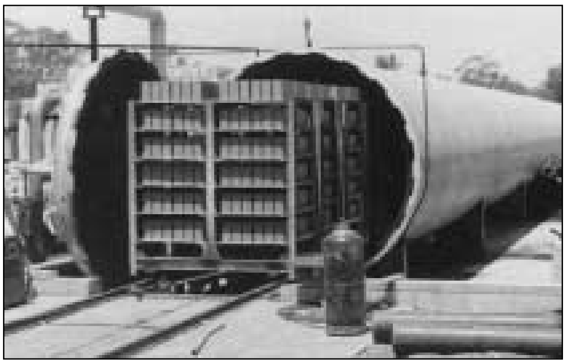

Figure 11.11 Autoclaving concrete blocks

Autoclaving Curing with high pressure steam, or autoclaving, refers to the curing of certain concrete products in an atmosphere of saturated steam at temperatures in the range 160–190°C and steam pressures in the range 6–20 atmospheres.

It is a specialised process requiring quite expensive equipment. Its use is therefore limited, although it is often employed in the manufacture of lightweight aerated concrete products to improve their strength and dimensional stability. **Figure 11.11** shows high-pressure steam curing of concrete blocks (which is a typical use for this method).

Autoclaving modifies the normal chemical reactions which occur when cement hydrates. Specifically, it causes the lime generated by hydrating cement to combine with any finely divided silica which may be present. Advantage is generally taken of this reaction by replacing up to 30–40% of the cement with a reactive silica to improve both the strength and durability of the resulting product. More-detailed information on high-pressure steam curing may be obtained from the ACI Publication SP-32[11.2].

11.4 SELECTING A METHOD OF CURING

Curing is one of the critical procedures which determines whether concrete will reach its potential strength and durability. Whilst site conditions may often indicate that curing will be inconvenient (it is at best a messy procedure), only very rarely will the cost savings resulting from failure to cure outweigh the very real damage which will be done to the long-term strength and durability of the concrete by its neglect. It is always feasible to choose a method of curing which will be both effective and economic. It should be automatic to do so.

The factors which affect the selection of a curing method include:

- the type of member to be cured, eg slab, column, wall, etc
- the specified finish for the concrete member, eg will the 'bond' of a subsequent layer or finish be affected by the application of a curing compound?
- whether the curing process will influence the appearance of the concrete?
- the construction schedule for the project, eg will work need to continue in the area during the curing period?
- the cost and availability of materials, eg is water available and how much will it cost?
- safety restrictions, eg are there any restrictions which may mean some methods are not appropriate for health or safety reasons, eg toxic fumes in an enclosed space, slippery surfaces from plastic sheeting.
- weather conditions, exposure and location.

REFERENCES

11.1 *Recommended Practice: Curing of Concrete* (Z9) 2nd edition, Concrete Institute of Australia, 1999.

11.2 *Menzel Symposium on High Pressure Steam Curing* American Concrete Institute Publication SP-32, 1972.

