ISSUE 623

BULLETIN

CURING CONCRETE

June 2018

- Proper curing requires maintaining an adequate amount of water within the concrete and controlling temperature while the hydration of cement occurs.
- Failure to properly cure concrete for the correct duration can impact on the durability, compressive strength, density and abrasion resistance for the concrete.
- This bulletin updates and replaces Bulletin 382 of the same name.

1.0 INTRODUCTION

1.0.1 Controlling the rate of moisture loss throughout the curing process is probably one of the most critical and yet least understood aspects of concreting. The curing process is arguably the most neglected aspect of concrete practice, and the need for proper curing cannot be over-emphasised. Failure to undertake timely and correct curing methods can cause:

- a reduction in compressive strength – up to 50% in small-scale tests and more likely in the outer or surface layers (30–50 mm depth)
- reduced durability and abrasion resistance
- crazing and dusting
- random cracking
- greater porosity, which allows moisture penetration leading to reinforcement corrosion and consequent spalling
- curling of the slab
- efflorescence
- difficulty in the bonding of applied finishes such as tiles and vinyl to a soft porous surface.

1.0.2 This bulletin explains the purpose of curing and describes practical methods of achieving good results. It should be read in conjunction with Bulletin 592 *Concrete slab-on-ground floors*.

1.0.3 This bulletin provides guidance for designers, builders, concrete placers, territorial authority building officers and building certifiers. It updates and replaces Bulletin 382 of the same name.

2.0 THE PURPOSE OF CURING

2.1 STRENGTH AND DURABILITY

2.1.1 Hydration of cement is a chemical reaction that occurs between the water and the cement. Curing needs to be controlled in newly placed concrete to ensure that maximum concrete strength and durability are developed (Figure 1). This is achieved as follows:

- Slowing the evaporation of surplus water from the body of concrete. Around half of the water in concrete is there to allow it to be placed. If this water dries too rapidly, the developed strength of the concrete can be compromised. In low water-cement ratio concrete (high-strength concrete), water must be maintained on the surface as there is little excess water in the mix. Loss of strength and durability mostly occurs when the initial curing (3 days) is inadequate.
- Maintaining a favourable temperature so the hydration reaction can occur in a reasonable time.

2.1.2 If the ambient conditions of moisture, humidity and temperature are optimal, no specific additional action is required, and curing will take place naturally. In practice, however, these conditions are rarely met, and specific curing procedures must be used. Concrete that is allowed to dry out without any curing will achieve only about 40% of the ultimate strength of concrete that is properly cured for a minimum of 7 days.

2.2 HYDRATION

2.2.1 Concrete is composed essentially of cement, aggregate and water. The water combines chemically with the cement to form a matrix that binds the aggregate. This matrix expands into the space occupied by the water, reducing porosity. The resulting concrete must possess adequate strength, wear resistance, watertightness and good dimensional stability to avoid cracking. These properties all depend on the completeness of the chemical reaction known as hydration.

2.2.2 Hydration commences as soon as water is added to the mix and proceeds rapidly at first. The concrete attains 70% of its ultimate strength in approximately 7 days and then gains further strength at a rate that slows with time (see Figure 1).

