles, the surface must have sufficient skid resistance to allow safe movement and access over often quite steep driveways. For pedestrians, the concrete surface must provide adequate slip resistance to reduce the risk of slipping to an acceptable level – particularly in wet conditions. For the types of pavement covered in this guide, slip resistance will typically be the more important consideration.

4.23.2 Skid resistance

Skid resistance relates to vehicles and is usually described as the ability of a surface to provide friction to a reference tyre or slider (usually measured wet) and is dependent upon the pavement's macro- and micro-texture.

Micro-texture has greater influence on friction at the low speeds encountered in residential streets and driveways and is typically provided by the fine surface texture, ie the sand in the mortar content of the concrete **Figure 186**.

To provide guidance on achieving the required skid resistance, research carried out by the Cement and Concrete Association of Australia on various decorative concrete pavements typically used for street and driveway applications suggests the following:

- Stippled, broom, wood float and exposed aggregate finishes provided sufficient skid resistance. Note that for driveways steeper than 1 in 20 and up to the maximum 1 in 4 allowed in AS/NZS 2890[13] the required BPN should be calculated and compared to the results in the report in order to select an appropriate surface finish.
- Caution should be exercised in using generic products or descriptions such as stamped or stencilled finishes since their heterogeneous nature could lead to wide variations in skid resistance properties.
- Stamped slate and cobblestone finishes with a 'smooth' surface did not provide adequate skid resistance. When using these types of finishes it is necessary to add more texture or greater roughness to the surface in order to provide the required skid resistance. Note that techniques are available with both stamped and stencilled finishes to improve the surface texture or roughness **Figures 187 and 188**.

For further information on the factors affecting skid resistance, measurement and details of the research work by the CCAA refer to *Skid Resistance of Decorative Concrete Paving*[41].

4.23.3 Slip resistance

Most pavements will require both adequate skid and slip resistance. Slip resistance of floors and pavements is a measure of the ability of the surface to resist accidental slipping by pedestrians – in dry or wet conditions. While many factors such as lighting conditions, fatigue, age and impaired vision may contribute to the risk of slipping and must be considered, the following information relates only to the specification and construction of the concrete flatwork surface.

It is important to consider the slip resistance offered by the combination of finish, texture and sealer (if present). To provide some guidance on achieving satisfactory slip resistance, numerous case studies have been investigated (refer to *Slip Resistance of Polished Concrete Surfaces*[42]) to determine what effect variations in the surface finish, texture and sealer have on the slip resistance. Major findings include:

- Rougher textures generally provide higher slip resistance results.
- Honed finishes up to a 300 grit generally comply with a Class W finish in accordance with the wet pendulum test provided a penetrating type sealer is used **Figure 189**.
- Sealers that fill the surface texture/roughness and form a film on the surface generally give unsatisfactory results if the surface is wet. The use of a slip resistant additive in the sealer is recommended if the surface can become contaminated.
- Stamped and broom finishes give similar slip resistance results as only the micro-roughness of the surface contributes to slip resistance.
- Abrasive blast finishes can provide variable results due to uneven removal of surface mortar.
- Broom finishes provide greater slip resistance across the grain than along it. This type of finish should therefore be provided normal to the direction of movement if possible.
- The more textured stippled, broom, wood float and exposed aggregate finishes all satisfied a Class W slip resistance. When using stamped and stencilled finishes, sufficient surface texture must be provided to ensure adequate slip resistance is achieved **Figures 187 and 188**.
- Use of colour pigments in the concrete does not affect the slip resistance.

BACK TO CONTENTS PAGE

- Caution should be exercised with ramps and steep driveways as the slope may preclude the use of particular types of finishes which may have low slip resistance when wet.

Further information on the factors affecting slip resistance, specification, measurement, achievement, maintenance and improvement of slip resistance can be found in *Slip Resistance of Polished Concrete Surfaces*[42].

4.24 CURLING

Curling occurs to some extent in the majority of concrete flatwork and may cause problems if the movement is excessive. An awareness of why curling occurs, the factors influencing the extent of curling and hence what steps can be taken to minimise curling when constructing concrete flatwork can assist to ensure the adequate performance of the pavement.

The upward or downward movement of a slab's corners or edges due to moisture and/or temperature gradients between the top and bottom surfaces of a concrete slab is known as 'curling' or 'warping' **Figure 190**. The slab edges curl upwards when the top surface is either drier (shrinks more) or cooler (contracts more) than the bottom of the slab, and the curling moment induced by the differential moisture or temperature gradient is greater than can be resisted by the weight of the slab plus any applied loads **Figure 191**.

Generally occurring some time after placement, the extent of movement is usually minimal (up to only a few millimeters) and within the surface tolerance allowed for most slabs. In severe cases it can be as much as 20–25 mm and slab edges and corners may lift off the ground and stepping between adjacent slab panels may occur. The areas typically affected are those within 600 to1500 mm of the free edges of the slab.

Factors that can influence the extent of curling include:

- Slab thickness. Curling is reduced as the slab thickness increases. Minimum 100 mm thickness is recommended.
- Concrete drying shrinkage. Avoid adding excess water on site which will increase the drying shrinkage and tendency to curl.
- Wet subbase/subgrade. Moist environments not only prevent drying, but may cause slight expansion of the concrete thus increasing the moisture gradient and curling moment/deflection.
- Reinforcement. Locate reinforcement in the top third of the slab to assist in controlling curling moments.
- Plastic membrane. This will prevent drying from the base of the slab and therefore increase the moisture gradient. Rapid drying of the surface should be avoided by commencing curing as early as practicable and application of surface coating or sealer should be considered to maintain more-uniform moisture conditions within the slab.

For critical applications such as very flat warehouse floors, factors causing curling should be addressed to ensure compliance with specified tolerances.

In assessing the need to rectify curled slabs, it is important to realise that if moisture and temperature gradients stabilise over time the extent of curling will reduce, especially as creep of the concrete also occurs with time. Thus, if time permits, reassessing the situation in say six to twelve months may avoid the need for repairs and possible disruption to operations. Repairs should be considered only if the curling affects the performance of the slab in some way.

More information on curling, the factors influencing its magnitude, assessing the need for rectification, repair methods and recommendations to minimise curling can be found in *Curling of Concrete Slabs*[43].

4.25 PROTECTION OF SURFACES

4.25.1 General

Flatwork is often constructed in exterior environments as part of larger projects and as such is often exposed to the prevailing weather conditions both during and after construction. Also, depending on the construction programme, completed flatwork may be used to provide access to the site and for continuing construction activities. The need for early use or loading of completed work can have an adverse impact on both its appearance at the end of the project and its long-term performance. To ensure that concrete flatwork elements perform satisfactorily and have a good appearance at the completion of construction works, protection from a variety of different sources that may result in damage may be necessary. The three main areas are:

- Weather conditions
- Construction activities
- Early loading.

FIGURE 190

Curled slab edge of industrial pavement

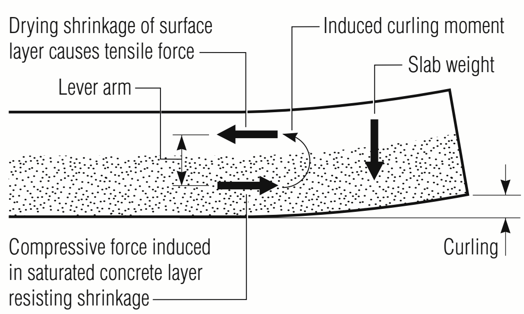


FIGURE 191

Curling of slabs due to differential drying shrinkage

FIGURE 192

Protection of polished concrete floor using felt and plywood sheeting

FIGURE 193

Cracking and spalling at anchorages of post-tensioned warehouse slab due to premature stressing of the slab tendons

4.25.2 Weather conditions

The main factors affecting flatwork are rain, high and low temperatures and wind.

Heavy rain during concrete placement may increase the water-cement ratio resulting in problems such as lower strengths, higher permeability, long-term drying shrinkage and dusting surfaces. During or immediately following finishing, rain may also affect the surface finish in a number of ways from causing a stippled texture on the surface from the impact of large rain drops to washing away of the finish and/or colour by runoff over the surface.

If rain is likely, the placement of concrete should be delayed. However concrete placement and finishing usually occurs over many hours and weather conditions can often change rapidly. The simplest way to protect the concrete is to cover it (generally with plastic) and divert runoff away from the area. Depending on the surface finish, the covering may need to be suspended above the surface to prevent damage or discolouration of the surface (see **Section 4.17**). Re-trowelling the surface after light rain is usually sufficient to correct any minor damage that may have occurred. Note that if the surface appears wet (similar to bleeding) the water should be removed and not trowelled into the concrete surface, possibly causing abrasion, dusting and shrinkage problems.

Rainwater will often need to be removed from the surface to allow continuation of finishing, as the extra drying time may be too long to allow the proper finishing of the already setting concrete. Typically a lightweight flexible hose dragged over the surface or a squeegee will remove the majority of the water. The practice of hand-casting dry cement over the surface to soak up the excess water should be avoided. This leads to a surface layer that is substantially different from the underlying concrete and as a result may cause problems such as flaking and dusting surfaces.

If unforeseeable weather conditions occur after completion of work and the surface is either not protected or re-trowelled and as a result becomes rain damaged, then rectification of the hardened surface will be required.

Information on protecting concrete in hot and cold weather conditions can be found in *Hot-weather Concreting*[26] and *Cold-weather Concreting*[27] respectively.

4.25.3 Construction activities

As noted earlier, providing the specified finish to a topping (placed late in the construction programme) rather than to the slab itself minimises protection requirements. Even then, some protection may be necessary to ensure that a suitable base is provided for the topping.

If flatwork finishes are installed prior to completion of other work, the surface should be protected from damage and/or staining during subsequent construction. Particularly with vehicles during wet weather, staining from mud and clay tracked onto completed slabs may be difficult to avoid. In this instance limiting access during wet weather or providing suitable ground cover such as a gravel layer to prevent pick up of clay and dirt may be options.

With decorative finishes such as polished concrete, protection from any subsequent construction activities is particularly important. The degree of protection will vary depending on the scale of building work to be completed over the floor or pavement and the likelihood of damage occurring. Methods may include covering with a soft material such as felt carpet underlay or old carpet, rigid materials such as plywood or a combination of methods **Figure 192**.

The possibility that staining may occur from the materials used to protect the surface must also be considered. A layer of plastic can be provided directly over the concrete surface to prevent staining from wet plywood (which should be softwood based) or other materials. Note that if the plastic is not fully in contact with the surface, this may itself cause staining by providing non-uniform curing conditions for the concrete (see **Section 4.17**).

Consideration should be given to constructing flatwork at a stage where the risk of damage is minimised. The trend towards the use of thin toppings applied at the end of construction addresses issues such as the added expense of providing protection during construction (and which may not completely eliminate damage) and the possibility that the protection method used may interfere with the construction activities.

