

PART II. CONSTITUENTS OF CONCRETE

WATER



CEMENT CONCRETE
& AGGREGATES AUSTRALIA

This section discusses the effect of impurities in mixing water on the properties of concrete and then elaborates on the important contributions water makes to concrete performance generally. Water can be taken for granted when considering concrete technology, but this section will attempt to detail some of the important contributions water makes to overall concrete performance.

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1. INTRODUCTION

Water is necessary in concrete for two primary reasons:

- To hydrate the cement;
- To provide adequate workability.

Water also plays a role in every aspect of concrete production, placement and service and ultimately concrete performance depends on properties that are due to, or affected by, water.

As discussed elsewhere in this document, water and cement react together chemically to form the paste that binds the aggregate particles together. Concrete sets and hardens through the chemical reaction between cement and water called ‘Hydration’ – which effectively means ‘binding water’.

The water required for this reaction is only part of that necessary to make usable concrete. If only the water required for hydration was used, the concrete would be unworkable and unable to be properly placed and finished. Additional water is required to provide (a) the aqueous environment necessary for the hydration reaction to proceed, and (b) the workability needed for satisfactory concrete placement.

The first part of this module will reiterate the important aspect of ensuring that the quality of the water used in concrete manufacture will not harm the concrete and will elaborate on the various chemical and physical properties that may impact on concrete quality. The second part of this module will discuss ‘water in concrete’ more broadly and emphasise and explain the critical role that water plays in some key aspects of concrete performance.

Most concrete specifications simply require that mixing water shall be potable, i.e. fit for drinking; or that it be clean and free from impurities harmful to concrete. AS 1379 ‘*Specification and supply of concrete*’ requires that mixing water be from a source of acceptable quality, i.e. that:

- Service records of concrete made with that water indicate that it is not injurious to the strength or durability of the concrete nor to the materials embedded in it; or
- The results of tests (in accordance with

AS 1379) are within the limits shown in **Table 4.1** and **Table 4.4**.

Under normal circumstances, water drawn from reticulated town-water supplies will meet these limits and be suitable for making concrete. However, in some parts of Australia, the chloride content of the water may be sufficiently high to require it to be taken into consideration in determining the chloride content of the concrete to ensure that the limits specified in AS 3600 'Concrete structures' are not exceeded.

On projects remote from town-water supplies it may be necessary to utilise water of unknown quality or, on occasions, water which, superficially at least, is unfit to drink because of its turbidity, its smell, its taste, or even its colour. Although such water may be shown by test to be acceptable, there may be impurities present which are potentially harmful to concrete. Some knowledge of their effects will then be required.

2. CONTAMINENTS

2.1 GENERAL

The solids content of water may have two components:

- Solid matter, generally very finely divided, which is carried in suspension; and
- Salts and/or organic matter which are dissolved in the water.

2.2 SUSPENDED SOLIDS

Suspended Solids normally comprise finely divided silts and clays which will settle from the water if it is allowed to stand for a sufficient length of time. Generally, even quite significant amounts of finely divided silt and clay have little effect on the strength or durability of concrete as long as they are evenly distributed throughout the mix. As a rough guide, it may be noted that AS 2758.1 permits up to 1% of material finer than 2 µm (fine silt and/or clay) for each of the coarse and fine aggregates (for more details, see Part II, Section 3 of this Guide). Clays which coat or adhere to the

aggregate particles are always problematic because they interfere with the paste-aggregate bond. On the other hand, evenly distributed in the mixing water, they are much less concerning.

2.3 ORGANIC MATTER

Organic matter can be particularly problematic because it affects strength and, in extreme cases, can prevent the concrete from setting. Even very small amounts of sugar, for example, can have a major retarding effect. (**NOTE:** *Water containing sugar will still be potable. Simply requiring mixing water to be potable may be an insufficient specification*).

More usually, however, organic matter simply retards the rate of strength gain and may be able to be compensated for by allowing additional time for the concrete to gain strength, by increasing the amount of cement in the mix or by the use of admixtures.