2.2.3 The amount of water necessary for complete

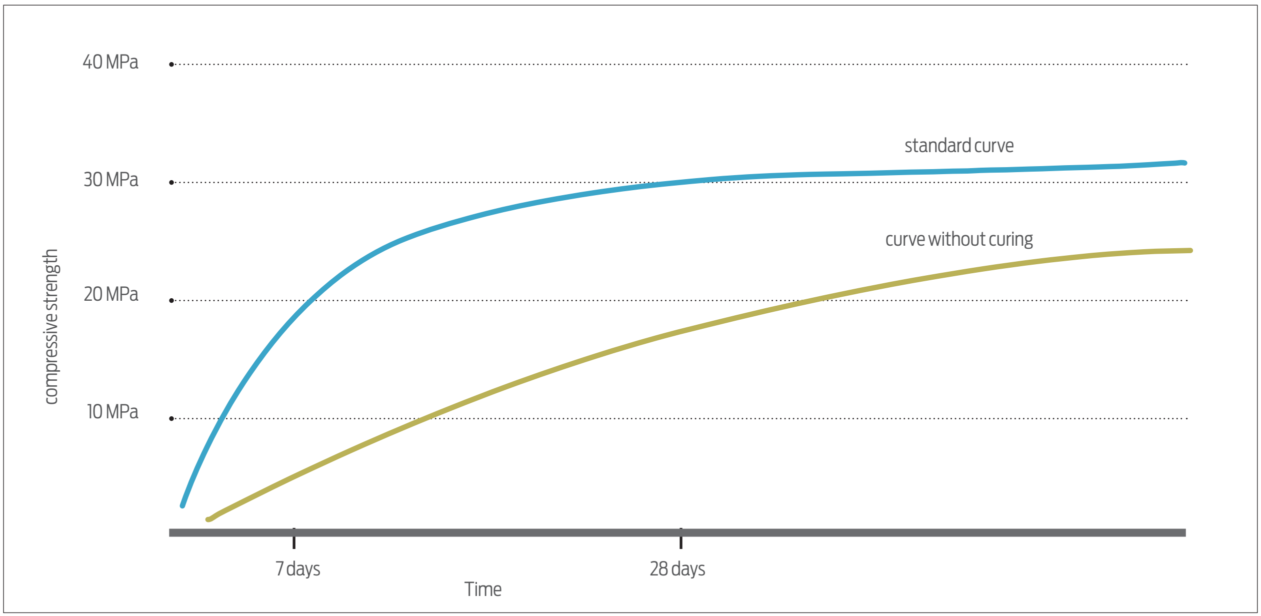

Figure 1. The relationship between compressive strength and curing of the outer 30 mm of concrete.

hydration is relatively small, being around 40% by weight of the cement for 20–25 MPa concrete. However, significantly more water (50–70%, expressed as a water-cement ratio of 0.5–0.7) is required to provide a workable and compactable concrete mix. Over time, this additional water dries from the concrete by surface evaporation.

2.2.4 Rapid and excessive loss of water by evaporation from newly laid concrete reduces the amount of water available to complete the hydration process. When this occurs, water-filled voids near the surface of the concrete dry out instead of being filled by hydrated cement, leaving the surface concrete porous and weak.

2.2.5 As a consequence of incomplete hydration:
- design strength (expressed in MPa) may not be met and the concrete may be softer and more porous
- cracking and crazing may increase
- salts carried by moisture may penetrate the completed work, increasing the risk of corrosion of steel reinforcement
- poor abrasion resistance may occur, resulting in increased surface wear accompanied by dusting.

2.2.6 The temperature of the cement matrix can also significantly affect the rate of hydration. At low temperatures (below 4°C), hydration will proceed at a much slower rate and will practically cease when the temperature approaches freezing point. After placing, concrete must be protected for at least 2 days to prevent the water freezing and expanding. This allows the concrete to gain sufficient strength before it can be allowed to freeze without suffering serious damage. Protection may be in the form of some type of insulating cover such as polystyrene sheets, sacking or dry sand covered with a polythene sheet.

2.2.7 Concrete placed in cold ambient temperatures can achieve a higher ultimate strength, is more durable and is less susceptible to thermal cracking than concrete placed in hot weather. However, it must be cured properly over a longer time period and must not be allowed to freeze. Frost protection will be required until the concrete has achieved a strength of at least 3.5 MPa.

2.2.8 Concrete that is likely to be subjected to a freeze/thaw cycle must also incorporate an air-entraining agent to allow space for the retained water to expand.

3.0 CURING

3.1 CURING COMMENCEMENT

3.1.1 Curing should begin as soon as possible after the concrete has been compacted and finished. The more severe the ambient drying conditions, the more urgent the need to promptly commence and maintain curing to avoid too rapid a moisture loss. Concrete must be kept moist for as long as practicable to ensure it achieves its maximum strength and durability.