4.25.4 Early loading

Early loading may also result in damage to the concrete surface. As a general rule, the concrete should not be subjected to its design load until it has reached its design strength. Lesser loads may often be applied to the concrete after the minimum curing period but care should be taken not to damage the concrete surface, finish or cause cracking by actions such as transporting heavy plant and materials over the surface, or continued construction activities. Some examples of early loading include stacking and erection of framing/formwork materials, stacking of pallets of bricks, blocks and other heavy materials on slabs, traversing over newly placed slabs with equipment such as backhoes, cranes and heavy trucks.

Early loading may also include actions such as stripping of formwork and backpropping of suspended slabs. Deflection under the dead load of the slab plus any stacked materials may result in increased deformations and possible cracking, especially when factors such as the greater creep deflection of lower strength concrete are taken into account. AS 3610 provides guidance on allowable stripping times for suspended concrete slabs.

Pavements often incorporate joints having dowels and keys. If these are subjected to excessive loads before the design strength of the concrete has been reached, cracking and damage to the thinner slab sections above such elements could occur.

Applications incorporating post-tensioning must also be monitored carefully as premature stressing may cause cracking around anchorages **Figure 193**.

Each specific situation should be discussed with the design engineer to assess the impact of such actions on the performance of the concrete, both in the short and long term.

5 Assessment of finishes

Flatwork finishes can be assessed objectively only if the project documentation makes it clear what is expected. Documentation should include 'Assessment and Rejection Criteria' outlining what properties will be checked for compliance, the method of assessment and the allowable variation from what has been specified. This is usually achieved by nominating specific items (type of finish, colour, etc) directly, and the general matters (tolerances, etc) by reference to other documents (eg Standards). As noted in **Section 4.1**, if assessment and rejection criteria are not specified, other (and possibly more-stringent) requirements may govern.

Approved test panels, reference projects and sometimes samples with a documented and/or agreed level of variation can provide the basis for approval of subsequent work. The construction and approval of test panels is also usually specified – and is highly recommended. If using a reference project, the effects of age (particularly on colour) should be recognised.

When assessing finishes, consideration should be given to how concrete finishes may change with time (especially for larger projects) and their sensitivity to variations in placing, finishing and curing. All final work should be placed, finished and cured in exactly the same manner as the test panel if a realistic comparison is to be made. Also, the timing of assessment is critical. If new work is being compared to a test panel made several months earlier, continuing cement reactions, exposure and moisture may influence the appearance. This is particularly relevant for coloured finishes where many variables can influence the final colour.

Once a mutual understanding of what is expected has been established, the assessment of what has been provided is relatively straightforward. On a typical project, the following aspects of surface quality may need to be assessed and any need for rectification of physical defects established.

- Off-form finishes. Typically checked for compliance with the requirements in AS 3610 for the specific class of formwork specified. Aspects of the finish which may require assessment include blowholes, form-face deflection, face steps, surface undulations, flatness and out of plumb, along with any of the items from Table 3.4.1 (in AS 3610) that have been included in the project documentation.
- Honeycombing, grout loss and misalignment. As these items are related to the appearance of formed surfaces, AS 3610 requires that for Class 1, 2 and 3 finishes such defects be repaired in accordance with the requirements of Clause 5.6.5 (in AS 3610).
- Surface tolerances. Both the flatness and levelness of unformed surfaces should comply with the requirements specified in the project documentation (recommended) or, if not specified, any State or Local Authority requirements that may apply. Most flatwork can be assessed using a 3-m straightedge for flatness and an optical level for comparison with a fixed datum for levelness. While larger areas such as warehouse floors can also be checked in the same way, the use of an F-Meter to check both flatness and levelness is recommended to reduce the time and cost involved. It will also enable a better assessment to be made of the more-stringent tolerances often specified for these types of applications. For roads and larger paved areas not having smooth surfaces, the use of specialist equipment such as a 'walking profiler' can considerably reduce the work involved in compliance checking.

  Tolerances should be checked within the first 72 hours and prior to any subsequent surface treatments such as abrasive blasting and activities such as formwork stripping and post-tensioning that may affect the flatness and levelness. If using an F-Meter for compliance checking of large areas or long slabs, it should be carried out prior to saw cutting joints.
- Grades and crossfalls. The maximum and minimum grades of surfaces such as ramps, driveways and parking areas should be checked for compliance with the requirements of the Building Code of Australia, relevant Standards and project documentation in order to provide safe and, where required, disabled access. Any drainage requirements should also be checked.

  Where slip and skid resistance requirements have been specified, the grade of the pavement should not exceed the value used to establish the appropriate slip resistance class.

Crossfalls (perpendicular to the direction of the grade) should comply with the maximum values allowed, eg AS 2890.1 requires the maximum crossfall in parking areas to be 1 in 16 (6.25%).

- Stepping. A reasonable maximum limit for the vertical step between adjacent concrete slabs to minimise the risk of tripping is 5 mm.
- Ponding. Compliance with minimum gradients and maximum tolerances should ensure that an unacceptable depth of ponding does not occur on exterior surfaces. Generally, ponding deeper than 10 mm should not occur more than 15 minutes after cessation of rainfall.
- Crazing. Crazing describes the very fine cracks which appear on the surface of concrete after it has been exposed to the atmosphere for some time. Crazing occurs in the top few millimetres of the concrete element and as such generally does not constitute a structural problem. It is usually acceptable.
- Cracks caused by formwork movement. If there is movement of the formwork, whether deliberate or unintentional, after the concrete has started to stiffen but before it has gained enough strength to support its own weight, cracks may form. Such cracks have no set pattern. Their acceptability or otherwise will depend on their location and extent.
- Cracking. Cracks may vary from those causing aesthetic problems to those that require repair. Cracks may be caused by a large number of factors but fall into two basic categories: prehardening cracks (plastic shrinkage, plastic settlement, formwork movement) and cracks in hardened concrete (drying shrinkage, flexural).

  Prehardening cracks are usually related to quality issues and poor workmanship at the time of placement, and will generally occur either during finishing, or within eight hours of placement. The new pavement should therefore be inspected for cracks the morning after placement to identify if any prehardening cracks have occurred, and the concreter's advice sought regarding any remedial work that may be necessary.

  Any cracks that occur in the hardened concrete (typically from drying shrinkage and temperature variations) usually become evident some time (perhaps three or more days) after placement. It is important to determine whether they have been caused by quality issues and poor workmanship (ie joints not installed properly or at the required locations), in which case they may need to be repaired, or they are part of the design, eg flexural cracks.

  The following guidance may assist in assessing the acceptability of cracking.

  - For residential pavements the maximum crack width should not exceed 1.5 mm.
  - The majority of standards and publications recommend that a 0.3- to 0.4-mm-wide crack is visually acceptable.
  - To provide durability in severe exposure environments, acceptable crack widths may need to be less than 0.3 mm: the extent depending on the exposure.
  - For unreinforced pavements, aggregate interlock across the joint is lost when the crack widths are greater than about 0.9 mm.
  - A maximum crack width of 2 mm (from all causes) is allowed in residential slabs and footings. Note that due to the large variability of soil conditions across Australia, the standard designs provided in AS 2870 are based on the principle that most slabs will exhibit either no cracking or only hairline cracking less than 0.3 mm in width (ie visually acceptable cracking), some slabs will have cracking up to 1 mm in width, but only a few slabs will have cracking approaching the maximum allowed.

  Based not only on the crack width, but also its depth and location, plus exposure and application of the concrete element, an assessment should be made of the load-carrying capacity of the member, ability to perform its designed function and effects on other finishes.
- Surface finish. The surface finish will generally be assessed based on a test panel constructed on site, a test area of the actual pavement that has been approved, other project or perhaps a test panel within a supplier's yard (eg decorative stamped/stencilled finish). Items to be assessed may include:
  - **Colour.** Ensure colour is correct and uniform (if required). For stencilled finishes, grout lines should be uncontaminated by coloured surface hardener.
  - **Pattern.** Ensure correct pattern used and pattern lines are straight. Adjacent sections of work should have the pattern aligned.
  - **Texture.** Ensure correct texture and depth and that it is uniform over the surface. For stamped finishes check that the pattern is continuous. Exposed aggregate finishes should have uniform aggregate exposure and therefore texture.

- Trowelled finish. Check if the surface contains trowelling marks and assess whether these are acceptable. Burnished finishes should display a surface lustre and be free of any trowel marks.
- Honed finishes. Aggregate exposure should be uniform and surface flatness maintained during grinding. Unless required as a feature, any blowholes should have been filled.
- Joints. These should have been positioned to line up with the pattern and, wherever possible, not cut across it. Correct detailing should be checked prior to concrete placement. Check correct joint sealant and installation.
- Sealer. Check for correct sealer and adequate preparation and application.

→ Dusting and wearing surfaces. If the surface exhibits rapid wear or dusting, either the concrete strength is inadequate for the application or quality issues during construction have resulted in a weak and/or powdery surface layer. If the cause is not obvious, the concrete strength can be checked. Generally, weak surfaces are unacceptable as they affect both the appearance and performance of the surface and should be rectified.

→ Flaking and blistering. A sound concrete surface should not contain any areas where a thin layer (small or large) has delaminated and 'flaked' off the surface.

→ Slip/skid resistance. The surface should provide the required slip and skid resistance. This is typically measured on site using the wet pendulum test.

→ Curling. Areas within 600 to 1500 mm from free edges should be checked for curling. In assessing the need to rectify curled slabs, it is important to realise that if moisture and temperature gradients stabilise over time, the extent of curling will reduce, especially as creep of the concrete also occurs with time. Thus if time permits, reassessing the situation in say six to twelve months may avoid the need for repairs and possible disruption to operations.

Suprenant and Malisch[44] report that for industrial slabs subject to forklift loads, movements less than 0.25 mm indicates acceptable joint performance and tolerable curling. Movements between 0.43 and 0.76 mm (or greater) are severe enough to cause deterioration three to four times faster than normal, while between these limits (0.25 to 0.43), the slab is in a grey area, where repairs may improve the floor's performance but not be cost-effective. Areas not subject to forklift traffic or other heavy loads may be acceptable as they can usually be easily corrected by providing a topping.

→ Contamination, staining or discolouration of the surface. Any foreign material such as dirt and grime or other discolouration of the concrete (eg pinto concrete) that affects the finished appearance of the surface may need to be removed or treated.

If colour control has been specified, formed surfaces can be assessed against the provisions in AS 3610; unformed surfaces will generally be assessed by comparison to some form of test panel. Cutting a small section (say 600 x 600 mm) from an approved test panel (if available) for transport around the site may assist with the comparison with the actual work. In the test panel shown in **Figure 131**, the preferred 'target' areas have been identified and cut out to facilitate portability. Note that smaller sections of the test panel should be carefully looked after in the same way as the actual test panel to ensure that a reasonable assessment can be made.

For 'grey' concrete finishes, once the acceptable 'colour' has been established from the test panel, a tonal range should be agreed. The chart in AS 3610 for formed surfaces may also be used for unformed surfaces provided the project documentation specifies an appropriate tonal range; a range of 5 or 6 tones would be reasonable for flatwork. Note that the approved colour of a test panel does not automatically become the middle tone in a range and it could in fact end up being either the lightest or darkest tone produced.

