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The Importance of the Factors Affecting Concrete Shrinkage

1 Purpose

This paper summarises the research on the causes creating shrinkage strains in concrete and thus the likelihood of shrinkage cracking, illustrates the conflicting requirements in the selection of concrete properties and attributes and provides information on the relevance of the accurate specification requirements as far as shrinkage limits are concerned.

Note:

1 Reference should also be made to PIN 11 (14 05 2008) – Control of Thermal and Drying Shrinkage in Lean Concrete Subbases.

2 For brevity I have not quoted all the references of the information herein, but these are available if anybody wishes to follow them up.

2 What causes Shrinkage?

Shrinkage of concrete is made up from three processes: autogenous shrinkage, drying shrinkage and thermal contraction, all of which can have variable magnitudes.

Autogenous shrinkage occurs in low w/c concretes and produces significant tensile stress which adds to the tensile stresses from drying shrinkage and thermal contraction. Normally this amounts to about 50 - 100 µm, but at low w/c, WRAs and flyash this can increase significantly. It disappears when the w/c is increased to above 0.55 and high fineness cements are avoided.

The loss of water from hardened concrete (stored in unsaturated air) causes **drying shrinkage**. Shrinkage of hardened concrete is influenced by various factors in a similar manner to creep under drying conditions. High cementitious materials content, particularly fine particles will reduce bleeding, but increase long term drying shrinkage. (The time of sawing the joints for induced cracking is now more important).

It is the Modulus of Elasticity of the concrete that most prominently influences drying shrinkage. A change in the Modulus, which is also dependant of the gain in strength with time, will cause considerable change in shrinkage. This is illustrated by the following results from Troxler, Raphael and Davis – Proc. ASTM 101-20 (1958), for an identical mix, but using different aggregates.

Aggregate	28 day shrinkage µm	10 year shrinkage µm
Sandstone	400	1130
Gravel	420	1000
Basalt	290	780

Granite	170	780
Limestone	200	550
Quartz	150	420

Even though the rate of shrinkage decreases rapidly with time, eg
An average of 25% of 20 year shrinkage occurs in 2 weeks;
An average of 60% of 20 year shrinkage occurs in 3 months; and
An average of 75% of 20 year shrinkage occurs in 1 year, the actual shrinkage stresses will increase with the hardening of the concrete.

The relationship between drying shrinkage and indirect tensile strength of concrete is given by the ARBP – CRSI Manual for Design of Continuously Reinforced Concrete for Highways:

Indirect tensile Strength - MPa	Shrinkage µm
2.1 or less	800
2.8	600
3.4	450
4.1	300
4.8 or more	200

This is an important relationship showing that the potential shrinkage decreases with the development of the (indirect) tensile strength.

Thermal contraction. There are significant differences in the Coefficient of Expansion of concrete using different aggregates:
Limestone - 6.8 x 10^{-6}/ºC
Basalt - 8.6 x 10^{-6}/ºC
Granite - 9.5 x 10^{-6}/ºC
Sand and gravel - 10.8 x 10^{-6}/ºC
Quartzite - 12.2 x 10^{-6}/ºC,
and hence there is about 100% difference in the shrinkage characteristics of concrete mixes with different aggregates. The remark by Harmon Meissner (1942) is very valid in these circumstances: *Nature has provided us with these aggregates and we should not find fault simply because man's product disagrees with them. We do not trim the foot when a shoe pinches, but secure a proper fit instead and it seems that the same remedy is logical for the troubles under discussion.*

In pavement design these variations are not recognised and an average of 10 x 10^{-6}/ºC is adopted. Obviously this is not correct in all circumstances.

The average expansion of fresh concrete is actually 23 x 10^{-6}/ºC, which means that with the mix placement temperature and heat of hydration, appreciable expansion occurs before the before the initial set of the concrete takes place.

Partial replacement of cement by pozzolan reduces the strength in early ages, thus also reducing the heat of hydration and hence the subsequent temperature shrinkage.

3 Variations in Specified or Nominated Requirements for Drying Shrinkage by Different Authorities

1 **AS 3600**. The Australian Standard "allows a basic shrinkage strain in concrete to be **850 µm**. For structural designs, this is multiplied by a factor which is a function of

the thickness of the slab. It also notes that shrinkage measurements have an accuracy of ± 30%, hence the range is 595-1105 μm.

2 **AUSTROADS** Pavement Design Guide recommends 500-**600** μm as maximum for total shrinkage. It also states that *the **estimated** shrinkage strain may be considered to be in the range 200-300 μm with the laboratory shrinkage not exceeding 450 μm (with 3 weeks drying).For the **estimated** maximum thermal strain from peak hydration temperature to the lowest seasonal temperature, a value of 300 μm **may be assumed**.*

3 **RTA** Specification **R82** for Lean Concrete Subbases specifies **550** μm as the maximum for concretes with maximum aggregate size ≤ 20 mm.

4 **RTA** Specifications **R83/84** for PCP and CRCP specify **450** μm, but state that this is only applicable to trial mixes.

5 **RTA** Specification **B80** for Structural Concrete specifies **550** μm

The above illustrates the uncertainty of giving even laboratory shrinkage meaningful limits. None of the references provide any commentary as to whether these can be replicated in the field. The fact that there is such a wide variation, infers that all cannot be correct.

4 To Shrink or not to Shrink?

A valuable and informative commentary is provided by the Professor P F Dux of the School of Civil Engineering in University of Queensland in his paper: "Importance of Concrete Drying Shrinkage in Construction". (CIA/IEAust/APMCA Seminar Proceedings: "To Shrink or Not to Shrink – That is the Question" (2000)).

