TMC	TMC – Tinni Management Consulting	Issue No.
	PAVEMENT INFORMATION NOTE	**11**
Edited by Arvo Tinni. Email arvo@tinni.com.au		14 05 2008

CONTROL OF THERMAL AND DRYING SHRINKAGE IN LEAN CONCRETE SUBBASES

1 PURPOSE

The purpose of this PIN is to explain the reasons for early age shrinkage cracking in concrete pavements, with particular emphasis on Lean Mix Concrete subbases. The predominant causes are discussed and suitable actions to reduce the likelihood, or at least the amount of shrinkage, listed.

2 SIGNIFICANCE

It is normal for expansion (or shrinkage) to start soon after mixing and the subsequent shrinkage to continue for a long time afterwards. There are a number of mechanisms that cause this to happen. The more significant ones are the thermal and drying effects. Because pavement concrete shrinkage movements are generally restrained in some way, concrete almost always cracks. This occurs when the concrete has not gained sufficient (tensile) strength to withstand the internal stresses due to shrinkage. Uncontrolled cracks that form at early ages may grow due to mechanical and environmental stresses.

In concrete pavement design, the LCS is not a structural component of the pavement structure. This fact is emphasised by the Austroads Pavement Design Guide (2004) which amongst other, states that: *"LMC subbases are constructed as mass concrete without transverse joints and will therefore develop cracks. It is* ***intended to achieve a pattern of relatively close spaced and narrow cracks that provide a degree of load transfer*** *and which in conjunction with the debonding layer will not reflect into the base".*

3 SIMPLE DEFINITIONS

Shrinkage is a decrease in length or volume loss of concrete due to thermal contraction or moisture loss.

Thermal shrinkage occurs when the concrete cools from the heat effect of the ambient temperature and the heat generated by the hydration of cement. (For road pavements, the peak temperature could be as high as 60ºC [RTA]).

Drying shrinkage occurs after the concrete has set. It is caused from the tensile stresses set up in the air voids when free water is used up in the hydration of the cement. If the shrinkage is restrained, drying shrinkage cracking will occur. This may also cause widening or propagation of cracks that may have already occurred.

4 MAIN FACTORS AFFECTING THERMAL AND DRYING SHRINKAGE

The effect of these will be individually variable, but the result is cumulative. The main factors are:

- Aggregate type
- Cement content
- W/C ratio
- Temperature range
- Curing efficiency

Of these, the **aggregate type** has the greatest influence as aggregates make up 60 – 75% of the concrete by volume. The larger the aggregate, the lower the shrinkage.

5 COEFFICIENT OF THERMAL EXPANSION

Thermal expansion and hence subsequent shrinkage starts with the mixing of concrete. In hot weather the pavement temperature rises before the Initial Set, which is when the heating from the hydration of the cement commences. From then on it is cumulative.

The variation in the Coefficients of Thermal Expansion (in 10^{-6}/ºC) for different coarse aggregates is illustrated below:

Marble	4 -7
Limestone	6
Basalt	6 - 8
Granite	7 – 9
Dolomite	7 - 10
Sandstone	11 – 12
Quartzite	11 – 13

It is important to note that the thermal expansion characteristics for **cement paste/mortar**, i.e. the plastic concrete, are about three times higher than for the set concrete:

For	W/C = 0.4	18 – 20
	W/C = 0.5	18 - 20
	W/C = 0.6	18 – 20

If our most common coarse aggregates are basalt and river gravel (quartzite) then the variation in their CoTE could be 220% which could be significant in producing unplanned cracks in one instance, but not in another. In practical terms, a 4.2 m basalt aggregate pavement base slab that is subjected to a 50ºC temperature differential could have a length change of **1.26 mm** compared to a quartzite aggregate slab which would have **2.73** mm.

Specifications require that the transverse shrinkage crack spacing in the LMC subbases should be in the range 3 m to 15 m. For a similar 50ºC drop in temperature, for the 3 m spacing the crack width in basalt aggregate concrete could be **0.9 mm** and for quartzite **1.95 mm**. At 15 m these would become **4.5 mm** and **9.75 mm** respectively.