For coloured concrete finishes, defining an acceptable tonal range in the documentation is difficult. This is because each colour will have variations and the impact of those variations will differ depending on the colour. Generally, only the colour and/or type of aggregate can be specified in the documentation. The acceptability can be realistically checked only by comparison with approved test panels.

When assessing colour, all surfaces should be clean and the assessment should be carried out at an appropriate time. Note that colours generally lighten following curing, and may be affected (lightened) by the presence of efflorescence on the surface, particularly with dark colours.

Colour variations and their possible causes are listed in **Table A2** of Appendix A.

6 Repairs

6.1 GENERAL

Repairs may be necessary where a surface fails to achieve the minimum requirements for the specified finish, has been damaged during construction work or develops defects whilst in service.

AS 3610 requires that repairs to off-form concrete surfaces satisfy a number of criteria including structural strength, durability, adhesion, appropriateness of materials and appearance; ie the repaired areas should deliver the same performance as the original concrete. While repairs to unformed surfaces are not covered by Standards, the same criteria are applicable.

Careful consideration should always be given to whether repairs and remedial work will improve or worsen the appearance of the concrete. While it is possible to repair most defective or damaged concrete, and repair procedures are fairly straightforward and standard, they are often expensive, especially where access is difficult. If extensive repairs are necessary, consideration should be given to complete replacement.

6.2 PHYSICAL DEFECTS

Table A1 in Appendix A lists options for the repair (where possible) of various physical defects. References to CCAA Data Sheets giving more-comprehensive information are also provided.

Some general recommendations are:

- Repairs should be carried out by skilled and experienced tradesmen.
- Repair techniques should be established early in the construction programme, preferably using any test panels that have been constructed, and an acceptable standard established.
- Repair should be undertaken at the earliest possible opportunity in order to ensure that the repair and the concrete are given the same curing and/or other treatments. Note that it is essential that the surface to be repaired is cleaned of any form oils, curing compounds, sealers or other contaminants that may affect the bond of the repair material.
- If colour control has been specified, then trial patches should be approved prior to any more extensive areas being repaired. The mortar for minor repairs should contain materials (sand and cement) as used in the original concrete. If 'grey' cement has been used, substituting up to about 40% of the cement with off-white cement should assist in matching the colour of the repair mortar to that of the original concrete. Repairs with the original mix will almost inevitably result in a darker colour; as does the tendency to use more cement to ensure bonding to the substrate. For larger repairs requiring a concrete mix, the same coarse aggregate should also be used.
- Extensive repairs may require an edge/corner to be formed up. Forms used in this situation should be similar to the original formwork.
- Bonding is typically achieved by the mixing water drawing cement particles into the surface of the substrate, where cement hydration creates a chemical bond. Bonding agents may be used to ensure adhesion to the substrate, particularly to high-strength concrete. High-strength substrates are generally relatively impermeable; this hinders the movement of water, cement particles and hence bonding.

  Bonding agents should be suitable for the application. For high strength concrete substrates, SBRs (styrene butadiene rubbers), acrylic polymers or EVA (ethylene vinyl acetate) emulsions may be used. For exterior situations and other applications where the concrete may become wet, PVA-based products are not recommended, as they tend to re-emulsify in such conditions.

  Bonding agents should be mixed with cement or cement/sand mixtures to form a slurry. They should be applied immediately prior to the repair mortar/concrete, so that the adhesive slurry is still wet when the repair material is applied. Manufacturers' recommendations should always be followed.
- Where proprietary repair materials are used for colour-controlled finishes, trial repairs should be carried out to assess the colour match.

6.3 OTHER DEFECTS

- **Concrete discolouration.** Correction is difficult and the older the concrete, the less effective are any of the treatments. To lighten darker areas and achieve a more consistent colour, the following may assist:
  - Immediately and thoroughly wash of the concrete surface with water.
  - Apply pure vinegar and allow to stand for 30 minutes before rinsing off thoroughly. A second application may be necessary.
  - Special chemical treatments suggested by Greening and Landgren[45] include:

    Apply a 10% solution of sodium hydroxide (caustic soda) for a day or two and then thoroughly wash to remove the caustic solution.

    Brush a 20% to 30% water solution of di-ammonium citrate onto the dry concrete surface. Continuously and lightly brush the treated area to maintain a uniform film of clear liquid on the surface. About 5 minutes after application, the liquid on the concrete surface will start to turn into a white gel. More water must be applied so the gel does not stiffen or dry. Continue to stir and brush this coating around on the concrete surface for about 15 minutes after gelation. Thoroughly clean all the gel from the surface with water and vigorous brushing. A second treatment may be applied once the concrete surface is dry. After treatment, alternate wetting and drying can further improve the uniformity of the surface.

- **Colour variations.** Correction with dyes may be possible, Mild-acid washes should be a last-resort method of moderating colour intensity or colour variations and should be attempted only by contractors experienced with the techniques. Note that when using such chemicals, all required safety and environmental protection measures should be strictly observed.

- **Efflorescence.**
  - **Soluble lime and salt deposits.** Many of these can be removed by stiff-bristled brush, especially if this is undertaken soon after deposition. Brushed-off material should be totally removed by vacuum cleaning or other means. If dry brushing is not effective, washing with water in conjunction with further brushing should be tried. However, washing with water may result in salt deposits appearing again as the washing water evaporates. Repeated dry brushing as the deposits appear is likely to be the most successful treatment.
  - **Hard, white, scaly or crusted deposits.** These cannot be removed by water washing. High pressure water jet is effective, sometimes augmented with the addition of fine sand to the water. Light sand blasting, where it can be used with care may be quite effective. However, sand blasting may change the texture of the concrete and in the case of coloured concrete may cause colour variations. It may therefore be necessary to treat the entire area.

    The controlled application of diluted acid is effective in most cases. In some cases such as calcium carbonate efflorescence, it may be the only way. As washing with acid may alter the texture of the surface and/or cause discolouration, treatment of the entire area may be required to avoid such effects. To assess the impact, a trial area in an inconspicuous location should be treated initially. The acid usually recommended is hydrochloric acid, diluted one part of acid to 10 or 20 parts of water. The normal procedure is to saturate the concrete with water, then wash or brush the area affected with a diluted acid followed by good rinsing with water. For coloured concrete, a more diluted acid solution may be required, 2% acid is suggested (1 part of acid to 50 parts of water).

    If the surface is to be coated/painted, it should be neutralised by washing with a 10% solution of ammonia or potassium hydroxide or allowed to weather for one month.

Further information can be found in *Efflorescence*[46].

7 Maintenance

Flatwork surfaces should be regularly cleaned to maintain the finish and ensure that properties such as slip resistance are not reduced by contamination of the surface. Maintenance of concrete flatwork may also involve polishing or resealing the surface. Over time, dirt will become trapped within most porous concrete flatwork surfaces.

RESEALING

Penetrating sealers rely on the abrasion resistance of the concrete surface for protection and should require little maintenance over the life of the pavement/floor. Those that form a film on the surface (eg polyurethanes used for high gloss levels in interior applications) will be subject to wear and require regular resealing. Referring to **Section 4.18**, the work involved with resealing depends largely on the type of sealer that was originally used. Epoxy-based sealers will require the surface to be roughened to allow mechanical bonding of the new to old sealer. Wax-based sealers may require removal of the old wax material to avoid a thick build-up on the surface within which dirt may become embedded. For textured finishes such as slate and other rock type patterns it may not be possible to roughen the surface to allow mechanical bonding of the new sealer, so the original sealer should be selected to avoid the need for this later on. If silicon-based sealers have been used, other than resealing with another silicon product, it will be impossible to adhere further surface sealers, coatings, toppings and coverings to the surface.

Surface sealers wear in high traffic areas, generally changing the appearance of the surface, ie the original gloss finish may be lost over time. Where possible, a sealer that can be dissolved or re-liquefied by the solvents in the new sealer should be chosen. This has the advantage that the new and old sealer can be spread evenly over the surface, eliminating a thick build-up in areas not subject to wear. Alternatively, it may be possible to remove the old sealer prior to application of the new one.

The new sealer should provide the same level of slip resistance as that of the existing surface. With a build-up of sealer on the surface over time, the original surface texture that provided slip resistance can become filled and it may be necessary to incorporate a non-slip additive (usually fine silica dust) into the new sealer to maintain the required level of slip resistance, refer **Section 4.23**.

FLOOR POLISHES

The regular application of floor polish provides a wearing layer over the concrete surface that protects the original finish and should eliminate the need for resealing. The original floor finish shown in **Figure 183** has been protected in this manner for over 100 years.

The regular application of floor polish will reduce surface roughness and therefore the slip resistance, particularly of polished finishes. The reduced slip resistance may be satisfactory for interior floors that are maintained in a dry condition (dry floors will provide adequate slip resistance), but in other situations it is recommended that the surface simply be coated with a durable sealer and maintained with regular sweeping and cleaning.

CLEANING EXTERNAL PAVEMENTS

Three common cleaning methods are available to remove dirt from concrete paving surfaces. Note that for new concrete surfaces, the concrete should be hard enough to prevent abrasion and damage of the surface by the cleaning process.

- Water washing. Using a water jet from a normal hose or high-pressure water blasting to loosen and flush dirt from the surface is the most common method. As very high water pressures are available from modern equipment care should be taken not to damage the concrete surface. The procedure can be supplemented by scrubbing the surface with a stiff-bristled brush or broom.
- Detergent water cleaning. As above, except that a strong detergent solution is used, and the surface is thoroughly rinsed afterwards.
- Steam cleaning. This is one of the most effective methods of cleaning a variety of stains and dirt from a concrete surface. High-pressure steam cleaning is used in conjunction with detergents or non-solvent emulsifying agents suitable for use in high-pressure steam cleaners. The surface is again thoroughly rinsed afterwards.

← BACK TO CONTENTS PAGE

A wide range of proprietary products are available to assist with cleaning the surface and removal of various stains. Products should always be tested on an inconspicuous area to assess the affect on the finish and colour prior to general use over the entire surface. As cleaned areas may appear different to non-cleaned ones, cleaning of more than isolated stained areas may be necessary to produce a uniform appearance.

Surfaces should always be cleaned as soon as possible after contamination to prevent the spread of the contaminant, avoid surface penetration and reduce the cleaning effort involved. For example, if mortar spills or splashes are promptly removed, washing the surface down with clean water may be sufficient to prevent surface staining. Once mortar has hardened, the use of a dilute acid solution is generally necessary.

CLEANING FLOORS

Unlike paved areas which normally have a textured surface to provide adequate slip resistance, floors generally have smooth, or at worst, very lightly textured surfaces. While the same cleaning methods can be used for pavements and floors, the options for cleaning the smoother floor (or pavement) finishes are greater.

Most level polished concrete floors will have adequate slip resistance if clean and dry, the issue of preventing contamination or, if contamination occurs, limiting its spread and effects should be considered.