Summary

CONSIDERATIONS FOR SELECTING A CURING METHOD

General	Type of member	Is the member vertical or horizontal? Some methods are affected or excluded by orientation, eg ponding. Is the member thin or thick? Thick sections such as large columns or mass concrete are mostly 'self-curing' but require temperature gradient at outer layers to be limited. Is the member insitu or precast? Precast members are suited to low-pressure steam curing while precast products may benefit from autoclaving.
	Environment	Does the location affect the availability or cost of some curing materials? eg water in an arid region. Is the weather likely to be hot or cold? If the temperature is higher than about 30°C or less than 10°C special precautions need to be taken. Is the site exposed to winds? If so, special precautions may be required to prevent plastic shrinkage cracking; sprinkling methods may be affected; or extra care required when using plastic sheeting.
Impermeable membrane curing	Retention of formwork	What is the effect on site operations and construction cycle schedule? Is there likely to be cold weather? This method allows easy addition of insulation. Is uniform concrete colour specified? If so, a constant stripping time will need to be maintained to avoid hydration colour change.
	Plastic sheeting	What is the effect on access and site operations? Is there a safety consideration? Plastic sheeting may be slippery, and therefore a hazard in horizontal applications. Is there likely to be hot or cold weather? Colour of sheeting should be selected to suit. Is the situation such that the seal can be maintained with minimum risk of holing? Is uniform concrete colour specified? If so, the sheeting must be kept clear of the surface to avoid hydration staining.
	Curing compounds	What are the manufacturer's recommendations? Both the rate of application and the timing are critical for effectiveness. What is the concrete surface texture? Coarse textures require higher application rates. Can a uniform application be achieved in the particular situation? Two applications at right-angles help. Sites exposed to wind create problems. Is there likely to be hot or cold weather? A suitably pigmented compound can help. Are there to be applied finishes (render, tiles, etc)? Compounds can affect the 'bond' of applied finishes. Is there a health consideration? Compounds may be toxic, and their use in enclosed situations therefore hazardous.

Summary continues page 11.10

Summary *continued*

Water curing	Ponding	What is the effect on access and site operations? Is suitable 'dam' material available? A clay soil is the most suitable. Is there likely to be hot weather? Ponding is an efficient means of maintaining a uniform temperature on slabs. Is concrete colour or appearance a consideration? 'Dam' materials, particularly clay, tend to stain.
	Sprinkling	What is the effect on site operations? Is there an adequate water supply? What is effect of run-off? Usually some form of drainage is required. Will required volume/timing be such as not to damage the concrete surface? Can application be maintained continuously? Intermittent wetting and drying can be deleterious. Is site exposed to winds? This makes continuous application very difficult.
	Wet coverings	What is the effect on site operations? Can they effectively cover all surfaces? Is site exposed to wind? Wet coverings are easier to keep in place than plastic sheeting. Is concrete colour or appearance a consideration? If so, sand should have low clay content; fabrics and water should contain no impurities. In the case of sand, is supply or removal a problem? Can coverings be kept continuously moist? Intermittent wetting and drying can be deleterious.
Accelerated curing	Low-pressure steam curing	What is the effect on the production cycle? Will there be a cost benefit through greater productivity? This usually results from quicker turnaround of formwork. Is high early strength required? Steam curing can help in achieving this.
	Autoclaving	Will the process increase productivity? Will the process increase quality? Does the product require the process?

CHAPTER 12

Hot- and Cold-Weather Concreting

This chapter contains information on the precautions which should be taken when concreting operations have to be carried out in either very hot or very cold weather. Whilst what constitutes hot and cold weather is nowhere specifically defined, AS 1379 *Specification and supply of concrete* requires that concrete temperatures at the point of delivery be within the range 5°C to 35°C. Precautions will always be necessary when air temperatures lie outside this range, but may well be necessary even when they lie within it. AS 1379 suggests appropriate measures may need to be taken when the air temperature is less than 10°C or more than 30°C. A knowledge of the effect of high and low concrete-temperatures on the properties of concrete will enable sensible decisions to be made on when and what precautions are necessary.

12

INTRODUCTION

It is generally well recognised that when concrete has to be mixed and placed in either very hot or very cold weather, it is necessary to take precautions to ensure that it is not damaged or adversely affected by the ambient weather conditions. At temperatures below freezing, for example, freshly placed concrete may be damaged by the formation of ice within its pore structure. In very hot weather the concrete may stiffen prematurely preventing it from being compacted and finished properly, or the temperature of the concrete may rise to the point where thermal cracking occurs as it cools.

It is perhaps not so well recognised, however, that even at moderate air temperatures, strong dry winds can cause concrete to dry out prematurely and to crack.

There are few fixed rules, therefore, on what constitutes hot or cold weather in respect of concreting operations. AS 1379 requires that concrete temperatures at the point of delivery be within the range 5°C to 35°C. Precautions will always be necessary when air temperatures lie outside this range.

