

DRYING SHRINKAGE of Cement and Concrete

INTRODUCTION

Knowledge of the shrinkage characteristics of concrete is a necessary starting point in the design of structures for crack control. Such knowledge will enable the designer to estimate the probable shrinkage movement in reinforced or prestressed concrete and the appropriate steps can be taken in design to accommodate this movement.

This Data Sheet reviews the factors affecting drying shrinkage of concrete seeking to put in perspective their varying influences enabling practical and effective controls to be placed on drying shrinkage.

DRYING SHRINKAGE MECHANISM

When concrete is exposed to its service environment it tends to reach an equilibrium with that environment. If the environment is a dry atmosphere the exposed surface of the concrete loses water by evaporation. The rate of evaporation will depend on the relative humidity, temperature, water-cement ratio and the area of the exposed surface of the concrete. The first water to be lost is that held in the large capillary pores of the hardened concrete. The loss of this water does not cause significant volume change.

However, as drying continues, loss of water from small capillary pores and later from gel pores takes place. With the reduction in the vapour pressure in the capillary pores, tensile stress in the residual water increases. Tensile stresses in the capillary water are balanced by compressive stresses in the surrounding concrete and as a result the concrete shrinks. Evaporation of gel water changes the surface energy of the solid phase and causes further shrinkage.

Drying shrinkage makes up a portion of the total deformation that is observed in a concrete member. **Figure 1** shows the various components of deformation, excluding thermal movement¹. Shrinkage strain is time-dependent and non-load-induced.



IT IS THE mix design of concrete, proper construction techniques and appropriate design and detailing that will produce concrete of low shrinkage characteristics

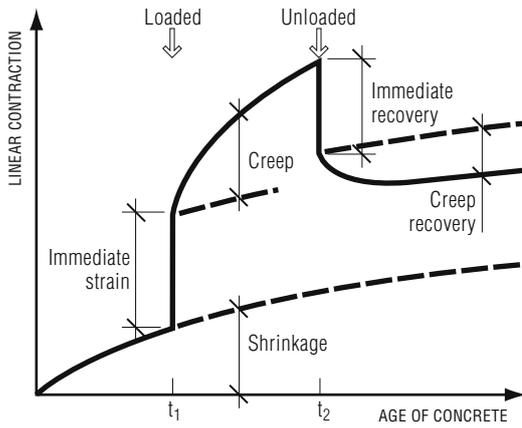


Figure 1 Various components of deformation

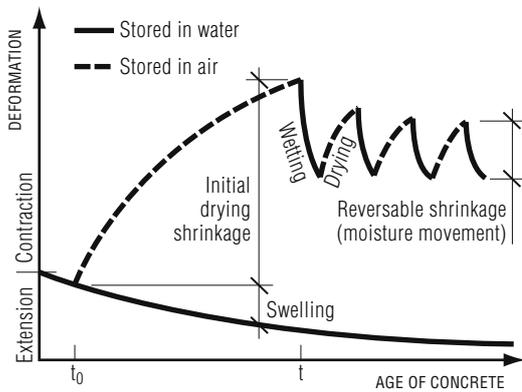


Figure 2 Concrete initially dried and then subjected to cycles of drying and wetting

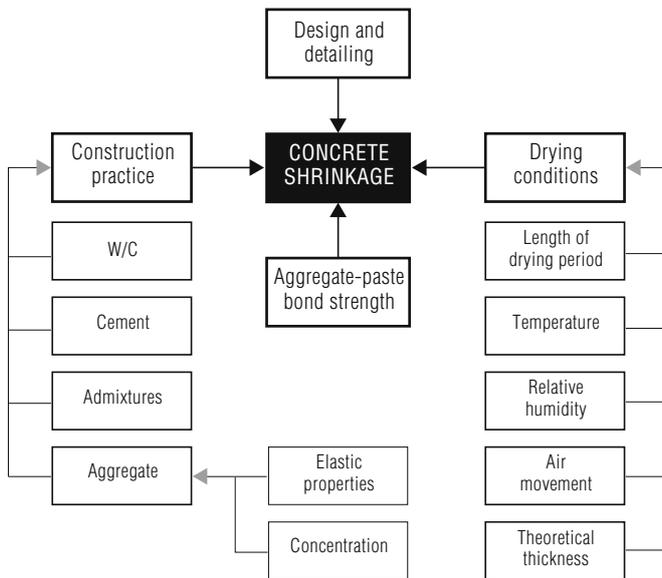


Figure 3 Factors affecting drying shrinkage

If the environment is wet or moist, the flow of moisture will be from the environment to the concrete, the result being a volume increase or swelling. A schematic description of volume changes in concrete due to alternate cycles of drying and wetting is shown in **Figure 2**¹. The greatest shrinkage movement occurs on first drying. A considerable part of this shrinkage is irreversible, that is it cannot be recovered on subsequent wetting.