The main methods of cleaning floors include:

- Spot cleaning. Paper towel or rag used to clean up minor water-based contamination and prevent spreading.
- Mop. Generally suitable only for smooth floors having surface roughness < 20 μm. Floors should be left dry, and mops should themselves be cleaned regularly. Simple mopping may not remove all greasy/oily deposits.
- Machine. Scrubber-driers come in three main categories: rotary action, contra-rotating (two brushes in opposite directions) and cylindrical. They are an effective way to clean large areas but the type of cleaner must suit the floor surface and all areas must be accessible. The squeegee must be able to recover all water, so their suitability for rough or highly profiled surfaces should be checked. Contra-rotating machines suit areas having recessed joints, small amounts of debris, high levels of dust and irregular features, while cylindrical machines are best for very smooth and flat surfaces having no debris. With the variety of materials available for brushes and designs of machines, final selection may depend on actual field trials.
- Hose cleaning. High-pressure water is suitable for dusty or doughy contaminants, with detergents added for greasy/oily contamination. This method should be used only on surfaces with adequate slip resistance when wet. Alternatively, the cleaned area should not be trafficked until dry.
- Wet vacuum. While suitable for liquid spills, drying of surface may also be required.
- Dry vacuum. Suitable for dusty contaminants, especially on rough surfaces.
- Sweeping. May spread contaminants and be ineffective on rougher floors and is generally not recommended, especially in areas where airborne dust may cause health issues.
- Scouring pad. May increases removal of contaminant but cause wearing of any surface coatings or sealers.
- Squeegee. May spread greasy/oily contaminants and leave rougher surfaces wet.
- Detergent. Used for removal of greasy/oily contaminants. Manufacturer's recommendations should be followed.

The selection of appropriate cleaning procedures will depend on the surface roughness, likely contaminants and the size of the areas to be cleaned. The recommendations of product manufacturers may also influence the cleaning methods.

Generally, food preparation areas require a daily wet scrub with hot water and neutral detergent. Disinfectant may also be required. Other areas may require only a damp mop and spot clean daily, a more extensive weekly clean with a mop and water/detergent solution, and periodic machine cleaning at intervals of one to three months depending on the nature of the contamination. Some textured finishes may not be appropriate in such areas **Figure 194**.

While each application will require its own cleaning procedure, case studies of various pavements[42] indicate that a suitable procedure for public areas that gives acceptable slip resistance results is as follows:

- Spot cleaning using mops. Note mops are not recommended for general cleaning as they tend to spread contaminants over the surface.
- Clean daily (typically by hosing at night after trading) and high-pressure clean every one to three months depending on level of contamination.

FIGURE 194
Textured finishes may be difficult to clean in some applications

More-regular hosing may be required depending on frequency of contamination during the day. For carparks a yearly degreaser scrub may also be needed.

- Preferred method of cleaning is with an auto scrubber fitted with squeegee and vacuum system in order to pick up contaminants from the surface. For applications such as shopping centres this should be done nightly, with other floors/pavements such as building foyers on a weekly basis if possible.
- Use of manufacturer's recommended chemical cleaners will generally provide more-efficient removal of contaminants and better slip resistance.

For further information on cleaning of floors to maintain, reinstate or improve slip resistance, see *Slip Resistance of Polished Concrete Floors*[42].

STAIN REMOVAL

Apart from dirt and various contaminants, concrete surfaces may be subjected to a variety of stains that affect the appearance. Procedures for removing some common stains are:

- Efflorescence (salt deposits). Information on the removal of efflorescence can be found in **Section 6**. Note that if treatment by acid washing is necessary, this may change the colour as well as etch the surface of the concrete so a trial area should be treated initially to assess the effect on the finish.
- Fungal growth. Vigorous scrubbing with chlorine bleach is commonly used. Surfaces should be wet prior to applying the bleach and thorough rinsing (repeated as necessary) should follow. High-pressure water cleaning can also be used to remove the fungal growth, with chlorine bleach then applied over the surface and rinsed off thoroughly.
- Mortar stains. Staining due to, say, mortar splashes from bricklaying operations may be treated with a dilute acid solution as for efflorescence – noting the risk of etching and/or changing the colour of the concrete. In terms of the colour, the acid dissolves the lighter coloured calcium at the surface of the concrete and thus tends to change it. If an acid wash is used on finishes with light and dark patches, a more uniform colour should result. Further information can be found in *Removal of Mortar*[47].
- Clay soil. Scrub the stained surface vigorously with warm soapy water and then rinse with clean water. Stubborn stains may require scrubbing with chlorine bleach, in which case the surface should be wet prior to applying the bleach and rinsed off afterwards.
- Oil and grease stains. Soak up as much of the spill as possible to prevent spreading and to limit the amount penetrating into the concrete. A proprietary engine degreaser should remove the majority of oil/grease from the surface. This can also be removed with absorbent material such as paper towels or cloths. For difficult stains, and an alternative to engine degreaser, is to cover the area with a poultice of 1 part lime to 2 parts mineral turpentine. Cover the area to about 50 mm past the edges of the stain with a 5-mm layer of the paste, cover with plastic sheeting and leave for 24 hours. Remove the plastic and scrape

BACK TO CONTENTS PAGE

off the powder. It may be necessary to repeat the process to remove any deeply ingrained oil or grease that sometimes continues to rise to the surface. Scrub with warm water and laundry detergent then rinse with clean water at the end of the treatment.

- Chewing gum. Scrape off as much chewing gum as possible and then remove the rest with a solvent such as amyl acetate. Alternatively, solidify the gum with ice cubes and scrape off as much as possible. Then apply a poultice (use cat litter or similar inert absorbent material) saturated with methylated spirits. Apply the poultice to the gum and leave until dry. This should make the residual gum brittle, making removal possible with a stiff bristle or wire brush. Finish by washing affected area with hot soapy water, then rinse with clean water.
- Rubber marks. Use proprietary rubber-removal compounds available from hardware stores. Follow manufacturer's recommendations and test the product on a small area to assess its affect on the concrete finish.
- Rust stains. Remove excess rust with a stiff brush then cover the stain with a poultice (use cat litter or similar inert absorbent material) impregnated with a solution of 1 part sodium citrate (also known as sodium tricitrate, available from chemical suppliers and some grain stores) to 6 parts warm water. Remove when dry. Scrape off residue then scrub with warm soapy water. Rinse with clean water.

Note that while colour variations and stains may be corrected by using particular chemical cleaning products and methods, for external paving the bleaching action of the sun over time can even out the colour and remove stains.

For further information and removal of other common stains refer to *Removing Stains from Concrete*[48].

8 Specification guidelines

There are three broad approaches to the specification of surface finishes, viz:

- by performance;
- by prescription (method); and
- by a combination of performance and prescription.

Performance specifications for off-form finishes (ie edges of flatwork) may be based on the provisions of AS 3610 and Supplement 1 to that Standard. Refer to *Guide to Off-form Concrete Finishes*[49].

Performance specifications are also used for the majority of unformed flatwork finishes, eg steel trowelled finish free of trowelling marks, stamped finish equal to (specify supplier's product sample and colour), light broomed finish with trowelled edges.

Prescriptive specifications describe the method or technique which is to be used to achieve the required finish. Such specifications need to be complete and unambiguous if satisfactory results are to be obtained. Good communication between all parties responsible for achieving the finish is also important, as they must have a clear understanding of what is required. Prescriptive specifications must be used for off-form finishes that involve anything other than the standard plain finishes included in AS 3610, such as textured, tooled or abraded finishes. Prescriptive specifications may also be necessary for special unformed surface finishes.

A combination of prescriptive and performance in the one specification may work if there is some objective standard, such as a test panel, against which to measure performance.

CHECKLIST

Items that may need to be borne in mind in preparing the specification include:

Design

- Formwork design should allow for concrete pressures without excessive deflection of the form face.
- Falls to prevent water ponding on surface.
- Joints types, details and locations.
- Sufficient cover to any reinforcement to allow for subsequent treatments such as tooled finishes if required and stamping depth.
- Grades for sloping surfaces.
- Slip and skid resistance – specify test method(s) and classification(s) from AS 4586.
- The finished surface level of any pavement abutting a wall should be below the wall damp-proofing course, should not obscure any weep holes or drainage openings, and should be graded away from the building.
- Gradient. The minimum gradient to allow adequate drainage of the pavement should be 1 in 100 (1.0%) for exposed areas and 1 in 200 (0.5%) for covered areas. The maximum gradients and need for transition zones should be in accordance with the BCA and AS 2890.1.

Colouring concrete

- Cement type – off-white or white (default will be normal grey).
- Fine aggregate – for subsequent treatments such as light abrasive blast that will expose the sand, the type and source.
- Coarse aggregate – for subsequent treatments such as water washing, heavy abrasive blast or acid etching, bush hammering or tooling that will expose the stone, the type and source.
- Stains, dyes and tints – colour, method of application, timing, preparation. (Note that experienced applicators should be employed.)
- Coating – specify product.
- Coloured sealer – specify product.
- Pigment – manufacturer and colour (from colour chart). Method of application (integral or as dry-shake). If a special colour has been developed for the project, specify manufacturer and sufficient details to identify colour. Approval to be based on test panel.

BACK TO CONTENTS PAGE

Floated finishes

- Hand or machine floated.
- Type of float – wood, sponge, magnesium.
- Patterns.

Trowelled finishes

- Hand or machine trowelled.
- Type of trowel – steel, coving.
- Acceptability of trowelling marks in steel trowelled finishes.
- Required patterns, if any, with coving trowel finish.
- Acceptability of 'burn' marks in burnished finishes.
- Concrete strength – 32 MPa minimum recommended for burnished finishes.

Textured finishes

- Application – steel trowel surface prior to applying broomed, tined, hessian drag, stippled or sponge finish.
- Concrete strength – 32 MPa recommended for tooled, abrasive blasted finishes.

Patterned finishes

- Colour (manufacturer and colour – typically from colour chart).
- Pattern (typically from sample panel or existing work).
- Surface texture. Note that the surface texture should have slip resistance appropriate for the pavement slopes in accordance with AS 4586.
- Release agent for stamped finishes – powder or liquid, colour.
- Joint types to avoid interference with stencilling and stamping.
- Joint locations to be sympathetic to pattern.
- Curing methods (to avoid discolouration).
- Concrete strength – 20 MPa satisfactory.
- Cover to reinforcement – increase by depth of stamping.

Exposed aggregate finishes

- Concrete strength – 32 MPa recommended.
- Slump – 100 mm recommended.
- Types of joints – preferable to avoid saw cutting at early age.
- Aggregates – type, colour, shape, size, texture, grading (gap graded recommended), proportions if more than one aggregate is being used.
- Seeded surface – aggregate and coverage (kg/m^2).
- Method of exposure – water washed, abrasive blasted, acid etched, set retarder.
- Depth of exposure – for water-washed finishes up to one third of the aggregate size. For abrasive blast and acid etched finishes either brush, light, medium or heavy exposure. Alternatively specify depth of exposure in mm.
- Acid wash – 1 part acid to 50 parts water to remove slurry from stones.
- Acid etch – 1 part acid to between 10 and 20 parts water or etching gels.
- Set retarder – manufacturer, application rate and removal procedure.
- Sealant – colour to match aggregates.
- Cover to reinforcement – increase by depth the cement matrix to be removed.