Where high levels of organic matter are suspected, there is really no satisfactory alternative to the making of trial mixes with the water in question to ensure its compliance with the limits set out in **Table 4.1**.

Table 4.1 – Limits on Setting Time and Strength of Concrete Made from Water from a Source with no Service Record (determined in accordance with methods specified in AS 1379, after Table 2.1, AS 1379).

Property	Limits
Time of initial set	Within minus 60 minutes and plus 90 minutes of setting time of control sample
Compressive strength:	
- At 7 days	≥90% of strength of control sample at 7 days
- At 28 days	≥90% of strength of control sample at 28 days

2.4 DISSOLVED SALTS

General – The salts commonly found in natural waters generally include the following:

CATIONS	ANIONS
Calcium (Ca ⁺⁺)	Bicarbonate (HCO ₃ ⁻)
Magnesium (Mg ⁺⁺)	Sulfate (SO ₄ ⁼)
Sodium (Na ⁺)	Chloride (Cl ⁻)
Potassium (K ⁺)	Nitrate (NO ₃ ⁻)

Any other salts are normally present in such small amounts as to be negligible in their effects. Of the salts commonly found, by far the most significant are the chlorides and the sulfates.

Chlorides – Chlorides are to be found in naturally occurring waters in arid regions, in brackish water which has been contaminated by seawater and, of course, in seawater itself. They may also be found in some town water supplies because it is derived from a source (e.g. possibly bore water) in which they occur naturally.

The World Health Organisation is reported to permit up to 350 mg/L of chloride in drinking water. A concentration as high as this would be highly unusual in drinking water in Australia. Even smaller levels need to be considered when assessing the total chloride content of the concrete.

Chlorides may affect concrete in two ways. Firstly, when present in relatively large amounts, they may accelerate the setting time of the concrete. While early-age concrete strengths may be improved, later age strengths tend to be less than might otherwise have been achieved. Calcium chloride, in amounts up to 2% by mass of cement, is sometimes used to accelerate the setting time of plain concrete in cold weather. Even seawater, which may contain up to 30,000 mg/L of chlorides, has been used to make satisfactory mass concrete when no other water has been available. (**NOTE:** *High levels of chloride in mixing water will be problematic if there is any embedded steel.*)

The use of calcium chloride as an accelerator is a practice which should generally be avoided. It can be added as a flake material or as a solution. Added as a solid there is a risk that it may not be evenly distributed throughout the

mix and lead to unacceptably high chloride concentrations in parts of the concrete.

Secondly, quite small amounts of chloride may be detrimental to the durability of reinforced concrete.

They act to initiate and accelerate corrosion of the reinforcing steel under certain conditions. In consequence, AS 1379 limits the acid-soluble chloride-ion content of concrete, from all sources, to 0.8 kg/m³ of the concrete.

Sulfates – Sulfates may be present in naturally occurring ground water, in industrial effluents, in sewerage and in marine environments. They can affect concrete by affecting setting times and later-age strengths, and potentially by exacerbating sulfate attack of the concrete. Some sulfate salts react with paste components (e.g. lime) to form an expansive reaction product that may lead to cracking, while others (e.g. magnesium sulfate) may react directly with the paste components and cause them to disintegrate and the concrete to lose its integrity.

The sulfate content of natural waters should be checked to ensure that the total sulfate content of the concrete, from all sources, does not exceed 50 g/kg of cement as specified in AS 1379.

Carbonates and Bicarbonates – Sodium carbonate and sodium bicarbonate, if present in sufficient concentrations can cause set acceleration, even very rapid set, with some cements. Reduced strength may also occur.

Calcium and magnesium carbonates are sufficiently insoluble as to be negligible in their effects. Whilst the bicarbonates are more soluble, it would be highly unusual for them to be present in amounts sufficiently large to cause significant problems except in waters highly charged with carbon dioxide (some mineral waters) where testing of the water would be advisable.

The maximum level of impurities in water for use in concrete has been collated from a variety of texts and Standards and is shown in **Table 4.2** below.