3.1.2 NZS 3101.1&2:2006 *Concrete structures standard* and NZS 3109:1997 *Concrete construction* set out the minimum periods for curing of concrete. NZS 3101.1&2:2006 requires that "concrete shall be maintained with minimal moisture loss for the period necessary for the hydration of the cement and hardening of the concrete".

3.1.3 Lack of early curing cannot be compensated for by additional curing later. Therefore, it is critical to properly cure the concrete **continuously** as soon as it has been placed until it has reached its ultimate strength, durability and impermeability.

3.2 CURING METHODS

3.2.1 Concrete can be kept moist by:
- supplying additional moisture during the early hardening period by ponding, sprinkling or wet coverings
- sealing the surface with covers such as plastic sheets
- using curing compounds
- in the case of walls and columns, leaving formwork in place to prevent moisture loss.

3.2.2 For high-performance concrete with a low water-cement ratio (less than 0.4), curing methods that prevent moisture loss are inadequate by themselves, and extra water is required to complete the curing process.

3.3 PONDING

3.3.1 On flat surfaces, such as floors or pavements, an earth or sand dam or bund is formed around the perimeter of the concrete surface to retain a pond of water within the enclosed area (Figure 2). A timber fillet nailed to perimeter boxing can also provide a dam to contain water. This is an effective method of both preventing loss of moisture and maintaining a uniform temperature in the concrete.

3.3.2 A disadvantage of ponding is that staining or uneven colouration of the surface may occur where surfaces may partially dry. Ponding of water may also delay the start of the following stages of construction, and run-off can make surrounding areas wet.

3.4 SPRINKLING

3.4.1 A fine mist spray applied continuously after the initial set (so that pitting of the surface by water droplets is avoided) through a system of nozzles, garden hoses or lawn sprinklers (Figure 3) can be used provided there is an adequate water supply. Careful monitoring is required to ensure continuous and uniform wetting, particularly in windy conditions.

3.4.2 If sprinkling is carried out at intervals, care must be taken to ensure that the concrete does not dry between the applications of water. There is a possibility of cracking where the concrete is subject to alternate cycles of wetting and drying.

3.5 WET COVERINGS

3.5.1 Wet coverings such as water-saturated hessian or moist sand should be placed as soon as the concrete has hardened sufficiently to prevent surface damage. Care should be taken to cover the entire surface, including the edges of slabs. The coverings should

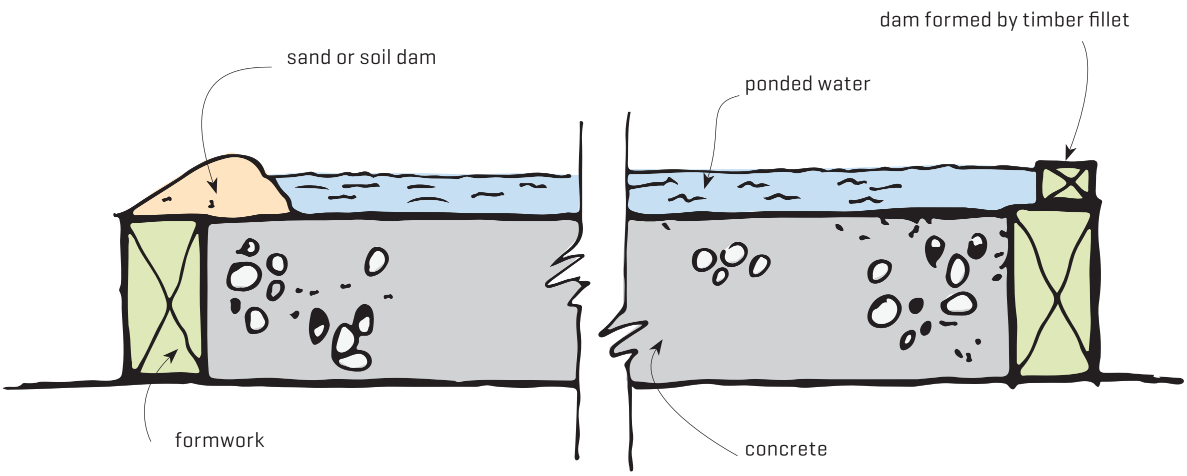

Figure 2. Method of ponding water on a flat slab.

be kept continuously moist to ensure a film of water remains on the concrete surface throughout the curing period. Polythene sheet can be laid over a wet covering to assist with water retention.