Honed finishes

- Aggregates – as for exposed aggregate finishes.
- Pigments if required – colour and dosage rate (typically 1 to 2%).
- Depth of grinding – from light grind to improve surface finish to removal of the top to uniformly expose the coarse aggregates.
- Timing – before or after construction of walls.
- Protection of finishes.
- Test panels.
- Cover to reinforcement – increase by depth of surface removed.
- Care needed when finishing to avoid tamping the surface during screeding and locally settling aggregate which may result in streaks in surface.

Rock salt texture

- Concrete strength – 32 MPa recommended.
- Method – rock salt, stamping mat, roller. For stamped and roller specify product.
- Steel trowel surface to compact.
- Size of rock salt – 9.5 mm maximum recommended.
- Application of rock salt – 0.2 to 0.6 kg/m^2 depending on appearance required.
- Embed into surface – trowel or use 20 kg roller (typical method). Rock salt not to be covered by mortar.

- Removal of rock salt – after 3 days curing, apply water to dissolve rock salt.
- Cover to reinforcement – increase by size of rock salt used.

→ Tolerances

- For formed surfaces, specify the class (typically 2 or 3) in accordance with AS 3610. The tolerances attached to specific classes have been shown to provide satisfactory finishes. More-stringent tolerances can be specified if required but are generally not required for flatwork construction.
- For unformed surfaces, specify both the flatness and levelness of the surface. Flatness by reference to the maximum deviation from a 3-m straightedge or the 'F' number system (eg $F_F = 20$) and levelness by reference to a fixed datum (eg ± 10 mm from design level) or by using the 'F' number system (eg $F_L = 15$). For residential work and other smaller projects use 3-m straightedge method (maximum deviation of 12 mm typical). More-stringent tolerances may be required for commercial and industrial flatwork depending on the application, while specification by the 'F' number method is recommended for larger areas to facilitate checking.
- Specifying that tolerances for concrete members be in accordance with AS 3600 will limit deviations for items such as slab thickness (5 mm for slabs up to 1000 mm thick) and position of reinforcement.

→ Subsequent surface finishes

This applies only if subsequent treatment of the surface or off-form finish is required. In this case the specification would normally become a combination of performance and prescriptive. Formed surfaces can be specified by the class of finish in accordance with AS 3610 (performance) and subsequent treatment such as exposed aggregate (prescriptive). Similarly, unformed surfaces will be specified by the basic surface finish (eg steel trowelled) and surface tolerances and then by the treatment/finish which is to be applied. Approval is generally by reference to an approved test panel. Some items which may need to be specified include:

- Tooled. Type of tool (eg chisel type), depth to which surface is to be removed and when the treatment is to be applied eg after curing for a minimum of 28 days, once the design strength has been achieved.
- Abrasive blasted. Sand or shot blasting (if not critical specify abrasive blasting), depth of exposure of fine or coarse aggregate (maximum one third of coarse aggregate to be exposed), timing of procedure.
- Acid etched. Typically, acid etching is carried out under factory conditions by experienced personnel. For paving elements in, say, a precast yard, all that is required is a performance approach where only the process and depth of etching/exposure of the aggregates need be specified. If carried out on site, the same approach may be taken regarding the finish, with prescriptive clauses added concerning acid type (usually hydrochloric), concentration of acid (usually in the range 1:10 to 1:20 acid:water), procedure (thoroughly wet surface prior to application and rinse off after etching) and compliance with relevant environmental and safety requirements/standards.
- Coatings – ensure concrete is dry enough. Specify that the relative humidity of the concrete is not more than 70% (use hygrometer test to confirm). Qualitative tests to determine relative humidity (eg impermeable material sealed around edges) can be used only as a guide or to determine the appropriate time for quantitative testing.

→ Subgrade

- Local soft material/spots and topsoil containing grass roots and other organic material should be removed from the area.
- Backfill service trenches with site material or other material equal in strength to site material and adequately compact to provide levels of strength and stiffness equal to subgrade material.
- Compaction of fill material – for residential applications may specify rolled or controlled fill in accordance with AS 2870. For commercial/industrial applications, specify in accordance with AS 1289.5.4.1[50] for cohesive soils (95% standard compactive effort) and AS 1289.5.6.1[51] for cohesionless soils (minimum density index of 65%).
- Cement or lime stabilisation to be used to improve strength/stability if required.
- Protect any existing services (stormwater and sewer pipes) from damage during preparation.
- Trim to within +0 and –25 mm of specified level to achieve minimum slab thicknesses.

- If the subgrade is to have concrete placed directly onto it, it should be in a damp condition at the time of concrete placement. Any ponding water on the surface should be removed prior to concrete placement.

→ Subbase

- Specify if required – typically on highly expansive sites and where subgrade strength inadequate
- Material – roadbase or other low volume change material
- Thickness – typically 100 mm for residential applications, as required for more heavily loaded commercial and industrial applications
- Compaction. For granular subbases, the material should be compacted in accordance with AS 1289.5.4.1 (minimum density ratio of 95% standard compactive effort). Note that where testing to confirm adequacy of compaction is not specified or deemed necessary, satisfactory compaction should be achieved when the subbase is compacted in maximum 100-mm-thick layers with at least three passes of a vibrating plate compactor or equivalent.
- The surface of the subbase should be finished to tolerances that will allow the specified minimum slab thickness to be achieved.
- The surface of the subbase should be in a damp condition at the time of concrete placement. Any ponding water on the surface should be removed prior to concrete placement.

→ Test panels

- Time of preparation of test panels – a period of 28 days prior to the commencement of concrete placement on site should be sufficient to allow approval and construction of further test panels if necessary.
- Aspects of the finish/work to be included in test panels, eg colour, texture, joints, edge formwork, positioning of dowels, patterns, tolerances, sealer, aggregate colour.
- Any testing required on test panels or samples, eg slip resistance, abrasion resistance.
- The size of the test panels – minimum 1000 x 1000 mm recommended but larger ones may be required to reasonably demonstrate combination of concrete mix and placement techniques (maximum 2400 x 2400). To assess achievement of surface tolerances even larger areas may be required.
- Identify non-critical areas of the actual pavement that can be used as test panels – this is essential for assessing items such as tolerances and will cost less than providing separate test panels.
- Test panels should be indicative of the actual work. They should incorporate the same concrete mix and placing, compacting, finishing and curing techniques specified for the concrete work and finish.
- Time of assessment. All work should be assessed at the same time after placement.
- Assessment and rejection criteria. Outline the variations acceptable for different aspects of the construction and finish, eg alignment of dowels, depth of brooming, straightness of formwork, uniformity of aggregate exposure.
- Repairs. Where possible, repairs should be carried out on the test panels and approved prior to work being undertaken on the completed pavement.
- Samples. If samples are required prior to the construction of test panels, the number and details should be provided.
- Portability of test panels. If test panels are to be saw cut into smaller panels (say 600 x 600 mm) to allow transport around the site this should be stated.
- Protection/storage of test panels. Test panels should be protected until all completed work has been accepted.

→ Formwork

- The class of off-form finish (Class 2, 3 or 4 in accordance with AS 3610 – specify Class 2C or 3C if colour control is required). Specify Class 2X or 3X if tolerances other than those contained in AS 3610 for the particular class of finish are required, along with any new limits. Note that Class 1 is not intended or recommended for flatwork applications.
- Items from Table 3.4.1 in AS 3610 that may be relevant for the application include:

  Test panels – mandatory for Class 1 and 2 finishes and for Class 3 if colour control or subsequent treatments have been specified.

  Form face span and direction of span – for slab edges formed up with plywood, Class 1 or 2 finishes have the option of specifying which direction the outer ply spans, ie vertically or horizontally. Typically it should span between supports as this provides greater strength and less deflection.

Distance between face steps – optional to specify for Class 1, 2 or 3 finishes. This limits the possible use of small or randomly sized pieces of formwork.

Repairs – the option not to repair is available only for Class 1 finishes.

— Treatment at edges and corners, eg fillets.

— Inspection of formwork prior to placement of concrete. AS 3610 requires that formwork for insitu concrete be inspected prior to placement to ensure (among other things) that it 'has the potential to achieve the required surface finish'. Many off-form finish defects could be avoided by ensuring that a simple check of the form face is carried out prior to placement.

— Requirements for stripping.

— Marking of formwork (generally not permitted).

— Form release agent – specify a particular product, that it be applied by experienced personnel and that the application be in accordance with the manufacturer's recommendations. Alternatively, if the choice of product is left to the contractor, that it be appropriate for the type of formwork and finish required, does not affect the colour or adhesion of subsequent surface treatments (if colour control or further treatment specified), that no change to the product is made during construction without approval.

— All debris and water to be removed from forms prior to concrete placement.

→ Reinforcement

— Reinforcement should be used if the slab/panel is of irregular shape, the length is greater than 1.5 times the width, or the joint spacing is greater than that required for an unreinforced pavement (ie 30 times the slab thickness)

— Reinforcement should be located in the top half of the pavement.

— Reinforcement should be provided with a minimum cover as follows:

(a) 20 mm to the top surface for internal applications

(b) 30 mm to the top surface for exterior applications

(c) 40 mm to the slab edge or a formed joint (isolation, expansion, keyed control joints)

(d) 50 mm to weakened plane control joints. Where the mesh is continuous at weakened plane control joints, the 50 mm is measured to the ends of the cut wires.

— Ensure the height of spacers or chairs allows for any subsequent removal of the surface required for particular finishes.

— Reinforcement should be fixed in position by bar chairs or other suitable means at maximum 800 mm centres. For meshes having smaller diameter wires, closer centres may be required to prevent excessive sagging of the reinforcement during concrete placement.

— Splicing of reinforcement to be in accordance with AS 3600. Generally, mesh should be lapped so that the two outermost wires of one sheet overlap the two outermost wires of the sheet being lapped.

— Reinforcement should not be continuous through control joints unless 50% of the wires are cut at the control joint location to assist in creating a weakened plane within the pavement.

— Where the pavement surrounds another structure such as a drainage pit or has a re-entrant corner, trimming reinforcement should be provided unless an isolation joint is provided. Trimming reinforcement should not be less than one N12 bar at least 1 m long. Note that at re-entrant corners in residential slabs, AS 2870 requires two strips of 3-L8TM, one strip of 3-L11TM or 3-N12 bars (minimum length 2 m) placed diagonally across a potential crack.

— Use appropriate chairs for durability requirements. Plastic tipped wire and plastic bar chairs may not be suitable for marine applications (wharfs) as the plastic tip may provide insufficient cover and concrete does not bond to plastic chairs.

— Provide suitable chairs or bases/plates to prevent damage to membranes.

— Provide adequate lap and fixing of reinforcement.