They may well be necessary, however, at air temperatures within this range, at less than 10°C or more than 30°C, say. At the lower temperatures, the concrete, whilst in no danger of freezing, may take an excessively long time to gain its specified strength. At the higher temperatures, particularly if accompanied by hot dry winds, plastic cracking and premature stiffening of the concrete may take place.

This chapter aims to provide guidance therefore: first on the effects of high and low temperatures on the properties of concrete; then, in the light of these effects, on the precautions which should be taken when air temperatures fall outside the range, say 10°C to 30°C, or when strong dry winds prevail.

Relevant Australian Standards

AS 1379 *The specification and supply of concrete*

AS 3600 *Concrete structures*

12.1 CONCRETING IN HOT WEATHER

High air temperatures, particularly when combined with strong dry winds, can affect the quality of both fresh and hardened concrete in a number of ways:

- By heating the constituent materials, notably the aggregates, they can increase the temperature of the freshly mixed concrete to the point where slump loss, increased water demand, and reduced setting times may occur.
- By causing the surface of the concrete to dry prematurely, they can cause cracking, even before the concrete has stiffened and begun to harden – this is known as plastic cracking.
- By accentuating the temperature rise in concrete caused by the hydrating cement, particularly in massive sections, they give rise to thermal shock (cracking) when the concrete subsequently cools.

12.1.1 Effect of High Concrete Temperatures

As the temperature of concrete rises, the setting time is reduced and the time available in which to place, compact and finish it is also reduced. More water is often added to the mix to maintain or restore workability with a consequent loss in both potential strength and durability. Where water is not added, the reduced setting time increases the dangers of incomplete compaction, the formation of cold joints or poor finishes **Figures 12.1 and 12.2**.

Even when potential strength and durability are maintained, by the addition of cement to the mix for example, the final strength of the concrete may be reduced by the higher temperatures **Figure 12.3**. It may be noted that, whereas increased concrete temperatures result in an increase in the early rate of strength gain, in the longer term, concretes cured at the lower temperatures achieve higher ultimate strength (see also **Figure 12.7**). Curing concrete at temperatures between 10°C and 25°C tends to achieve optimum results.

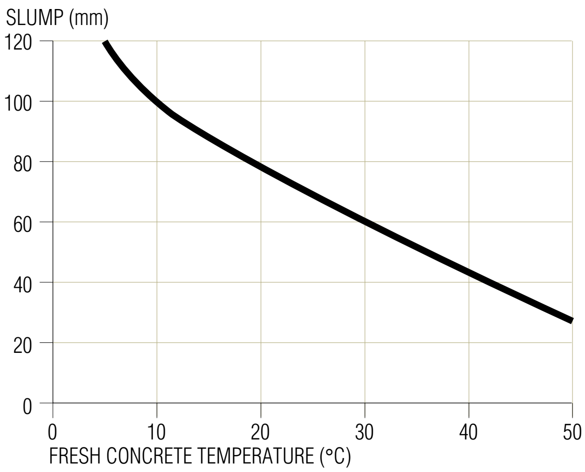

Figure 12.1 Decrease in workability of fresh concrete (as measured by slump), made with constant water content, as temperature increases

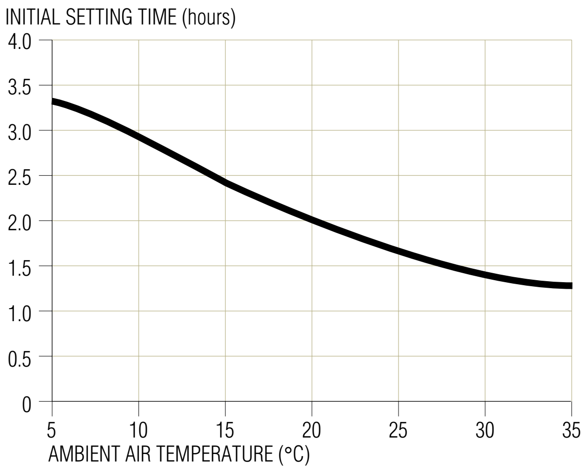

Figure 12.2 Influence of air temperature on setting times of concrete made with Type GP cement