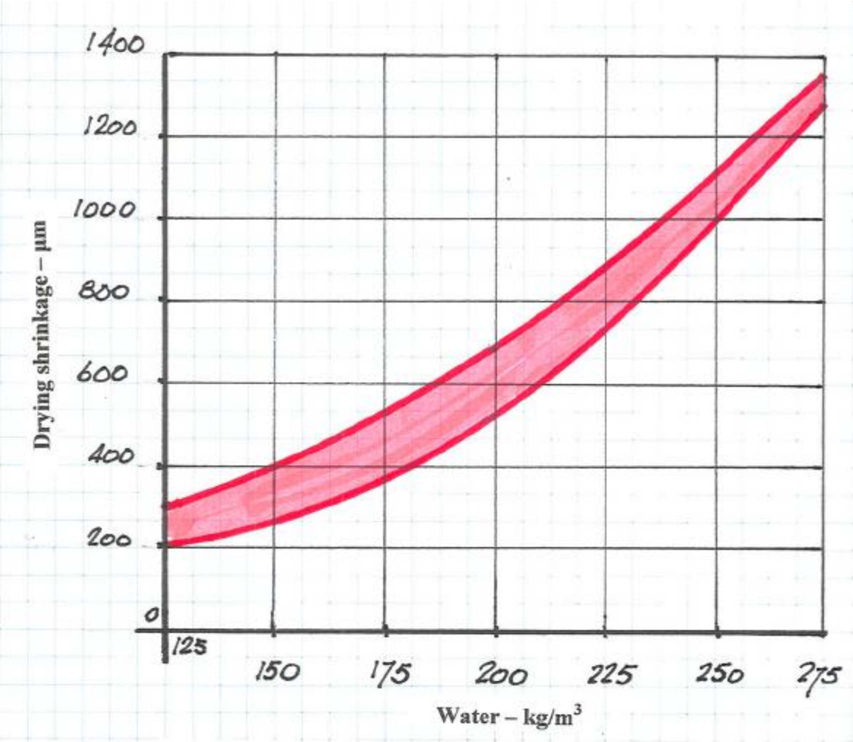
The higher the **cement content**, the higher the concrete temperature from heat of hydration, which in turn will cause greater expansion and hence subsequent shrinkage. This also requires more water to hydrate the cement and thus there will be also an increase in the magnitude of drying shrinkage.

.

6 FACTORS THAT CAN BE PARTIALLY CONTROLLED

There are a number of factors that affect the magnitude of shrinkage. These have a cumulative effect, but in most cases they are at least partially controllable to minimise the amount of cracking:

- The effect of the volume of water per unit volume of the concrete is illustrated by the following graph. The importance of minimum variations in water content between different batches is obvious.



Relationship between total water content and drying shrinkage. (Drying shrinkage increases with increasing water content).

- The total shrinkage can be minimised by keeping the water (or paste) content in the concrete as low as possible. (For even cracking, it stands to reason that an even water content, i.e. W/C ratio, should be maintained throughout the batches.)
- The W/C also has a direct bearing on the strength of the concrete. Recent tests have shown core strength variations of up to 50%, which are attributable to the variations in the water content in the mix. This must be avoided as far as possible. Cracking will occur along the weakest locations and hence quite irregular patterns can result.

- The higher the cement content, the greater the magnitude of drying shrinkage.
- The paste/mortar content can be minimised by keeping the total coarse aggregate content as high as possible while achieving workability and minimising segregation.
- Avoiding aggregates that contain excessive amounts of clay in the fines. (Here it might be noted that these fines are beneficial for reducing bleeding.)
- Quartz, granite, felspar, limestone and dolomite aggregates generally produce concretes with low drying shrinkage, but with higher thermal shrinkage.
- The right weather conditions such as air temperature, wind, relative humidity and sunlight all influence concrete hydration and shrinkage. These, of course, are not controllable in practice, but their influence can be minimised.
- The use and optimum dosage of retarders (in hot weather) must be evaluated as part of the Trial Mix process. The importance of these is discussed in the following Section.

Note: It has been shown that cement types and use of flyash have little direct effect on shrinkage (IMCP).

7 CAUTION REGARDING USE OF RETARDERS

One of the popular and approved retarders is Pozzolith 300 Ri. It is important to be aware of its effect and dosage requirements. The essentials are summarised as follows:

a. It is manufactured by BASF. The applicable extracts from the manufacturer's recommendations are:

- "Mild to extended retardation".
-

Ambient Temperature °C	Recommended dose range mls per 100kg		
	Characteristic strength (MPa)		
	25 - 30	30 - 35	40+
20 - 25	200	250	300
30 - 35	250	300	350
40+	300	350	400

For the 5 MPa LMC the dosages in the 25 – 30 MPa column should be used.

b. **Comment by M van Koeverden of CQT Services** in Report to Abigroup Contractors dated 5 May 2008: "*Pozzolith 300Ri has a long history of use and within the manufacturer's dose rates will be stable and consistent in performance. The Author has had extensive experience with the admixture and in particular has found Pozzolith 300Ri to be inconsistent in performance above the BASF 300 ml/100 kg of cementitious recommended dose and of little benefit as a water reducer beneath the 200 ml/100 kg recommended dose.*

It is believed that using Pozzolith 300Ri outside this dose range may be less stable to environmental fluctuations".

c. The effect of delaying the Initial Set.