→ Concrete supply

Many decisions here will reflect the importance of the concrete to the required finish. A performance approach where the concrete strength and method of delivery are specified (ie N32 concrete to be pumped) is satisfactory for most 'grey' flatwork applications. However, for decorative flatwork where

← BACK TO CONTENTS PAGE

properties such as colour or colour control, special aggregates and low slump mixes are required, a special class concrete will generally be required. In this case, the concrete strength (eg S32) along with the requirements that make it a special mix must be specified. Some of the properties which may be specified include:

- Concrete strength grade. Typically N20 for common residential applications (higher strengths may be required for heavier loads or in saline soils), N32 minimum for burnished floors and honed finishes (higher strengths may be required for commercial and industrial floors), N32/N40 where subject to freezing and thawing (specify 'S' grade if air entraining agent > 5%), S32 for exposed aggregate finishes, N32 or S32 maximum for stained, dyed and tinted finishes.
- Manufactured and supplied in accordance with AS 1379.
- Slump. If not specified, 100-mm slump will be supplied for residential floors.
- Colour control (if required).
- Cement colour – off-white or white.
- Pigments – manufacturer, type, colour (from colour chart) and addition (plant or site).
- Placement method – pump or chute.
- Application – premixed concrete suppliers often have special mixes for applications such as patterned finishes.
- Aggregate types, quantities, proportions and whether gap grading is required eg exposed aggregate finishes.
- Bleed characteristics, eg low bleed for patterned finishes.
- Consistency, particular slump if colour control has been specified.
- Concrete truck to be adequately cleaned prior to batching where pigments are to be added.
- Discharge time – maximum 90 minutes after batching.
- No excess water to be added on site.
- Slump testing on site to determine consistency of concrete, particularly if colour control has been specified.
- Concrete to be adequately mixed.
- Admixtures – specify if particular ones required.

→ Concrete placement

- Pump priming material to be excluded from placement in completed work. For coloured work, the priming material (cement slurry) should also be coloured, or sufficient concrete discarded initially to ensure that the concrete incorporated into the work is uniform in colour.
- Protect concrete surfaces from adverse weather conditions including winds, rain, freezing and hot-weather conditions.
- Place concrete at a continuous rate and consistently for each section of the work.
- If placement is in layers, it should occur in uniform horizontal layers (300 – 400 mm thick) and the settlement in each layer should be substantially complete before the next layer is placed, taking care to avoid cold joints.
- Place concrete as near as possible to its final position.
- Avoid damage to form face from concrete placement.
- Concrete should not be moved horizontally or made to flow by the use of vibration (to reduce risk of segregation).
- Concrete should not be dropped from a height exceeding 2 m (to reduce risk of segregation).
- Requirements for hot- and cold-weather placement. Use of evaporation retarders, wind breaks and protection from freezing for first 24 hours. Take precautions if the temperature is below 5°C or above 30°C. Concrete temperature at point of delivery must be within the range 5 to 35°C. Commence curing as soon as possible.

→ Concrete thickness

- Increase to allow for particular finishes such as stamped (depth of impression) and washed/honed (thickness of surface mortar or layer removed)
- Thickness may need to be increased to allow use of particular joint types.
- In accordance with AS 3600 tolerances, ie deviation from specified cross-sectional dimension shall not exceed 1/200 times the specified dimension or 5 mm, whichever is the greater.

→ Concrete compaction

- Compact concrete thoroughly to remove entrapped air – insertion pattern and rate of compaction (m^3/h/vibrator) will depend on the unit being used[28]. For vibrating screeds, the rate of movement will be governed by the rate at which it can compact the concrete (refer to manufacturer's literature)
- For slabs thicker than 100 mm use immersion vibrators or vibrating screeds.
- If using vibrating screeds compact edges using immersion vibrators.
- Additional compaction should be provided to top 500 mm of vertical edges/downturns prior to concrete stiffening to minimise formation of blowholes.
- If placed in layers, compaction by immersion vibrators to extend about 150 mm into previous layer.
- If compacting by vibrating screed the slab thickness should not exceed that which can be adequately compacted (refer to manufacturer's specifications) unless supplemented with other forms of compaction, eg immersion vibrators.
- Damage to form face or joints from contact with immersion vibrators should be avoided.

→ Finishing

- Screed and finish the surface to the required level and to within specified tolerances.
- Initially float the surface with a bullfloat prior to bleedwater appearing.
- Final floating should be carried out after all bleedwater has evaporated.
- Do not float dry materials such as cement into the surface (to soak up surface water).
- Dry-shake toppings should be applied and floated into the surface after all bleedwater has evaporated.
- Compact the surface by steel trowelling (a minimum 3 passes with a steel trowel is recommended).
- Do not add water to the surface during trowelling ('wet wiping') as this may affect abrasion resistance.
- Apply surface textures such as wood float and broom finish (after steel trowelling).

→ Formwork stripping

- Time of stripping – earlier is preferred to minimise risk of damage to off-form surface and uneven curing due to gaps between formwork and concrete.
- May require minimum concrete strength prior to stripping to avoid damage to edges, corners and finish from stripping operation.
- If colour control has been specified, formwork stripping time must be consistent for all elements. This may require scheduling of concrete placement.

→ Curing

- Curing method – forms left in place, plastic sheeting, liquid membrane forming curing compound (complying with AS 3799[52]).
- Plastic sheeting–- lap and tape joints, seal and secure edges, minimise wrinkles or suspend above surface, colour (clear or orange for exterior use).
- Water curing – water temperature should not be more than about 5°C lower than the concrete surface, keep surface of concrete or hessian/sand covering continuously wet, ensure impurities do not stain surface if colour is important. Measures required to protect the surface until it has hardened sufficiently and water curing can be commenced.
- Curing compounds – specify type and that application and rate of coverage be in accordance with the manufacturer's recommendations for the type of surface finish. Fugitive dyes to assist in assessing coverage.
- Commencement – generally as soon as possible after finishing.
- Decorative finishes – curing method to minimise colour variations. If plastic sheeting used for curing and protection, method to avoid contact with surface to reduce risk of hydration staining.
- Curing period (minimum 3 or 7 days depending on exposure classification).
- For cold climates, control of temperature during curing, ie to avoid freezing.
- If adhesives/coatings are to be applied to surface, remove all curing compounds from the surface. If same-day sealers have been used, ensure they are compatible with subsequent coatings/adhesives.

Also, if colour control has been specified:

- Curing procedure consistent for all areas/ elements.

→ Joints

— General

(a) To be provided where indicated on the drawings (if available).

(b) To be constructed square to the finished top surface with a tolerance of ±5°.

(c) The angle formed between joints or a joint and the edge of the pavement should not be less than 75°.

(d) Joints should be continuous from edge to edge of the pavement and not terminate within the paved area.

(e) If joints are saw cut, specify the timing to avoid random cracking, extent of ravelling (no greater than 20 mm in depth or width adjacent to the saw cut), and cleaning of surface before the residue dries.

(f) Concrete saws should have a maximum weight of 0.5 t.

— Control joints

(a) Type – formed, scoring of plastic concrete with a suitable tool, inserting proprietary crack-inducing device or sawing the concrete.

(b) Location – recommend maximum spacing of 30 times slab thickness and to ensure longest dimension of slab panel is no more than 1.5 times shortest dimension. Spacing may be increased but risk of cracking also increases.

(c) Depth – one-quarter to one-third of the pavement thickness.

(d) Sealant – typically not required but may be necessary in food preparation areas, to improve appearance, hygiene and assist with cleaning.

— Isolation joints

(a) Location – provide where a pavement adjoins a building or other rigid structure such as a drainage pit or access hole.

(b) Width – typically 10 mm.

(c) Filler material – high-density foam or self-expanding cork recommended.

(d) Extend the full depth of the pavement.

(e) Sealant – type and application.

— Expansion joints

(a) Type – straight or keyed

(b) Location – recommended at maximum 6-m centres for pavements less than 100 mm thick and at maximum 15-m centres for pavements 100 mm thick or greater.

(c) Widths – minimum 10 mm recommended. Greater widths required depending on spacing.

(d) Dowels – size, length, spacing, profile (eg circular, square, plate) and material (eg galvanised steel). Fix in position to ensure adequate alignment and height within slab. Also, method to allow for movement, eg coat one half with bitumen and provide expansion cap or provide proprietary dowel sleeves to one side.

(e) Filler material – high-density foam or self-expanding cork recommended.

(f) Sealant – type and application.

— Construction joints

(a) Type – straight joint formed up to allow compaction and finishing of concrete.

(b) Preparation – first-cast face to be roughened prior to placing the adjacent concrete.

→ Sealants

— Type – manufacturer and product, eg polyurethane, silicon. Ensure elastomeric properties can accommodate expected movement and use, ie sealants for road pavements can be softer than those subject to pedestrian (and possible high-heel) usage.

— Sealant width and depth. The depth of the sealant should not be less than half the width of the joint and not more than the width of the joint.

— Use of backing rod or other material to control joint depth.

— Sealant to be applied in accordance with manufacturer's recommendations in respect of preparation (eg clean and dry), priming of surfaces, temperature (eg not less than 5°C), adhesion to the sides of the joint.

— Timing of application – should not occur when the joint is either at its narrowest (shortly after construction on hottest day) or widest (coldest day after drying shrinkage) unless joint width and properties of material can accommodate the maximum elongation or contraction possible. The concrete should be fully cured and have reached its design strength.

— Backfilling against edges should not occur until the sides of isolation and expansion joints have been sealed.

— The joint should be protected from traffic until the sealant has gained sufficient strength.

→ Sealers

- Sealer type, eg solvent- or water-based, same-day followed by final sealer, penetrating or surface film forming, allow bonding of subsequent coatings/finishes. Specify manufacturer and product.
- Colour (if required). If pigmented, ensure colourfast for exterior applications and where exposed to sunlight.
- Extent of sealed area.
- If colour control has been specified for large areas, same sealer to be used throughout project.
- Applied by experienced personnel in accordance with the manufacturer's recommendations.
- Compatible with other materials, eg sealants.

→ Protection of finishes

- Concrete should be protected from traffic until the end of the curing period or until the concrete has reached a minimum strength of 15 MPa.
- Protection of finishes from cementitious slurry/spoil, eg grinding surfaces, placing concrete above.
- Protection of concrete following removal of formwork.
- Protection until subsequent construction work is complete.
- Protection from freezing.

→ Assessment

- Time of assessment.
- Measurement criteria.
- Comparison to test panels.
- Allowable variations.

→ Repairs

- Procedures for minor and major repairs.
- Criteria for acceptance/rejection, eg colour match, finish.
- Trial repairs to test panel for approval.
- Repairs to be completed as soon as possible to provide same curing conditions as remainder of work.
- Repairs to be carried out prior to any subsequent surface treatment.
- Repairs to be carried out by suitably qualified and experienced personnel.