Table 4.2 – Limits on Impurities in Concrete Mixing Water (extracted from various international standards specifying mixing water quality)

Impurity	Maximum Concentration (mg/L)
Total Dissolved Solids (TDS)	2,000
Chloride (as Cl ⁻)	500
Sugar	100
Sulfate (as SO ₄)	1,000
Alkali carbonates and bicarbonates	1,000
Sodium Equivalent (as Na ₂ O Equivalent)	1,500
Oil and Grease	50

The potential effect from a range of impurities that may be present in concrete mixing water is shown in **Table 4.3** below.

Table 4.3 – Possible Effects from Impurities in Mixing Water

Impurity	Possible Effect
Oil, fat or detergents	Air entraining possible
Calcium Chloride / some other calcium salts	Probability of set acceleration
Sugars, salts of zinc, lead and a range of other inorganic and organic materials	Probability of set retardation
Chloride ions	Strong probability of steel corrosion

3. ACID AND ALKALINE WATER

3.1 GENERAL

AS 1379 requires that mixing water have a pH greater than 5. Whilst pH of water is not an entirely satisfactory quality measure, it nevertheless serves to alert the user to the possibility of undesirable impurities being present.

3.2 ACIDITY

Acidity in natural waters is most often caused by dissolved carbon dioxide but may also be caused by industrial wastes or by the oxidation of pyrites or other sulfides. Some mine waters, for example, become highly acidic as a result of the formation of sulfuric acid by this process. Water may also become acidic from decaying vegetable matter resulting in the formation of humic and tannic acids. It is not necessarily the pH of these organic acids that is problematic, but other properties of these compounds may affect concrete performance.

3.3 ALKALINITY

Alkalinity in natural and treated waters may be due to the presence of sodium carbonate, which hydrolyses in solution to form hydroxyl ions, or to the presence of the alkali hydroxides, sodium and potassium. The effect of sodium carbonate on the setting and rate of strength gain of concrete has already been mentioned in 2.4.

The alkali hydroxides are unlikely to be present in sufficient concentration to cause problems since cement itself is a highly alkaline material.

3.4 RECYCLED WATER

It is almost universal practice in many parts of Australia for the pre-mixed concrete industry to recycle the water used to wash out truck mixers and agitators. This is one of the practices undertaken by the industry to minimise the impact of concrete manufacture on the environment. Such water is invariably alkaline and numerous tests have shown the practice to be satisfactory.

AS 1379 permits the practice provided that the water is stored in a manner which prevents it becoming contaminated with materials deleterious to concrete and the water drawn from the storage outlet is of acceptable quality as noted in the Standard.

Specific water quality limits, as noted in AS 1379, are shown in **Table 4.4**.

Table 4.4 – Limits on Impurities in Mixing Water (determined in accordance with methods specified in AS 1379, after Table 2.2, AS 1379)

Impurity	Maximum Concentration
Sugar	100 mg/L
pH	>5.0
Oil and grease	50 mg/L

NOTE: ppm = mg/L

4. THE EFFECT ON CONCRETE DURABILITY

In considering the effect of mixing water on the durability of concrete, it is important to distinguish between short- and long-term effects. It is important also to assess the content of impurities in the mixing water in the light of their content in the other components of the concrete.

It should be noted that mixing water which is satisfactory for plain or mass concrete may be unsuitable for reinforced concrete, and even more unsuitable for prestressed concrete, in relation particularly to its chloride content and the danger of steel corrosion being initiated and/or accelerated. Similarly, the presence of sulfates in the mixing water may have little effect in the short term but be detrimental in the long term if the concrete is exposed to cycles of wetting and drying. The presence of chlorides and sulfates in the mixing water should always be regarded as undesirable and the limits set in AS 1379 should always be applied.

The cumulative effect of some impurities if they are present in some of the other components of the concrete should be noted. For example: AS 1379 limits the total chlorides and the total

sulfates in the concrete from **all sources**. Chlorides or sulfates in the mixing water may be sufficient to cause these limits to be exceeded. Similarly, sodium salts in the mixing water may be sufficiently low as to have little or no effect on the setting time or strength of the concrete but they could be sufficient to influence the development of alkali-aggregate reactions (ACR/ASR, see Part II, Section 3 of this Guide) should the aggregates be potentially reactive.