12.1.2 Controlling Concrete Temperature

Estimating the Temperature of Fresh Concrete

The temperature of fresh concrete may be estimated from the following equation:

$$T = T_aW_a+T_cW_c+5T_wW_w/W_a+W_c+5W_w$$

where

T = temperature of the freshly mixed concrete in (°C)

T_a = temperature of the aggregates in (°C)

T_c = temperature of the cement in (°C)

T_w = temperature of the mixing water in (°C)

W_a = mass of aggregates including free moisture (kg)

W_c = mass of cement (kg)

W_w = mass of mixing water (kg).

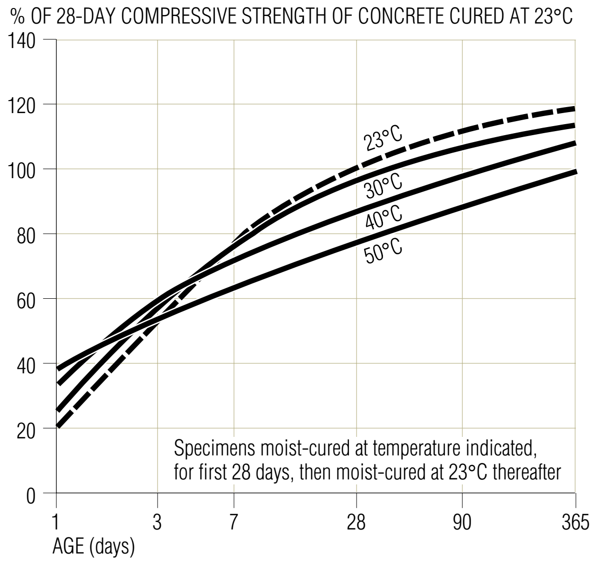

Figure 12.3 Effect of high curing temperatures on concrete compressive strength

(*Note* This equation gives approximate results only but is sufficiently accurate for practical purposes. For more accurate results a knowledge of the specific heats of the constituent materials is necessary.)

By substituting typical mix proportions in the above equation it may be readily seen that the aggregates (and their temperature) have a dominating effect on the temperature of freshly mixed concrete. Next in significance is the temperature of the mixing water, whilst the cement has a minor effect unless, as may infrequently occur, its temperature is much higher than those of the other materials.

If the temperature of the cement and the aggregate are assumed to be the same, a quick approximation of the concrete temperature may be obtained from the chart in **Figure 12.4**.

Aggregates As the temperature of the aggregates is the most significant, measures taken to limit it have the greatest effect in minimising the temperature of freshly mixed concrete. Shading stockpiles from the sun and/or keeping them moist with sprinklers are commonly used means of reducing the temperature of aggregates. Storage in bins (painted white) will also assist.

Water sprays, continuously applied as a fine mist, are particularly effective and serve also to suppress dust in hot, dry and windy conditions. Adequate provision for drainage and/or recycling of the water must be made, however, to prevent the storage site becoming unworkable. A continuous spray is preferable to intermittent spraying in order to maintain a constant