→ Cleaning

- Water washing (ensure water pressure is not such as to damage finish).
- Use of detergents or chemicals. Evaluate effect on finish (texture and colour) by application to test panel or inconspicuous area prior to general use.
- Procedures for removal of particular stains. Either specify products and procedures or require contractor to submit these for approval prior to any work being undertaken. Procedures can be evaluated on test panel.
- Efflorescence. Specify how this is to be dealt with, eg removed on occurrence by scrubbing and rinsing with fresh water only, or perhaps left to the end of the defects liability period.
- Use of acid-based cleaners/products that may etch the surface should be avoided. Acids such as oxalic acid should not affect the finish but trials on the test panel should always be used to confirm the suitability and dilution ratio of products and their effect on the colour.
- Hydrochloric acid (also known as muriatic acid) should be used as a last resort. A less dangerous acid that will perform equally well under most circumstances is phosphoric acid, which is typically found in a variety of concrete and grout cleaners.
- All surfaces to be thoroughly rinsed after any cleaning operation.

→ Safety

- Use appropriate safety equipment to minimise exposure to dust, noise, wet concrete and other chemicals (eg hydrochloric acid).
- Use correct lifting, handling and work procedures to avoid effects such as muscle strains and back pain.
- Implement work methods to avoid/reduce risk of loose objects falling on workers heads or equipment being dropped on their feet.
- Ensure site is safe for delivery of materials.

← BACK TO CONTENTS PAGE

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Appendix A

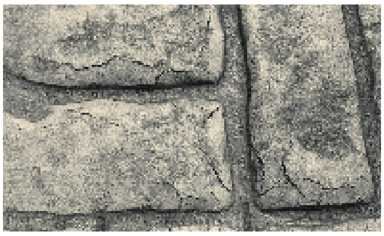
Physical defects and colour variations

TABLE A1 Physical defects in concrete flatwork, their causes and repair options

DEFECT	PROBABLE CAUSE(S)	REPAIR OPTIONS
DUSTING[53]  Low strength surface layer marked by an accumulation of fine material requiring to be swept up after the floor has been used.	**Concrete mix** Inappropriate concrete strength Addition of excess water **Ambient conditions** Rainwater on surface Freezing of the surface **Finishing** Premature (while still bleeding) Excessive use of water Use of dry cement on surface Over trowelling Applying textures to moist concrete Wet wiping finishing of the surface **Curing** Inadequate **Compaction** Inadequate	> Apply a chemical surface hardener or dust inhibitor if the problem is not too severe. Typical products include lithium, sodium or potassium silicates. Because they react with the calcium hydroxides to form compounds that assist to strengthen the surface layer, they are generally applied after 28 days. > Grind of the surface down to concrete of sufficient strength. > Apply a topping.
FLAKING[54]  Discrete pieces of the surface (usually flat) become detached as a result of bleed water trapped beneath the surface layer leaving a rough indentation behind.	**Concrete mix** Use of retarders **Application** Applying coloured topping after the concrete has set resulting in poor bond **Finishing** Too early Use of driers (cement or dry-shake topping) to absorb bleed water **Ambient conditions** Hot, dry, or windy conditions	> Grind surface and apply a sealer. > Remove delaminated areas and apply a topping or epoxy coating.
BLISTERING Low-profile bumps in the concrete surface.	*Refer **Flaking** above*	

continues

TABLE A1 *continued*

DEFECT	PROBABLE CAUSE(S)	REPAIR OPTIONS
POPOUTS[55]  Roughly conical depressions in the concrete surface created by localised pressure within the concrete from expansion of a deleterious aggregate particle or freezing of water absorbed by an aggregate particle. They generally occur after some time. Small < 10 mm Medium >10 and < 50 mm Large > 50 mm	**Concrete** Expansion of deleterious aggregate particle close to the surface **Concrete mix** Particles known to cause popouts such as pieces of wood, clay and coal Alkali reactive aggregates Low strength concrete **Compaction** Inadequate compaction **Curing** Inadequate curing **Ambient conditions** Concrete subject to freezing	> Accept variation in surface appearance/tolerances. > Fill holes with mortar.
CRUSTING  Surface dries forming a crust that is unable to deform without cracking during the stamping process. Usually occurs at locations where deep depressions are stamped into the concrete surface.	**Concrete** Use of retarders **Ambient conditions** Hot, dry, or windy conditions **Finishing** Surface dries too rapidly Stamping undertaken too late	> Accept cracked surface. > Fill with a matching coloured mortar.
HONEYCOMBING[56]  Coarse stoney surface with air voids, lacking in fines. Voids in concrete surface.	**Formwork** Leaking joints Holes and gaps present **Concrete mix** Insufficient fines Workability too low **Placing methods** Segregation occurs **Compaction** Inadequate **Detailing** Shape/detailing prevents adequate placement of concrete **Reinforcement** Congestion prevents adequate placement of concrete	> Square off any tapered edges and deepen shallow holes to a minimum of 5 mm. > Remove all loose material. > Fill with mortar.

continues

TABLE A1 *continued*

DEFECT	PROBABLE CAUSE(S)	REPAIR OPTIONS
BLOWHOLES[57]  Individual rounded or irregular cavities that are formed by the entrapment of air against the inside face of the formwork and become visible when it is stripped. Usually less than 10 mm in size. Blowholes within the concrete may also become exposed if the concrete surface is removed.	**Formwork** Texture and stickiness of the surface Inclination of the surface **Concrete mix** Poorly proportioned or sticky Workability too low Sand too coarse Too lean **Compaction** May be inadequate	> On formed surfaces, fill with earth-damp mixture after moistening the surface. > On honed surfaces, to fill holes over a larger area use a cement slurry during one of the grinding stages.
STEPPING AT JOINTS  Vertical displacement greater than 5 mm across a joint or crack in the pavement.	**Preparation** Uneven settlement of subgrade Inadequately compacted fill Inadequate backfilling of service trenches **Detailing** Aggregate interlock lost across joint **Loading** Overloading causing settlement **Site conditions** Loss of material from under slab Damage by trees	> Grind the surface of the higher slab over an appropriate width (typically 150 to 200 mm for minor stepping). > Lift the lower slab by injecting grout beneath the slab. > Top the lower slab adjacent to the step. This would apply to significant stepping caused by tree roots, expansive soils, moisture problems and subsidence where grinding is not an option. Where there is a serious case of subsidence, and the slab has lost support, an alternative to replacement is the injection of grout under the slab ('slab jacking'). This is expensive but may be necessary in some cases.
CURLING[43]  Vertical displacement at slab joints, edges or corners due to moisture or temperature gradients within the slab.	**Preparation** Wet subgrade/subbase Slab too thin Plastic membrane under slab Large joint spacing **Concrete** High drying shrinkage **Curing** Inadequate **Ambient conditions** Low relative humidity High/low temperatures	> Minor-out-of-tolerance. For minor corrections, locally grind high spots, ensuring that the minimum slab thickness and properties such as abrasion resistance are complied with. For significant curling deflections, scabbling the surface and providing a topping to reinstate the surface finish may be an option. Ensure that the thinner slab is still structurally adequate. Alternatively, low areas can be filled with an appropriate topping material.

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← BACK TO CONTENTS PAGE

TABLE A1 *continued*

DEFECT	PROBABLE CAUSE(S)	REPAIR OPTIONS
		> Loss of support. Methods include providing extra joints across the corners of the slab to allow curled corners to settle onto the supporting material and grouting the void beneath the slab. > Stepping. As for stepping above plus lowering the curled slab by loading or ponding with water (to increase surface moisture) and then providing mechanical connection across the joint. > Joint failure. If curling has reduced effectiveness of joints, some form of mechanical connection may be required, eg dowels, transverse bars. > Slab replacement. Replacing slabs should be considered as a last resort and not undertaken unless the cause of the problem has been identified and corrected.
RAIN DAMAGE Varies from stippled texture of the concrete surface from drops of rain to surface washed away from runoff. Depth may vary and coloured pigments (if present) may be washed over adjacent surfaces.	**Concrete** Insufficient hardness/strength Not protected **Ambient conditions** Rain **Curing** Method unable to protect surface	> Grind the surface. > Provide a topping.
HOLES IN STAMPED SURFACE Similar to stippled finish, surface displays small craters over much of the area	**Concrete** Too wet when stamping begins Re-wetted to facilitate stamping	> Fill with matching coloured material.
DEPTH OF STAMPING VARIES The depth of stamped impressions tapers down to a minimal imprint.	**Concrete** Hardened too much prior to stamping	
RAVELLING AT EDGES OF SAW CUTS  Breaking away of small pieces of concrete or aggregates along the edges of saw cuts	**Saw cutting** Too early Inappropriate saw	

continues

TABLE A1 *continued*

DEFECT	PROBABLE CAUSE(S)	REPAIR OPTIONS
PLASTIC SETTLEMENT CRACKING[58]  If plastic concrete is locally restrained from settling during the bleeding process (eg by a reinforcing bar, duct or insert), cracks may form over the restraining element.	**Concrete mix** High bleed with increased settlement Retarding admixtures may contribute Addition of excess water **Detailing** Ratio of cover to reinforcing bar diameter too low Reinforcement too close to surface **Construction** Excessive water loss into dry subgrade Flexible formwork Deep sections placed in single pour **Compaction** Inadequate consolidation	> Dormant cracks (not moving) can be filled with a rigid material such as cementitious or epoxy grout. Live cracks (still moving) should be filled with a flexible material such as mastic, thermoplastic or an elastomer. Mastics are the cheapest of the available sealants but are not suitable for trafficked surfaces and with movement (particularly in hot weather) may extrude from the crack. Thermoplastic materials are those which soften and become liquid or semi-liquid at higher temperatures, normally in excess of 100°C. Although less susceptible to temperature than mastics, they suffer from much the same disadvantages. Elastomers are the most common materials used and include a wide range of one- and two-part materials, such as polysulphides, polyurethanes, silicones and various acrylics. They have the advantage that they are less susceptible to temperature, adhere strongly to concrete and are able to accommodate quite significant movements without failure. > Due to the wide range of products, manufacturers should always be consulted to determine the correct product for a particular application and repair method.
PLASTIC SHRINKAGE CRACKING[59,60,61]  Formed by the rapid drying of the plastic concrete, cracks may be random or roughly parallel to each other. Cracks: > are usually straight; > range in length from 25 mm to 2 m but are usually 300 to 600 mm long; > can be up to 3 mm wide at the surface; > usually taper quickly over their depth but may penetrate right through a concrete element; > form a weakness in the concrete that may widen/extend with drying shrinkage and/or thermal movement; > may not always be evident during finishing and may not be discovered until the next day.	**Concrete mix** High water content Low sand content Low bleed potential Use of retarders delaying setting **Ambient conditions** Hot, dry or windy conditions cause rate of evaporation greater than the rate of bleeding **Curing** Not commenced early enough **Placing** Addition of excess water Rate of drying of the surface not controlled by use of products such as aliphatic alcohols	