3.5.2 A disadvantage of this method is the possibility of discolouration of the concrete resulting from intermittent contact with covering materials such as hessian or discolouration from sweating that may occur under plastic.

3.6 SEALING THE SURFACE WITH COVERS

3.6.1 Covering the concrete with polythene or similar waterproof sheeting is an effective curing method. Such lightweight moisture barriers are readily applied to both simple and complex shapes (such as beam/column joints) and, if carefully handled, may be reused. Sheet materials should be laid as soon as the concrete is sufficiently hard enough to withstand any surface damage, and the concrete surface should be thoroughly saturated before rolling out the sheeting.

3.6.2 A range of proprietary synthetic fibre sheet products are also available. Light-coloured membranes should be used where possible to reflect solar radiation. Black polythene is acceptable for use in cold temperatures or for internal applications but can cause increased surface temperatures if exposed to sunlight. It can also be difficult to secure when used externally. Proprietary curing blankets incorporating an insulating blanket such as fibreglass bonded to a synthetic fabric are used to accelerate curing in low ambient temperatures as they retain the heat given off by the curing concrete.

3.6.3 If the surface of the concrete has a textured finish (such as exposed aggregate), sheet materials should be supported above the surface by means of a lightweight tent frame structure to avoid contact with the surface.

3.6.4 Plastic sheeting can be difficult to restrain in windy conditions and requires extensive taping where reinforcing or service conduits project beyond the concrete surface. On horizontal surfaces, the plastic can be restrained by covering with sand.

3.7 CURING COMPOUNDS

3.7.1 Curing compounds that seal the concrete surface can provide an effective method of reducing the rate of moisture evaporation when correctly applied. Curing compounds are usually composed of resins dissolved in a solvent that evaporates to leave a low-permeability membrane on the surface. Sealers that penetrate below the surface offer advantages over film-forming curing compounds because surface films can be easily degraded by abrasion or ultraviolet light. Penetrating-type curing compounds are more likely to be highly volatile because of their molecular structure and should therefore be used with caution.

3.7.2 Curing compounds can be applied to fresh concrete immediately after the surface has been finished and can also be used for further curing following the removal of formwork. When considering a curing compound, the key is to ensure that the proposed compound has proven effectiveness in retaining moisture.

3.7.3 To meet the requirements of NZS 3109:1997, membrane-forming curing compounds must comply with AS 3799-1998 *Liquid membrane-forming curing compounds for concrete* or ASTM C309-11 *Standard specification for liquid membrane-forming compounds for curing concrete*. The efficiency of curing compounds in preventing moisture loss varies. Most manufacturers supply curing compounds in two grades:

- Standard grade – provides a curing efficiency of 75%.
- Super grade – provides a curing efficiency of 90%. In tropical climates or hot weather, super grade compounds should be specified.

3.7.4 Types of curing compounds meeting NZS 3109:1997 include:

- water-based wax emulsion
- water-based hydrocarbon resin

Figure 3. Curing concrete using a fine mist sprinkler.

- water-based acrylic copolymer
- resins containing a high level of volatile organic compounds (VOCs) such as silanes (a derivative of the silicone family).

While silicates are often specified, none currently available meet the requirements of NZS 3109:1997.

3.7.5 Appropriate safety measures should be taken when handling any curing compounds, and the manufacturer's material safety data sheet should be complied with. A higher level of caution is required when using products with high VOC content, especially when using them indoors. Generally, skin and eye contact should be avoided for all compounds, and safety masks and gloves should be worn.

3.7.6 Water-based compounds have the advantage of being non-toxic with low VOC content. Clear or translucent compounds may contain a fugitive dye that fades out after application. The colour provides a visual assurance that the total exposed area has been covered. During hot, sunny weather, white pigmented compounds are preferred for external work as they reflect solar radiation and prevent excess heat build-up in the concrete.