FACTORS AFFECTING DRYING SHRINKAGE

Since drying shrinkage is related to moisture loss from the concrete, it is influenced by external factors that affect drying and also internal factors related to the concrete and its constituents

Figure 3.

External Factors

The external factors affecting loss of moisture from concrete are ambient conditions, and size and shape of the concrete member.

Ambient conditions Air temperature, relative humidity and wind velocity will affect the loss of moisture from the concrete surface. Reference 2 discusses how any combination of these factors affects the evaporation rate. Different ambient conditions on opposite sides of a member result in differential drying out, hence differential shrinkage with the possible consequence of warping.

When all other factors are equal, the typical effect of varying relative humidity on the drying shrinkage of concrete is shown in **Figure 4**³.

In summary, higher drying shrinkage is to be expected with rise in ambient temperature, with decrease in relative humidity, with increase in air movement around the concrete, and with increase in the length of time for which concrete is subjected to drying conditions.

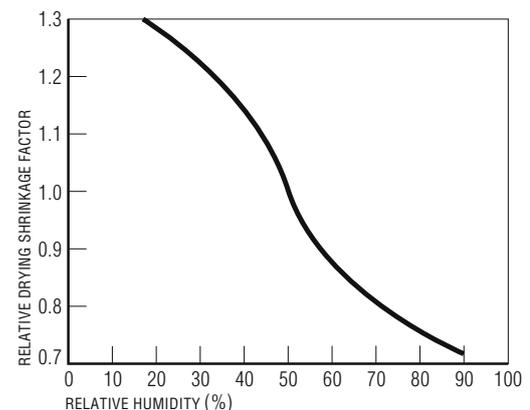


Figure 4 Effect of relative humidity on drying shrinkage

Member geometry Large, thick concrete members dry out more slowly than small, thin ones. As a result, for the same drying period, shrinkage of large-size members is lower than the smaller-size ones which can dry out to their cores more quickly.

The effect of concrete member geometry on drying shrinkage is represented in most codes and standards by its 'theoretical thickness' or hypothetical thickness which is defined as twice the area of the cross-section of the concrete member divided by the exposed perimeter of the cross-section. It follows that a higher theoretical thickness will be associated with a lower drying shrinkage.

Internal Factors

The internal factors affecting drying shrinkage of concrete are those related to its constituents: cements, aggregates, admixtures; concrete mix design; water-cement ratio and water content; aggregate properties and volume fraction; and those related to the construction of the concrete: placing, compaction and curing.

Cements Although it is generally concluded that the composition of cement can affect drying shrinkage the effect is not completely determined. The C_3A and alkali content have been observed to have a dominant effect⁴. In turn, the effect of C_3A and alkali content on shrinkage is influenced by the gypsum content of the cement, ie shrinkage of cements of the same C_3A content differs for different gypsum contents⁵.

As a result, for many years, some major specifications in Australia have been specifying the chemical composition of cement as a means of controlling shrinkage of concretes to be used in structures, such as road pavements and bridges. An example of the chemical limits included in those specifications is a maximum C_3A content of 7% and a minimum SO_3 content of 1.8%. It was recognised, however, that there are other cements outside these specifications which have performed well in low shrinkage concrete applications. This has led to the development of a cement characterised in terms of its shrinkage performance 'Shrinkage Limited Cement, Type SL'. Engineers/specifiers should not be concerned with the complex details of cement chemistry as it is the final performance that is important.

A reliable test method and associated performance criteria are required to characterise cement in terms of its shrinkage performance. Based on an extensive investigation by the cement industry under the auspice of the Australian Standards Committee BD/10, a standard test method for measuring the drying shrinkage of cement mortar has been established and is published as AS 2350.13. A maximum limit for drying shrinkage at 28 days is set at 750 microstrain for Type SL cement. This maximum

limit takes into account not only the performance of the cement but also the precision of the test method. The precision of the test method is such that the difference between two test results for 28-day drying shrinkage obtained in two different but experienced laboratories, under conditions of reproducibility, is expected to be up to 150 microstrain. So, for a cement to comply with the maximum limit of 750 microstrain a typical average result should be around 600 microstrain. This maximum limit also implies that it must not be exceeded by a single result.