5. WATER AND CONCRETE – IMPLICATIONS AND EFFECTS

Viewed simply, water quality may impact the setting time and strength performance of concrete, while water quantity may impact workability, strength and durability performance. From the perspectives of concrete production and concrete placement, the effects of water are quite immediate and obvious. However, the role of water is far more fundamental and nuanced.

Several important topics relating to water as a material, the role that it plays in concrete, and how it impacts concrete performance will be discussed below.

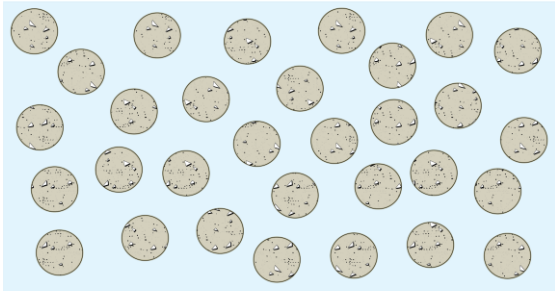
5.1 DENSITY OF WATER

W/C ratio is calculated on a mass basis – so for a cubic metre containing 300 kg of cement and 180 L of water (a W/C ratio of 0.6) – it might appear that the water is the minor partner – and by mass it is. However, mass measures do not provide a reasonable reflection of the hydration reaction space.

The interaction of cement and water is better reflected by considering their relative volumes, as this more correctly reflects the surface area available for the hydration reaction to occur. In the above example, in one cubic metre the 300 kg of cement (SG = 3.15) occupies a space of about 95 litres, while the 180 L of water (SG = 1) occupies 180 litres. Volumetrically, the water overwhelms the cement – that is, the cement particles are relatively diluted. In fact, a W/C ratio of 0.32 is necessary before the water (180 L) and cement (560 kg) occupy the same

volumes (i.e. 180 litres) (**Figure 4.1**). As the water reacts with the cement it leaves behind voids (porosity) – so the concrete we think of as ‘solid’ is in fact quite ‘porous’. Water is <10% of the mass of concrete but occupies almost 20% of the volume.

W/C Ratio = 0.6



W/C Ratio = 0.32

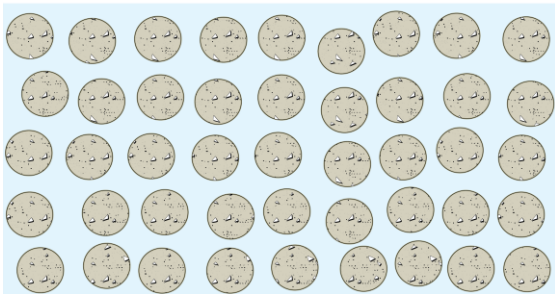


Figure 4.1 – Comparison of Relative Volumes – W/C 0.60 versus W/C 0.32

5.2 COMPLETE CEMENT HYDRATION

It is noted in some texts that 1 kg of cement requires about 250 mL of water to fully hydrate it. This properly reflects the amount of chemically combined water in the Calcium Silicate Hydrates (CSH), but not the environment in which the hydration reaction occurs.

The hydration reaction occurs in an aqueous environment and water is being bound both chemically (to form CSH) and physically (by absorption into pores and adsorption onto the surface of the CSH). The consequence is that about 420-450 grams of water is required to fully react with 1 kg of cement – that is a W/C ratio of 0.42-0.45. So, if only 250 mL of water is added to 1 kg of cement, the maximum degree of cement hydration possible is about $0.25/0.42 = 60\%$.

5.3 WATER AND CONCRETE POROSITY

There are competing issues in relation to the ‘ideal’ W/C ratio. Unless there is sufficient water (W/C ratio >0.42) in the mix, the cement will not be fully hydrated. However, the inter-particle space in concrete – the porosity – has its origin in the initial volume of water in the mix.