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← BACK TO CONTENTS PAGE

TABLE A1 *continued*

DEFECT	PROBABLE CAUSE(S)	REPAIR OPTIONS
DRYING SHRINKAGE CRACKING[62]  Any restraint that results in the tensile stresses from the drying and hence shrinkage of the concrete exceeding the tensile strength of the concrete will cause cracking. The extent of shrinkage is a combination of external factors causing moisture loss from the concrete and internal factors related to the concrete and its constituents. The spacing and width of shrinkage cracks depends upon the percentage of reinforcement within the concrete.	**Concrete mix** Aggregate shrinkage, grading, size, shape and texture Inclusion of contaminants such as silt, clay, coal, wood or organic matter Admixtures Water content Adding excess water on site **Compaction and curing** Inadequate **Ambient conditions** Air temperature Wind velocity Relative humidity **Detailing** Size and shape of the member Inadequate joints **Reinforcement** Insufficient to control width **Joints** Spaced too far apart	*As above*
CRAZING[63]  Network of fine random surface cracks caused by the shrinkage of the surface layer relative to the base concrete and spaced from 10 to 70 mm apart, dividing the surface up into irregular hexagonal areas.	**Concrete mix** A high water-cement ratio combined with a cement-rich mix can be a contributory cause **Ambient conditions** Hot, dry or windy conditions causing rapid drying of surface **Finishing** Working bleedwater into surface Overworking of the surface Adding driers to the surface **Curing** Commenced too late Inadequate **Other** Cycles of wetting and drying	> If the problem is an aesthetic one, rubbing down the surface with a carborundum stone followed by sealing with a water-repellent material, such as sodium silicate, may provide a solution. This should prevent dirt collecting in the very fine cracks and accentuating them.
SLAB EDGE DAMPNESS[64] Damp slab edge due to rain, garden watering or by contact with the ground	**Preparation** Plastic membrane incorrectly/not installed Inadequate site drainage provided Concrete in contact with the ground Finished level of paving adjacent to slab too high **Concrete** Honeycombed Inadequately compacted	> Extend vapour barrier/DPM to finished ground or paving level. > Seal exposed face of concrete. > Repair any defects such as honeycombing. > Grade ground/paving away from building. > Improve drainage.

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TABLE A1 *continued*

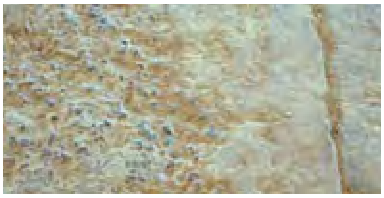
DEFECT	PROBABLE CAUSE(S)	REPAIR OPTIONS
WEARING SURFACE   Surface wears quickly	**Concrete** Insufficient strength **Concrete mix** Addition of excess water **Finishing** Commenced while bleed water still present **Compaction** Inadequate **Curing** Inadequate **Ambient conditions** Abrasive material such as sand/ fine aggregate present on surface	> Grind down to sound concrete of adequate strength. > Provide topping of appropriate strength. > Apply a suitable surface hardener.
RAGGED EDGES ALONG STENCIL After the stencil has been removed the lines display ragged and untidy edges	**Application** Stencil embedded too far into base concrete **Finishing** Surface coating depth over stencil too great Stencil removed too late	> Accept finish. > Provide topping. > Carefully grind edges to improve appearance.
STENCILLED PATTERN DISTORTED Stencil lines and/or pattern are not straight	**Application** Positioning the stencil by dragging it across the surface	> Accept finish. > Provide topping.
STENCILLED PATTERN NOT ALIGNED Stencil lines and/or pattern are out of alignment	**Application** Unplanned Alignment not achieved between separate concrete pours	> Accept finish. > Provide topping.
DEPTH OF GROUT LINES VARIES The grout lines formed by the stencilled pattern vary in depth	**Concrete** Too wet **Application** Too early allowing deep embedment into soft surface	> Accept finish. > Provide topping.
SURFACE FLATNESS/ LEVELNESS EXCEEDS TOLERANCE OR INCORRECT[40]  The surface of the concrete exceeds the maximum deviation allowed	**Preparation** Incorrect formwork levels set Problems with laser/dumpy level **Placing** Screeding levels inaccurately set Short screed used Poor screeding technique **Finishing** Commenced too early	> Grind high spots. > Fill low areas. > Provide topping (usually self-levelling). > Accept tolerance if still appropriate for application.

TABLE A2 Colour variations in concrete flatwork and their causes

DEFECT	DESCRIPTION	MOST PROBABLE CAUSE(S)
INHERENT COLOUR VARIATION	Variation in colour of the surface	**Materials** Change of cement brand, type or colour Change of source of fine and coarse aggregate Variation in admixtures Use of calcium chloride admixtures **Concrete mix** Variations in mixing procedure Variation in mix design/batching Inadequate mixing Segregation of materials Addition of excess water Variation of colour dosage **Application** Dry-shake colour addition insufficient or inconsistent Colour inadequately worked into concrete surface Surface texturing inconsistent Incomplete removal of release coat **Finishing** Steel trowelling 'burn' marks Wet wiping during trowelling Inconsistent **Compaction** Inconsistent or inadequate **Curing** Inconsistent or inadequate
AGGREGATE TRANSPARENCY	Dark areas of size and shape similar to the coarse aggregate Mottled appearance	**Concrete mix** Low sand content Gap-grading of sand Gap-graded aggregate dry or porous Excessive coarse aggregate Excessive slump with lightweight concrete **Compaction** Over-vibration of lightweight concrete **Curing** Inadequate
NEGATIVE AGGREGATE TRANSPARENCY	Light areas of size and shape similar to the coarse aggregate Mottled appearance	**Materials** Aggregate dry or highly porous **Curing** Too rapid drying
HYDRATION DISCOLOURATION (Due to moisture movement within or from plastic concrete)	Variation in shade of the surface	**Curing** Uneven

continues

TABLE A2 *continued*

DEFECT	DESCRIPTION	MOST PROBABLE CAUSE(S)
DYE DISCOLOURATION OR CONTAMINATION	Discolouration foreign to the constituents of the mix	**Formwork** Stains, dyes, dirt on form face, timber stains, rust from reinforcement or other metal form components. **Release agent** (formed surfaces) Impure or improperly applied **Materials** Dirty Contaminated by pyrites, sulfates, clay, organic matter or other impurities **Curing** Impure curing compounds Impure curing water Dirty covers
OIL DISCOLOURATION (FORMED SURFACES)	Cream or brown discolouration Sometimes showing sand or coarse aggregate.	**Release agent** Excessive amount Low viscosity Impure Applied too late or unevenly
LIME BLOOM OR EFFLORESCENCE[46] 	White powder or bloom on surface	**Concrete mix** Addition of excess water Salts in aggregates/water Excessive bleeding **Ambient conditions** Periods of wet weather after placement Uneven washing by rain **Curing** Uneven conditions Intermittent wetting and drying
LAITENCE	Weak layer of powdery fines on surface	**Concrete mix** Addition of excess water Excessive bleeding **Finishing** Working in of bleedwater Over-working the surface
'PINTO' CONCRETE 	Large, irregular-shaped, dark-coloured blotches on the surface of concrete flatwork	A combination of factors listed below is usually responsible. The use of calcium chloride admixtures, inadequate curing, trowel burns and trowelling cement into the surface are the major contributors. **Preparation** Changes in subgrade absorptivity **Concrete mix** Variations in water-cement ratio Changes in mix constituents such as cement source and supplementary cementitious materials

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← BACK TO CONTENTS PAGE

TABLE A2 *continued*

DEFECT	DESCRIPTION	MOST PROBABLE CAUSE(S)
		Admixtures Use of calcium chloride **Finishing** Steel trowelling of the surface ('burn' marks) Variation in evaporation rate at surface Entrapment of water below the finished surface Procedures which cause surface variation of water-cement ratio and changes in the concrete mix Trowelling additional cement into the surface **Curing** Inadequate or inappropriate Uneven curing
UNEVEN COLOUR WITH DRY-SHAKE MATERIALS WHEN NEW 	Surface does not have uniform colour	**Concrete mix** Addition of excess water **Ambient conditions** Presence of salts Efflorescence **Finishing** Uneven/insufficient application of material **Sealing** Inadequate
COLOUR CHANGE WITH USE/TIME 	Surface appearance/ colour changes over time	**Materials** Pigment is not colourfast **Concrete** Inadequate strength Surface coloured layer worn off *(pictured)* **Concrete mix** Addition of excess water **Application** Dry-shake topping applied while bleedwater present Insufficient material applied to surface Colour not worked adequately into concrete surface **Finishing** Commenced while bleed water still present **Compaction** Inadequate **Curing** Inadequate **Sealing** Sealer wearing off Inadequate removal of release agent prior to sealing (for stamped finishes) **Ambient conditions** Abrasive material such as sand/fine aggregate present on surface Accumulation of dirt/grime on surface

continues

TABLE A2 *continued*

DEFECT	DESCRIPTION	MOST PROBABLE CAUSE(S)
STAINING/CONTAMINATION 	Discolouration of the concrete surface from various minerals and other materials	**Concrete mix** Impurities within ingredients **Placing** Inadequate cleaning of agitator bowl **Curing** Impurities within water Leaching of colour from covering such as wet hessian **Ambient conditions** Colour leaching from materials such as timber *(pictured)* Spills of various materials Accumulation of detritus/grime Walked in soil Rust or mill scale from reinforcement
COLOUR VARIATION FROM TROWELLING 	Dark coloured areas ('burn' marks) on surface of highly trowelled concrete	**Finishing** Friction from trowelling drier surface generates heat and affects colour
COLOUR UNDER STENCIL	Colour from dry-shake topping has penetrated under the stencil (due to poor adhesion with the surface) and discoloured the grout lines within the pattern	**Concrete** Too hard **Application** Stencil not worked into concrete surface Stencil applied too late Stencil dragged over surface causing loss of bond Application of colour has lifted stencil **Finishing** Poor screeding to tolerances
COLOUR VARIATION BETWEEN DIFFERENT CONCRETE PLACEMENTS 	The colour of the concrete varies between batches	**Concrete mix** Varying water content Variation in ingredients Pigments from different batches **Concrete** Variation in concrete strength **Curing** Inconsistent curing conditions

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BACK TO CONTENTS PAGE

TABLE A2 *continued*

DEFECT	DESCRIPTION	MOST PROBABLE CAUSE(S)
NON-UNIFORM COLOUR FROM CHEMICAL STAINING 	Colour or mottled effect varies from one area to another	**Concrete mix** Variation in water content/ingredients Variable absorbency of stain into the concrete surface **Finishing** Variation in trowelling and hence compaction of surface **Compaction** Variable over area causing changes in density **Application** Uneven
NON-UNIFORM EXPOSURE OF AGGREGATES	Variable exposure or aggregate density to any exposed aggregate application	**Concrete** Poor material grading Addition of excess water **Application** Excessive washing off Uneven abrasive blasting/acid etching **Finishing** Not trowelling surface during washing off process
PAVER COLOUR VARIES 	Variation in colour or finish of segmental units	**Concrete mix** Different colour Different aggregates **Finishing** Different finish used. Photo shows honed finish used as replacement for abrasive blast finish. **Concrete** Different batch