It should be pointed out that the use of Type SL cement alone will not guarantee the production of low shrinkage concrete. As outlined in this article other factors are involved which should be considered as they may outweigh the effect of cement on the drying shrinkage of the concrete.

Aggregates Aggregates have a restraining effect on shrinkage. This effect is illustrated in **Figure 5**. However, the restraining effect varies and reports both from Australia and overseas show that some types of aggregate, if they shrink more than the paste, increase concrete shrinkage significantly⁶⁻⁸. This work shows that there is a reasonably direct relationship between the shrinkage of an aggregate and its absorption capacity. That is, good quality, low shrinkage aggregates are usually characterised by low absorption. If the aggregate shrinks less than the paste then the aggregate restrains shrinkage and the shrinkage of the concrete will decrease with increase of the aggregate volume fraction. The effect of aggregate volume fraction on drying shrinkage is shown in **Figure 6**⁹. Both **Figures 5 and 6** illustrate the substantial restraining effect of aggregates on the drying shrinkage of the paste. As can be seen, shrinkage of concrete may be only 20% of that of the cement paste.

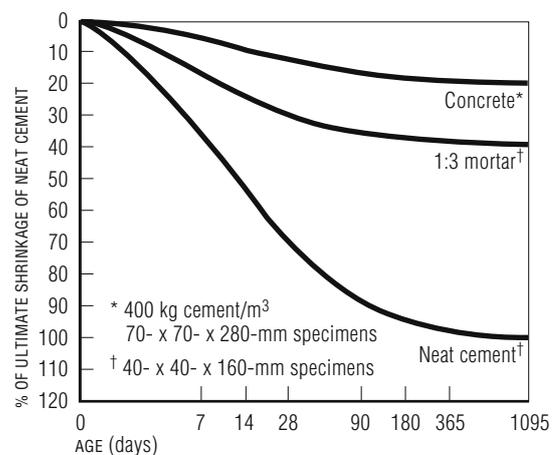


Figure 5 Comparative drying shrinkage of concrete, mortar and neat cement paste at 50% relative humidity

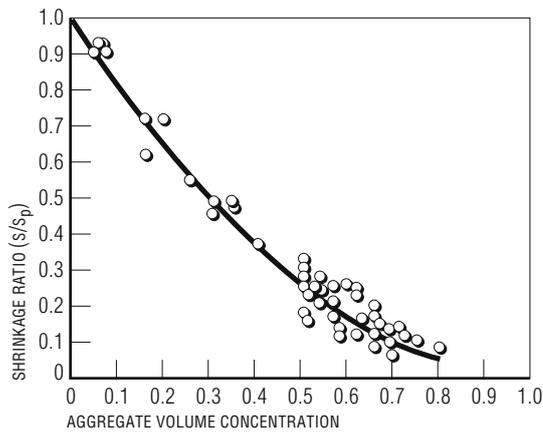


Figure 6 Effect of aggregate volume concentration on shrinkage

s = shrinkage of concrete

s_p = shrinkage of paste

Other aggregate properties such as grading, maximum size, shape and texture affect drying shrinkage indirectly. In practice variations in any of these properties can lead to a change in the water demand and/or paste content and their effect on drying shrinkage is only measurable in terms of the changes they cause to the concrete mix.

Aggregates can be contaminated by other materials such as silt, clay, coal, wood or organic matter. Most of these materials do not restrain shrinkage and in fact can increase it, especially in the case of clay which absorbs moisture and shrinks considerably on drying out. AS 2758.1 *Concrete Aggregates* specifies maximum limits for these materials. Most of these contaminating materials can be removed by washing the aggregate.

In summary, hard, dense aggregates with low absorption and high modulus of elasticity are important for the production of concrete of low drying shrinkage.

The effect of aggregate on restraining the drying shrinkage of concrete is governed by:

- The volume fraction of the aggregate
- The modulus of elasticity of the aggregate
- The shrinkage of the aggregate upon drying.