In low (say, 0.35) W/C ratio mixes, although the cement will not at any time be fully hydrated, sufficient hydration product can ultimately be produced to fill the void spaces between particles (which are closer together at lower W/C ratios) to provide the strength and durability performance that is required of this ‘high strength’ concrete. While this is not necessarily an efficient mix (in terms of cement utilisation), it is an effective mix (provided the required workability and strength and durability performance levels specified are achieved).

It is also worth noting that, because of the (relative) lack of water at this low W/C ratio, this concrete will ‘self-desiccate’ – that is, dry itself from the inside. (This is due to water that is held in the pores reacting with cement as the hydration reaction proceeds). This then emphasises the need for curing (by adding water) with low W/C ratio concretes – to ensure that capillary porosity is kept full of water to allow the hydration reaction to proceed to its maximum extent.

5.4 WATER AND CONCRETE WORKABILITY

The relationship between water content of a mix and slump is not linear – it is exponential. Once slump is achieved, as more water is added the increase in slump per (say) litre of water added becomes greater.

An initial on-site addition may not greatly increase slump, so more water is added, and then possibly one or more extra additions may occur. Suddenly, the mix turns into what has been described as ‘cream-of-aggregate soup’.

The effectiveness of water additions in increasing slump varies. Mixes with larger maximum aggregate size require less water per cubic metre to achieve a given slump increase.

The effect of water addition on slump also depends on the initial slump value.

To double the slump value, it has been found that the amount of water required for 38 mm top size, 20 mm top size and 10 mm top size mixes is about 11 litres, 13 litres and 17 litres per cubic metre respectively.

5.5 WATER AND CONCRETE SHRINKAGE

A considerable amount of research work has been carried out to assess the quantitative

effect of water on concrete drying shrinkage. A generally accepted estimate of this effect is that drying shrinkage increases by about 5 microstrain per kg of water per cubic metre of concrete.

While water content is by no means the most important determinant of concrete drying shrinkage, it does need to be considered as part of the array of contributors to concrete drying shrinkage performance.

6. SUMMARY – WATER IMPURITIES AND CONCRETE

Component	Comment	Limits specified (AS 1379)
Suspended Solids	Fine solids evenly distributed in the mixing water have little effect.	
Organic matter	Adversely affects strength; Can prevent setting (sugar particularly); Where suspected, trial mixes may be required.	Sugar <100 mg/L Oil and grease <50 mg/L
Dissolved chloride salts	May accelerate setting times and reduce long-term strength; Detrimental to durability when used in reinforced or prestressed concrete.	
Dissolved sulfate salts	Significant effects unusual; Natural water in arid regions requires checking.	
Dissolved carbonates and bicarbonates	Combined sodium carbonate/bicarbonate content of up to 2,000 ppm may be safe but testing advisable when content exceeds 1,000 ppm; Calcium and magnesium carbonates usually negligible in their effects.	
Acidic water	Acidity itself not usually a problem (cement being highly alkaline neutralises the acid) but the materials which caused the acidity may be a problem (e.g. sulfides, decaying vegetable matter, etc).	pH > 5.0
Recycled water	Generally satisfactory; Should comply with limits shown in Table 4.2 .	
Concrete durability	Note different quality requirements for plain (unreinforced) concrete and reinforced/prestressed concrete. Cumulative limits if some impurities are present in other components of the concrete. Note the cumulative limits placed upon chlorides and sulfates particularly.	<u>Chlorides:</u> – 0.8 kg/m ³ or specified limit – with embedded steel; – 2.0 kg/m ³ or specified limit – no embedded steel. <u>Sulfates (as SO₃):</u> 50 g/kg cement in hardened concrete

7. RELEVANT AUSTRALIAN STANDARDS

- 1) AS 1379 – *The specification and supply of concrete*
- 2) AS 2758 – *Aggregates and rock for engineering purposes*
- 3) AS 2758.1 – *Concrete aggregates*
- 4) AS 3600 – *Concrete structures*

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