3.7.7 Hand-operated garden sprayers or power-driven spray equipment may be used to apply curing compounds (Figure 4), and the treatment should be done while the concrete surface is still moist. Normally, only one coat is applied in a smooth, uniform process, typically at a rate of 4–10 m²/litre. Two coats will prolong the effective curing period and ensure better coverage. The second coat, if required, should be applied at right angles to the first for optimum coverage. Manufacturers' specific product data sheets should be followed for application rates.

3.7.8 Some dual-purpose curing compounds are used to prevent bonding between hardened and fresh concrete. Therefore, such types must not be used if structural bonding is necessary – for example, between a floor and a wall.

3.7.9 Where the formwork for walls has to be stripped within 24 hours after placing to allow work to proceed, the simple solution is to spray on a curing compound. However, if plastering, rendering or the attachment of finishes with an adhesive is to follow, the use of curing compounds should be carefully considered to ensure that adhesion is not affected. Spraying with water or wrapping with a plastic sheet are alternative methods to prevent moisture loss.

3.7.10 Some curing compounds can affect the adhesion of materials such as vinyls, ceramic tiles and paint to concrete floors or walls. Manufacturers of some curing compounds claim that they disintegrate after a time, usually from the effects of sunlight, and won't affect the subsequent adhesion of other materials to concrete. However, caution is advised, and manufacturers' product data sheets should be consulted to determine whether potential bonding problems exist. If curing compounds must be used on surfaces to which other materials are to be bonded, the residue can be completely removed by scabbling or sand blasting.

3.7.11 Curing compounds that do not break down fully and wash off may cause surface discolouration and may slow the drying of the slab.

3.7.12 Liquid compounds are available for internal curing of shotcrete and mortars by reducing water evaporation while improving the consistency of pumped concrete and the stability of fresh mortar and shotcrete.

3.7.13 Curing compounds should not be used for sand-cement screeds. A screed should be keep moist for at least 7 days, preferably by using a plastic sheet membrane.

Figure 4. Curing compounds are spray applied.

3.8 FORMWORK LEFT IN PLACE

3.8.1 Formwork left in place for as long as the construction schedule allows provides satisfactory protection against loss of moisture, provided that exposed edges are kept wet. Timber forms left in place should be kept moist by sprinkling, especially during hot, dry weather.

3.8.2 The colour of finished concrete can be affected by the length of time the formwork is left in place. Where uniformity of colour is essential for textured surfaces or fair-face concrete, curing compounds should be avoided because of possible discolouration. The formwork should be left in place for a minimum of 4 days.

3.8.3 Reinforcing rods left exposed (at the top of columns, for example) should be painted with cement grout or be provided with protective plastic coverings to prevent rust stains appearing on the concrete.

4.0 CURING PERIOD

4.1 DURATION OF CURING

4.1.1 All the desirable properties of concrete are improved by curing, so the curing period should always be as long as practicable. The duration of the curing period and the resulting strength and durability of concrete depends on a number of factors including:

- specified concrete strength
- concrete mix proportions (including type of cement, aggregates and additives)
- ambient weather conditions
- anticipated exposure conditions
- subsequent work activities.

4.1.2 For domestic construction, including concrete floor slabs, driveways and footpaths that do not require specific design generally, the minimum curing period is 3 days.

4.1.3 For other types of construction, minimum curing times are:

- a minimum of 7 days when the mean temperature exceeds 10ºC (refer NZS 3109:1997 clause 7.8.4) – any concrete subject to coastal spray should receive a minimum 7 days' curing (special requirements apply to marine concrete)
- to be nominated by the construction reviewer when the temperature is less than 10ºC
- different for the various exposure classifications as set out in NZS 3101.1&2:2006. If the designer designates that concrete is in an A1 or A2 exposure zone, curing may be reduced to 3 days.

4.1.4 In hot, dry conditions, windbreaks and sunshades can help to lengthen finishing time and to reduce the risk of plastic shrinkage cracking.