Admixtures There are many types of admixtures available for incorporation in concrete to achieve/enhance certain properties or to achieve economy or both. Generally, admixtures affect shrinkage of the concrete to a varying degree depending on their formulation, their interaction with the cement, their interaction with other admixtures in the mix, and on the variations or adjustments they bring about in the proportions of the concrete mix. A detailed discussion of the effect of various admixtures can be found elsewhere^{10,11}. It is well established that admixtures containing calcium chloride can increase the drying shrinkage of concrete.

Water content The drying shrinkage of concrete increases with increasing its water content. The variation in shrinkage with water content may be explained by the difference in types of water lost at the various stages of drying mentioned earlier. It is also associated with the modulus of elasticity of the concrete. Concrete of high water content (and high water-cement ratio) has a lower strength and lower modulus of elasticity and hence has a greater tendency to shrinkage. The effect of water-cement ratio on drying shrinkage is illustrated in **Figure 7**¹². As can be noted, at ages beyond 28 days, higher water-cement ratios lead to significant increase in drying shrinkage.

It has been advocated that high cement content always leads to higher drying shrinkage. This is not strictly correct as can be illustrated in **Figure 8**¹³ which shows that high performance/high strength concrete which is characterised by high cement content, low water content (hence low water-cement ratio) and good quality aggregate could have low shrinkage characteristics.

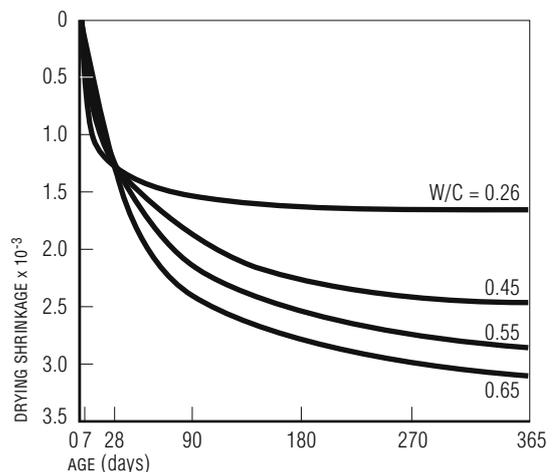


Figure 7 Effect of water-cement ratio on shrinkage of cement pastes

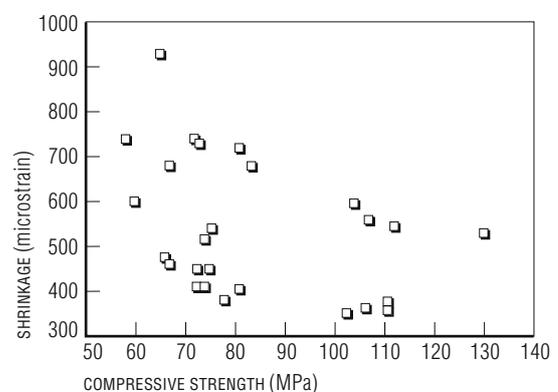


Figure 8 Drying shrinkage of HSC

Construction practice Concrete placing, compaction and curing are important factors in minimising the magnitude of drying shrinkage. Adding further water on site during placing of concrete to restore slump or to aid with final finishing will increase the drying shrinkage of concrete.

Proper compaction and curing are required to produce dense concrete of reduced capillaries and/or with discontinuous capillaries, resulting in reduced loss of moisture from the concrete and reduced drying shrinkage. Applying appropriate curing measures immediately after finishing the concrete will prevent drying of the concrete surface especially in hot weather conditions.

REDUCING CONCRETE DRYING SHRINKAGE

Some of the measures that can be taken to reduce the drying shrinkage of concrete include:

- Use the minimum water content (consistent with placing and finishing requirements).
- Use highest possible volume fraction of good quality aggregate and maximum possible aggregate size.
- Use Shrinkage Limited Cement (Type SL) where available.
- Do not use admixtures known to increase drying shrinkage, eg those containing calcium chloride.
- Ensure concrete is properly placed, compacted and cured.

DRYING SHRINKAGE CRACKS

Drying shrinkage is not a problem if the concrete is free to move. If the concrete is restrained in any way, drying shrinkage will introduce tensile stresses which if they exceed the tensile strength of the concrete, will cause the concrete to crack. Reducing drying shrinkage will not necessarily prevent cracking which is also influenced by the restraint and the design and detailing of the concrete element.