We use retarders to ensure that the Initial Set does not occur before the placement and finishing of particular concrete has been completed. Generally this is in hot weather when the ambient temperature is or is likely to be well above the concrete temperature at delivery. The magnitude of the shrinkage is dependent on the temperature difference between the maximum pavement temperature and that of the cooled pavement.

The following generic graph illustrates the effect of the use of retarders on the temperature build-up, the subsequent cooling and the consequential shrinkage.

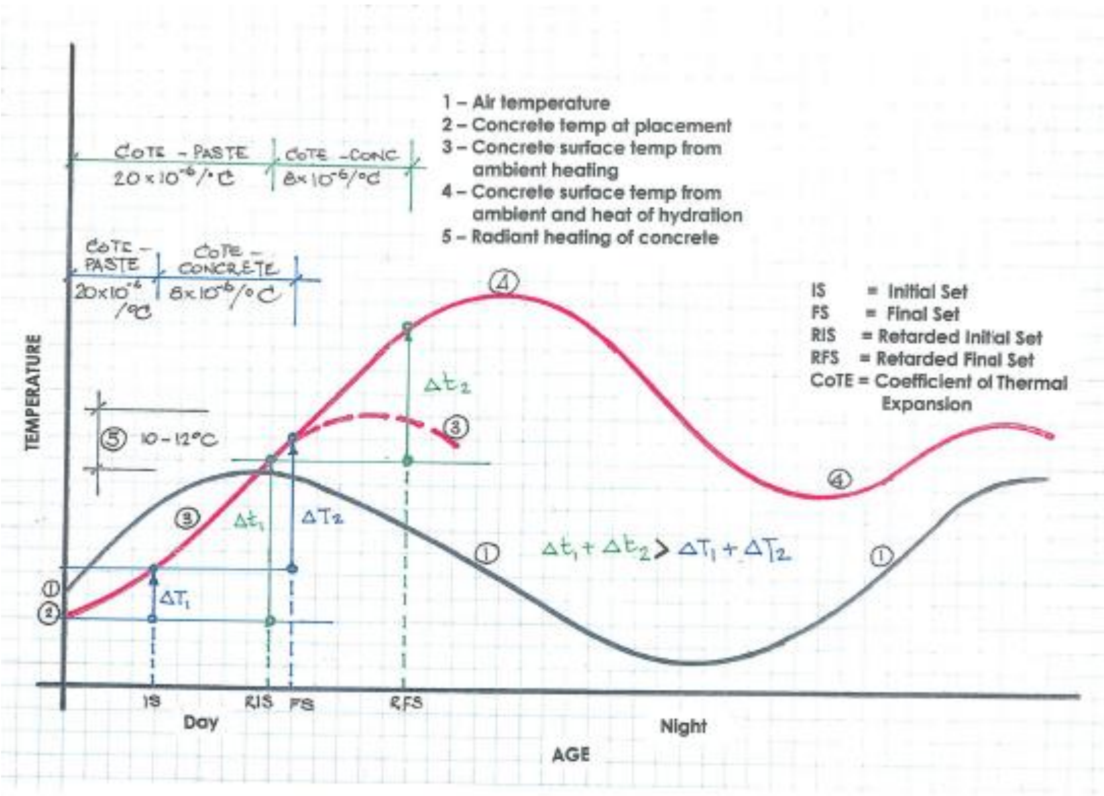


ILLUSTRATION OF THE EFFECT OF RETARDERS ON EARLY EXPANSION AND SUBSEQUENT SHRINKAGE

Even though the Initial Set of the concrete is being delayed, the plastic concrete still expands as it is being warmed up by the higher ambient temperature. This rate of expansion is about three times more than that of the hardened concrete, eg if the concrete temperature rises 10ºC before the Initial Set occurs, it has expanded to the equivalent of 30ºC rise in hardened concrete. This 30 degrees probably equates to that caused by the heat of hydration of the cement. In winter casting this is not an issue, but for summer casting it is important to be aware of the need to have the retarder dosage that does only extend the Initial Set to a practical time. The detrimental effect of over dosage must be appreciated.