4.2 ACCELERATED CURING

4.2.1 Accelerated curing is a method used to get high compressive strength in concrete in a short space of time. These processes are typically used in concrete prefabrication where high-strength precast concrete can be achieved quickly while allowing the formwork to be removed, often within 24 hours as opposed to several weeks. The reduced timeframe means the cycle time for repetitively used formwork in precast concrete units can be significantly reduced with obvious cost-saving benefits.

4.2.2 These are the most commonly used accelerated curing techniques (provided temperatures do not exceed 60–65°C):

- Steam curing at atmospheric pressure.
- Warm or boiling water curing.
- Electrically heated forms, pads or blankets.
- Electric heating (sometimes using the reinforcing as the heating element).
- Autoclaving – an autoclave is a pressure chamber in which processes requiring high temperature or controlled pressure can be carried out. The binder changes with temperatures over 120°C, and special mix formulations are needed where this form of curing is proposed.
- To a lesser extent, hot oil, infrared and microwave curing, used primarily in the precast industry.

4.2.3 Accelerated curing can affect the long-term strength gain and the durability characteristics of the concrete. Testing should be carried out to prove the concrete cured this way will meet the requirements of the design.

5.0 PLASTIC SHRINKAGE

5.0.1 In some weather conditions, horizontal surfaces of concrete slabs are prone to dry out too quickly as the work proceeds. The water in the top layer of concrete may evaporate more quickly than it can be replaced by bleed water. This drying out results in cracks appearing on the surface soon after pouring and is known as 'plastic shrinkage' because it occurs when the concrete is still in a workable (plastic) state. These cracks will remain (unless trowelled out) when the concrete has hardened and will result in a loss of durability.

5.0.2 Weather situations that cause plastic shrinkage can occur anywhere in New Zealand, particularly in summer. The conditions most likely to give rise to plastic shrinkage include any combination of:

- wind
- low humidity
- higher concrete temperature.

5.0.3 Practical plastic shrinkage control methods:

- Pouring early in the morning when it is likely that temperatures are cooler, wind speeds lower and humidity higher.
- Dampening the ground (where there is no DPM) and previously poured concrete.
- Erecting a wind barrier to reduce air movement across the slab surface.
- Using a fog or mist spray while placing to keep the concrete surface damp — a sprinkler is not satisfactory as it delivers too much water, which will wash away the surface.
- Covering the surface with plastic sheeting immediately after placing — the sheeting is rolled back in sections to allow finishing work to proceed.
- Spray application of an evaporation retarder after

each finishing operation and at least once an hour until final setting. Evaporation retarders are alcohol-based products that are applied by spray immediately after bull floating. They develop a fine film over the bleed water, which reduces evaporation during the finishing process by 40–80%. Evaporation retarders are not a curing compound, and normal curing must be carried out as described in this bulletin.

6.0 MORE INFORMATION

MINISTRY OF BUSINESS, INNOVATION AND EMPLOYMENT

New Zealand Building Code Handbook

Acceptable Solutions and Verification Methods
- B1 *Structure*
- B2 *Durability*
- F2 *Hazardous building materials*

STANDARDS

NZS 3101.1&2:2006 *Concrete structures standard*

NZS 3104: 2003 *Specification for concrete production*

NZS 3109:1997 *Concrete construction*

NZS 3604:2011 *Timber-framed buildings*

AS 3799-1998 *Liquid membrane-forming curing compounds for concrete*

ASTM C309-11 *Standard specification for liquid membrane-forming compounds for curing concrete*

BRANZ

Good Practice Guide *Concrete Slabs and Basements* (2nd edition)

Bulletin 574 *Preventing corrosion of reinforcing steel in concrete*

Bulletin 592 *Concrete slab-on-ground floors*

CONCRETE NZ (FORMERLY CCANZ)

B 04 *Curing Concrete*

IB 09 *Removing Stains from Concrete*

IB 73 *Cracking*

SB 1 *Concrete Floors*

TM 35 *Guide to Concrete Construction* (Chapter 11 Curing)

CONCRETE SOCIETY (UK)

GCG8 *Concrete practice: Guidance on the practical aspects of concreting* (2016)

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