In a very detailed paper he gives examples from research and draws a lot of conclusions. In summary his pertinent points are:

1 It is increasingly common for a minor deviation from the specification to be viewed seriously;

2 If the construction develops defects that might be ascribed to shrinkage, the assumption being that a tight shrinkage specification should produce a desirable outcome. This in reality may be quite wrong;

3 The specifications with low shrinkage limits began with the desire to eliminate dimensionally unstable aggregates from concrete. This led to the 56 day shrinkage test limit of 1000 microstrain, which remains the standard N class limit;

4 If shrinkage is to be used in design, a reliable prediction method is needed. In accordance with AS 3600, the best would have an accuracy range of ± 30%;

5 He argued that whether a concrete is 500 μm or 600 μm is of no practical significance;

6 The average strain in concrete at the time of cracking is about 115 μm; (AT: Compare this with the tables under 2 above).

7 Drying shrinkage cracks may initiate in susceptible zones and propagate under the effects of stress concentration, despite the notional average stress being well under the design tensile stress. This points to uneven vibration, hence compaction and thus strength variations;

8 Often only a part of the slab is affected even though the potential exposure to the atmosphere is uniform. This implies that if conditions are generally around critical, small environmental changes or small changes in the mix can tip the balance;

9 Cracking can be intense and random;

10 Bleeding helps to reduce plastic cracking;

11 It is only a convention to specify a shrinkage limit of 600 µm or less to prestressed concrete slabs;

12 If the mix has reduced susceptibility to bleed, it is most likely to have increased susceptibility to plastic cracking;

13 Shrinkage reduction can be achieved through mix design;

14 **The specified shrinkage value should not be arbitrarily selected without reference to the supplier's ability to meet the specification;**

15 **A tight shrinkage specification is no guarantee of successful outcome;**

16 It is prudent to accept that cracking and other shrinkage related effects are unlikely to be eliminated. This should lead to critical assessment of details and systems in order to control the effects.

5 Summary of Factors Affecting Shrinkage

1. Coarse sands **reduce** volumetric shrinkage.

2. Fineness Modulus (FM) of fine aggregate is typically 2.3 to 3.1. The smaller number indicates fine sand. FMs of 3.1+ provide **minimum** shrinkage.

   FM = Σ[% retained on 150 µm to 9.5 mm sieves]/100

3. Larger coarse aggregate **reduces** the amount of paste/mortar, thus reducing shrinkage.

4. Larger aggregate and denser grading **reduces** the amount of shrinkage**.**

5. Drying shrinkage occurs all in the cement paste**.**

6. A reduction of cement in paste **reduces** the amount of shrinkage and thermal deformation (i.e. curling) during curing.

7. A total water content of less than 145 l/m^3 and paste volume of less than 60% are **recommended** for minimum shrinkage.

8. Partial replacement of cement by pozzolan **reduces** the strength in early ages with a reduction of the heat of hydration and hence the temperature shrinkage.

9. Mixes with high creep characteristics will absorb some of the shrinkage stresses and hence exhibit **less cracking**.

10. High cementitious materials content, particularly of fine particles, will reduce bleeding, but **increase** long term drying shrinkage.

11. The higher the strength, the higher the Modulus and hence the loss of creep capacity and thus **increase** in the amount of cracking.

12. Dirty, silty aggregates can **increase** shrinkage beyond that expected from their effect on the water content.

13. Use of accelerators will **increase** the early strength of concrete and hence there is an increase to creep resistance and as a corollary makes the concrete more prone to cracking.

14. The higher the likely shrinkage, the earlier joint induction is required.

15. Shrinkage of concrete is related to the absorptivity of the aggregate, e.g. shrinkage of sandstone is four times that of quartz.

16. For a given aggregate content, shrinkage of concrete is also a function of the w/c ratio.

17. It has been found that drying shrinkage with different cements varied by a factor of at least two and the different aggregates also caused a factor of two variations. Hence for the same mix proportions, **shrinkage could vary four fold.**

18. A number of studies in the US have shown that by increasing the compressive strength from 20 MPa to 27 MPa, there was a notable **increase** in cracking. (In some States the actual cement content has now been reduced to pre-existing conditions). Authorities need to evaluate the value of increases in strength against the concern of aggravated cracking.

19. A Kansas study (1995) showed that bridge decks with 45 MPa concrete had three times the cracking of 31 MPa concrete.

20. Another 1995 study revealed that the lower the w/c ratio, the more cracking occurred

6 Conclusions

1 Many factors affect shrinkage, with a number of these being outside the control of the user;

2 There is no cracking that can be defined as “planned” or “unplanned”;

3 The cumulative shrinkage stresses can be such that some cracking cannot be avoided;

4 Cracking is always due to a number of factors where any one can “tip the balance”;

5 The generally 90% methods and 10% end product specifications will create conflicting requirements which will cause different levels of cracking, eg the higher the strength requirement the more cracking is likely. (AT: I note that the low strength concrete for LCS has a higher acceptance limit (550 μm) compared to that

of the high strength base concrete (450 µm), this in itself is a conflicting requirement);

6 The shrinkage limits nominated for the trial mixes should be regarded as a guide, as the field conditions may be quite different;

7 There are measures that will reduce the amount of cracking and these should always be practiced;

8 It is incorrect for any Specifications to nominate the actual acceptable quantum of cracking that is acceptable;

9 Variations in the Trial Mix shrinkage will not affect the end product.

10 The laboratory tests do not represent actual field conditions and would not reflect the likely shrinkage cracking during the development of the (indirect) tensile strength of the concrete.