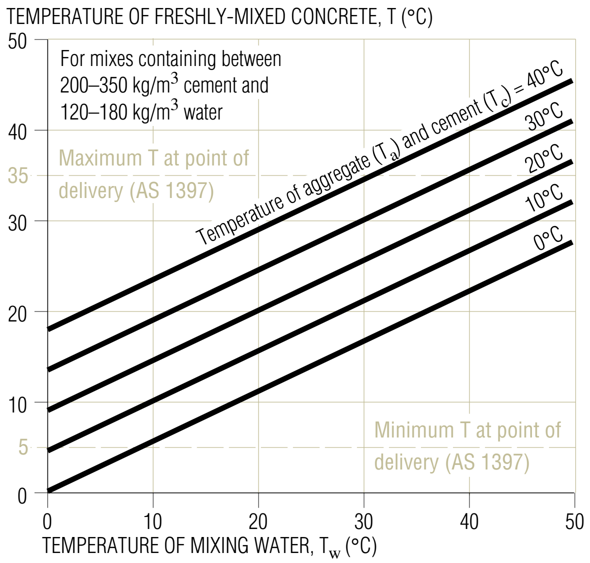

Figure 12.4 Estimation of the temperature of freshly-mixed concrete made with Type GP cement

moisture content in the aggregates and thus to avoid variations in the water-cement ratio of the concrete.

Water The temperature of the mixing water may have a significant effect on the temperature of the concrete. For example, if stored on site in tanks unprotected from the sun it may become quite hot. Conversely, if cooled by refrigerating the water supply or by adding crushed ice to it, it will serve to lower the temperature of the concrete and offset higher temperatures in the other materials.

More normally, of course, water will be drawn from town water supplies. In such cases, reticulation lines should be shaded and lagged to protect them against solar radiation. Intermediate surge or storage tanks should be similarly protected.

Cement The temperature of cement does not usually contribute significantly to the temperature of freshly mixed concrete because of its low specific heat combined with its relatively small mass in the mix. Nevertheless, unnecessary rises in temperatures should be avoided by painting silos white or other reflective colours.

The type of cement will affect the properties of the freshly mixed concrete, however, and advantage of this may be taken in some situations. Blended cements and low heat cements, for example, may provide additional time for placing and finishing, depending on the proportion of fly ash and/or slag used in the mix.

The use of rapid-hardening cement should be avoided except where very rapid strength gain is essential.

Admixtures Admixtures are very helpful in offsetting the effects of hot weather and high concrete temperatures. They may be used to improve the workability of the concrete without the addition of extra water and to retard setting.

Admixtures do not offset the other ill-effects of high concrete temperatures. They do not replace, therefore, appropriate techniques for cooling constituent materials nor those for transporting, placing and curing the concrete.

Liquid Nitrogen Injection For large and important pours where temperature control is critical, cooling may be achieved by injecting liquid nitrogen directly into the mixer or agitator truck **Figure 12.5**.

The quantity of nitrogen is adjusted to the temperature of the constituent materials and, in this way, effective control of temperature is maintained. Injection lances, storage tanks, etc are available from the suppliers of industrial gases.

12.1.3 Batching, Mixing and Transporting

To minimise the effect of high ambient temperatures on the concrete during the batching, mixing and transporting operations a number of simple precautions should be taken:

- All handling equipment such as chutes, conveyors and pump lines, should be either enclosed or alternatively shaded and painted white or with a reflective colour.
- Site mixers themselves should be shaded and/or painted white.
- Transport from the mixer to the site, and on the site itself, should be planned carefully to minimise transport time and avoid unnecessary delays. Transit mixer trucks should be discharged as soon as possible after the water has been added to the mix. Prolonged mixing should be avoided.

Fortunately, these precautions tend to coincide with the need, in urban areas at least, to minimise noise and dust pollution of the environment.

12.1.4 Placing and Compacting

Formwork and Reinforcement Wherever possible, subgrades, formwork and reinforcement should be shaded to minimise surface temperatures but in any event should be cooled by spraying with water prior to concrete being placed. A fine mist spray is well suited to this purpose but care must be taken that water does not collect on the subgrade or in the forms. Surfaces at the time of concreting should preferably be damp but not wet.

Figure 12.5 Injection of liquid nitrogen into an agitator truck to lower concrete temperaure

Placement As far as practical, concrete placement should be carried out in the cooler parts of the day. For most of Australia these are in the early morning. This permits the concrete to be finished in the natural light and for curing to commence immediately.