Shrinkage cracks, as opposed to flexural cracks, are parallel sided and in the case of slabs usually extend right through the slab thickness. Such cracks can cause water penetration/leakage and ultimately impair the durability of the concrete element.

Therefore, control of cracking due to drying shrinkage is important and requires appropriate design and detailing of the concrete element.

Adequate reinforcement Where cracking occurs, the spacing and width of shrinkage cracks depend upon the percentage of reinforcement in the restrained concrete and the bond characteristics of the reinforcement. The provision and location of adequate reinforcement to distribute the tensile stress caused by drying shrinkage is particularly important in slabs-on-ground and similar applications where

reinforcement may not be required for structural reasons. AS 3600 gives minimum percentages of primary and secondary reinforcement to control cracking due to drying shrinkage and thermal stresses in reinforced concrete slabs, depending on the degree of restraint.

Whilst reinforcement resists tensile stresses in restrained concrete and helps prevent the formation of large cracks, it does not completely prevent cracking, but ensures that the cracks, as they occur, are more closely spaced and of a smaller width. In properly designed reinforced concrete, they will be invisible to the naked eye.

Joints The provision and location of contraction joints permit movement as a result of drying shrinkage. Unreinforced concrete will tend to develop larger cracks at irregular intervals wherever the tensile strength of the concrete is exceeded by the stresses induced by drying shrinkage. To prevent such cracks, contraction joints should be installed at appropriate intervals. It may also be more economical to install contraction joints in reinforced concrete than to rely on reinforcement to control shrinkage stresses. The location of contraction joints is a matter for the designer but normally they will be situated where the greatest concentration of stresses due to drying shrinkage are to be expected: at openings; at sudden changes in cross-section; in long walls; and in large areas of concrete pavement where they are used to divide the concrete into approximately square bays.

CONCLUSION

The importance of the many influences on concrete shrinkage cannot be too highly emphasised, including concrete constituents, construction practices, ambient conditions, geometry and design and detailing of the concrete element.

Whilst the influence of cement is important, obviously it is not the only influence. Indeed in most situations other factors will have an equal, if not over-riding influence. It is the mix design of concrete, proper construction techniques and appropriate design and detailing that will produce concrete of low shrinkage characteristics.

REFERENCES

- 1 *Fulton's Concrete Technology, Seventh (revised) edition* edited by B J Addis, Portland Cement Institute, South Africa, 1994.
- 2 ACI Committee 308 *Standard Practice for Curing Concrete* ACI Manual of Concrete Practice, Part 2, 2001.
- 3 Blakey, F A, *Influence of Creep and Shrinkage on Structural Behaviour* Constructional Review, November 1963, pp 15–21.

- 4 Roper, H, *Shrinkage Tensile Creep and Cracking Tendency of Concretes* Australian Road Research, Vol. 5, No. 6, December 1974, pp 26–35.
- 5 Pickett, G, *Effect of Gypsum Content and Other Factors on Shrinkage of Concrete Prisms* Proceedings, American Concrete Institute, Vol. 44, October 1974, pp 149–175.
- 6 Welch, G B, *Creep and Drying Shrinkage Characteristics of NSW Concrete* Concrete Institute of Australia, Special Publication No. 1, Shrinkage and Creep, 1978.
- 7 Roper, H, *The Properties of Concrete Manufactured with Coarse Aggregate of the Sydney Area* University of Sydney, Research Report R204, January, 1973.
- 8 L'Hermite, R G, *Volume Changes of Concrete* Proceedings 4th International Symposium on Chemistry of Cement, Session V, Paper 3, 1960.
- 9 Hobbs, D W and Parrott, L J, *Prediction of Drying Shrinkage Concrete* Beton Nr28, 1982.
- 10 Morgan, D R, *Effects of Chemical Admixtures on Creep and Shrinkage of Concrete Paper* presented at a Workshop on the Use of Chemical Admixtures in Concrete, University of NSW, Sydney, 1975.
- 11 Popovics, S, *Concrete Materials – Properties, Specifications and Testing* Second Edition, pp 221–271, Noyes Publications, 1992.
- 12 Soroka, I, *Portland Cement Paste and Concrete* Macmillan Press Ltd, 1979.
- 13 *High Strength Concrete* National Ready Mixed Concrete Association of Australasia and the Cement and Concrete Association of Australia, 1992.

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