In very hot areas night-time pours may be advantageous, particularly in mass concrete structures. Because the time during which the concrete remains workable is generally reduced in hot weather, the provision of stand-by equipment and/or additional manpower to eliminate delays due to breakdowns becomes more crucial.

Placing of slabs should be organised so that a 'minimum' front is employed to which fresh batches of concrete are added. Concrete walls and deep beams should similarly be placed in shallow layers to avoid the 'cold joints' which occur when fresh concrete is placed against concrete already stiffened.

12.1.5 Finishing and Curing

Finishing Two separate, albeit related, problems may be experienced in finishing concrete during hot, dry and windy conditions.

The time available in which to finish the concrete is generally reduced under these conditions. Finishing operations should therefore be carried out promptly once the water sheen has disappeared from the surface and it is strong enough to support the weight of a man. Temporary sunshades and windbreaks will assist to lengthen the time during which finishing can be done.

The second problem which may occur in hot, dry, windy conditions, or, indeed, even at moderate temperatures with strong dry winds, is known as plastic cracking. This can occur when the surface of the freshly placed concrete is allowed to dry out rapidly, generally before the body of the concrete has had time to take its initial set.

Under these conditions, fine cracks may open in the surface of the concrete. Whilst they may be closed over during finishing operations, they constitute a line of weakness in the surface and will very often open up again as the concrete dries out following curing operations. Special care may be necessary to prevent this occurrence. Necessary precautions are further discussed below (see Clause 12.1.6 *Plastic Cracking* below).

Curing Curing should commence as soon as practical to prevent moisture being lost prematurely from unformed concrete surfaces.

Whilst the concrete is still plastic and unable to be cured by conventional means (see Chapter 11 *Curing*) loss of moisture due to evaporation can be minimised by spraying the surface of the concrete with an aliphatic alcohol,, available from manufacturers of concrete admixtures. It forms a thin film over the surface of the wet concrete which reduces evaporation by up to 80% in windy conditions without interfering with subsequent finishing operations. The technique is particularly useful in the prevention of plastic cracking. As soon as the concrete has hardened sufficiently, normal curing procedures should commence.

In hot, dry conditions, water curing is the preferred method because it not only ensures that the concrete is kept moist but also assists in cooling the concrete whilst it hardens and gains strength. The use of a wet covering, such as hessian, is particularly useful for this purpose as it also shades the concrete. It should be kept continually wet with a fine mist of water (which minimises water usage) or more simply, perhaps, with soaker-hoses. Care should be taken that the temperature of the water is not higher than that of the concrete, the result, perhaps, of exposed reticulation lines. Where adequate water supplies are available water curing should be maintained for at least seven days.

In situations where water is not readily available, or even when site conditions are not favourable, every effort should be made to water cure for at least 24 hours. It should be followed immediately by some other form of curing, eg the application of a suitable curing compound or the use of a membrane such as plastic sheeting.

Where the latter is used in hot, windy weather it is essential that it be well secured and anchored at edges and joints lest much of its effectiveness be lost. There is always the danger also that the sheeting will be torn loose by strong winds.

12.1.6 Plastic Cracking

Plastic cracking, the formation of cracks in the surface of the concrete before it has taken its initial set, may be caused in a number of ways:

- By drying out of the surface of the concrete before the body of the concrete has set
- By settlement of the concrete around reinforcing bars, aggregate particles or other obstructions
- By settlement or movement of the formwork.

Cracks caused by settlement of the concrete and/or the formwork are discussed in Chapter 14 *Control of Cracking.*

Plastic Shrinkage Cracking Plastic shrinkage cracks, ie cracks caused by too rapid drying out of the surface, most often occur in hot, dry, windy conditions but are not unknown in even quite moderate temperatures if the wind velocity is high enough and/or the relative humidity is low. The primary cause is always the too rapid loss of moisture from the surface of the concrete.

Figure 12.6 may be used to estimate the likelihood of plastic shrinkage cracking occurring and, hence, the need for suitable precautions to be taken. As may be seen, the factors which affect the rate of evaporation of moisture from the surface include:

- air temperature;
- relative humidity;
- concrete temperature;
- wind velocity.

Where these factors combine to produce a rate of evaporation greater than 1 kg/m^2/h, then plastic shrinkage cracking is likely and precautions should be taken. As may be noted, high air temperatures are not necessary for this to occur; concrete temperature and wind velocity have a greater effect.

An alternative to using the nomograph in **Figure 12.6** is the equation shown below. Both are based on evaporation from a water surface and are not applicable after bleed water, the sheen, disappears from the surface.

Alternative equation to calculate evaporation rate[12.1]

$$E = 5([T_c + 18]^{2.5} - r[T_a + 18]^{2.5})(V + 4) \times 10^{-6}$$

where

E = evaporation rate, kg/m^2/h

r = Relative Humidity/100

T_a = air temperature, °C

T_c = concrete (water surface) temperature, °C

V = wind velocity, km/h

Precautions The most effective way to reduce the risk of plastic shrinkage cracking is to prevent rapid loss of moisture from the surface of the concrete. Practices to achieve this are:

- Dampen subgrade and forms ensuring any excess water is removed prior to placing concrete.
- In hot weather, lower the temperature of the fresh concrete by using cool aggregates and chilled mixing water.
- Add polypropylene fibres to the concrete mix[12.3]
- Erect wind breaks to reduce wind velocity over the concrete surface.
- Use aliphatic alcohols sprayed over the surface prior to and after finishing before curing can commence to reduce rate of evaporation from the surface.
- Commence curing promptly after finishing is complete and ensure the surface is subject to continuous curing.

Revibration If plastic cracking does become evident before the concrete has taken its initial set, the cracks may be closed by revibration of the concrete over the full depth of the cracks. The feasibility of doing this should be assessed by an experienced operator, but a good rule of thumb is to permit revibration of concrete only if the vibrator will sink into the concrete under its own weight. Surface revibration may be only partially effective as it may not close the cracks to their full depth. They will then almost certainly recur as the concrete dries out.

12.2 CONCRETING IN COLD WEATHER

In Australia, freezing conditions are generally encountered only in the mountains of NSW, and in Victoria and Tasmania, although frosts are not uncommon over wide areas of inland Australia during the winter. More commonly, however, concreting in cold weather in Australia entails operations in ambient temperatures above freezing, but still low enough to have potentially adverse effects on the progress of the work.

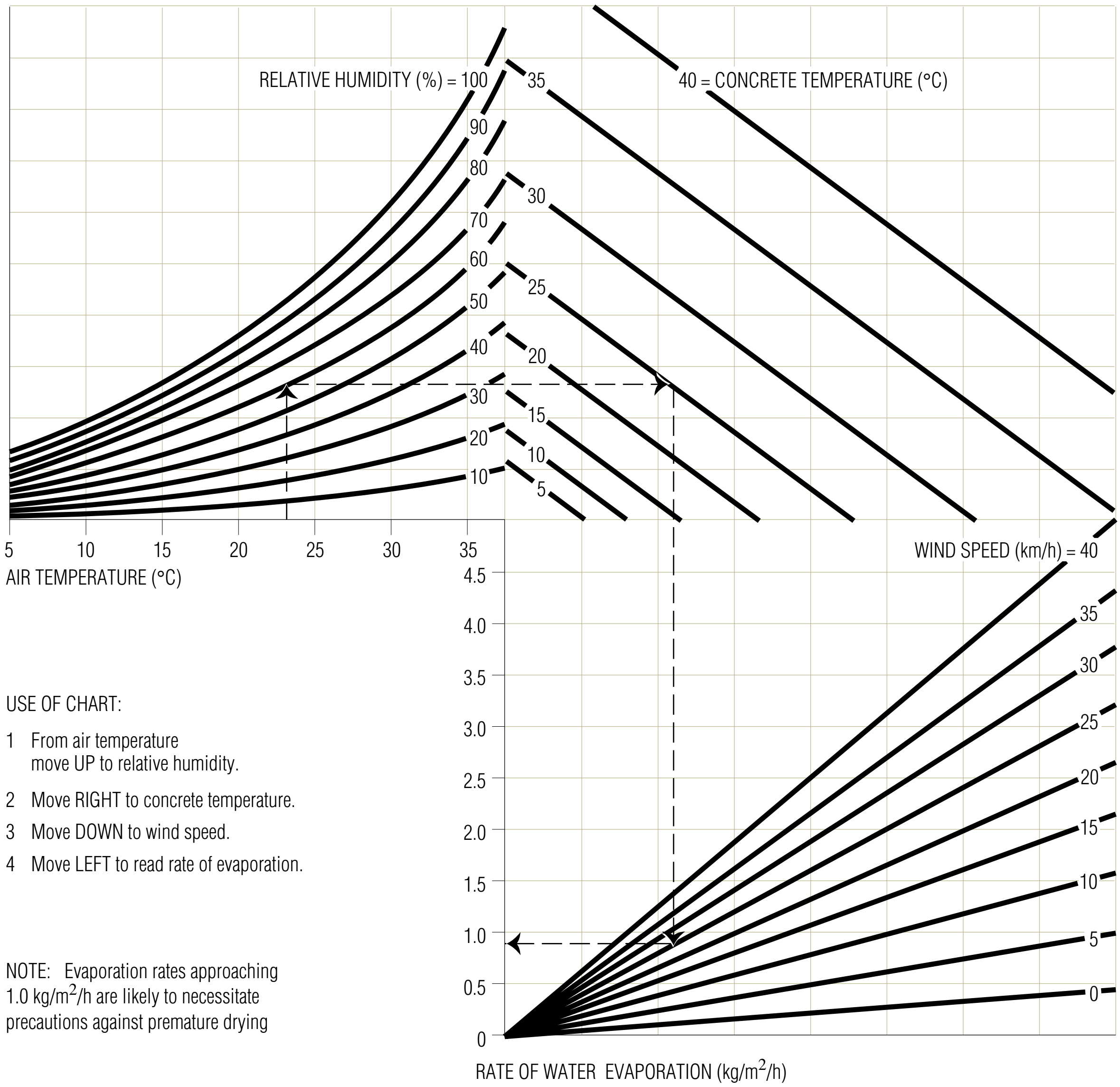

Figure 12.6 Effect of concrete and air temperatures, relative humidity and wind velocity on the rate of evaporation of surface moisture from concrete (after ACI 305, 1999[12.2])

12.2.1 Effects of Low Concrete Temperatures

By reducing the rate at which the cement hydrates, low concrete temperatures have a number of effects on the behaviour of the concrete. Firstly, and most noticeably, the setting time will be increased, delaying concrete finishing operations **Figure 12.2**. At the same time bleedwater will take longer to evaporate.

Under these conditions, there is a temptation, in finishing flatwork, to have recourse to 'driers' (cement or mixtures of cement and sand applied to the surface of the work) to mop up excess water and allow finishing to proceed. This practice leads almost inevitably to poor wear resistance.

Secondly, if the low temperatures are prolonged, the concrete will take longer to harden and gain strength, thereby delaying the removal of formwork **Figure 12.7**. AS 3600 sets out minimum periods for which formwork and formwork supports must be left in place; periods which vary with the average ambient temperature over the period specified **Table 12.1**.

When freezing conditions are encountered, irremediable damage may be done to the concrete whilst it is still plastic or when it is commencing to harden (see Clause 12.2.5 *Freezing Conditions*).