MOISTURE CONTROL ON VOLUME STABILITY IN CEMENTITIOUS REPAIRS

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ABSTRACT

The focus of this presentation will relate to the cementitious medium of repairs. It will cover certain aspects of cement properties and its interaction with pore water formed in the repair zone. It concludes in the influence of moisture control in curing to maintain Volume Stability in the repair.

Initially viewing water cement ratios and the importance of early interaction between cement particles on the pore water structure is imperative to control impermeability and encourage early strength gain. Product performance is based on distance of the binder particles from each other and the need to marry these particles together at the earliest possible time. This expected interaction of particles is inherent in permeability control and strength gain.

Moisture losses in the plastic state during the first four hours are of particular importance followed by reactive time between cement and water and the need to encourage early state curing. The surface area of the finer constituents in a repair mortar have a marked influence on the availability of the pore water and subsequent product performance and repair volume. Internal and external curing is an aid to this end.
The performance requirement of low and high grade curing mediums for short and long term applications will be viewed.

Keywords
Repair Mortar, Cementitious, Pore water, Shrinkage, Volume Stability.

INTRODUCTION

This presentation will focus on the cementitious medium of repairs, with specific reference to pore water and capillaries formed in the repair material. It will highlight the influence which moisture has on Volume Stability and Impermeability in the repair.

STRUCTURES AND ZONES OF PERMEABILITY

Deterioration of existing structures are initiated many times by weak permeable zones in the concrete. These weak zones need not be created purely by physical (or visual) weaknesses such as grout leakage, cracks, honey-combing, or low cover zones. Other factors that cause permeability relate to conditions where moisture has been allowed to migrate upwards in the plastic concrete (during placing) increasing the water: cement ratio. This increasing w:c ratio in the mix most times happens at the highest level of a structure, poured in situ, where it appears as bleed water. The finished structure in many cases provides no clue to this state of permeability. Columns, retaining walls, deep beams and parapets are practical examples of structures likely to generate this condition. These upper areas are now permeable and are susceptible to attack.

Chloride Penetration

Surfaces of concrete structures capture chlorides from different sources (ie atmospheric chemicals, aerosols, wind blown chloride rich sands, Industrial pollution, soils, recycled water, garden sprayers etc.). Migration of chlorides takes place over rough concrete surfaces by condensation water capturing the free chlorides and focussing their flow via migration paths along the concrete structure. This condition is relevant for elements in vertical faces of a structure (such as windowsills, reveals, lintel beams or even parapets and ring beams) as well as horizontal structures, such as floors (the lowest element of any catchment area), where chlorides are deposited. These structural elements then offer zones of penetration to the migrating chloride ions. The inward migration is encouraged by wetting and drying (condensation overnight and drying during the day) and diffuses through concrete (even water filled pores) resulting in reinforcing corrosion and structural deterioration.

Middle East influence on Repair Mortar properties

Sand cement mixes have a long history in the repair industry and with hindsight past repairs and their performance in the gulf environments aggressive conditions are observed. Improvements in repair mortars (in moisture control, volume stability and impermeability without compromising strength and workability) are being constantly achieved. Repairs of repairs, are common in the Gulf and are very costly. Repair materials are constantly being improved to eliminate those unnecessary expenses.

Moisture losses in the plastic state in the mix

The first four hours of a mortar's life are crucial (even more so than concrete -speaking specifically of the effect of rapid drying in the plastic state). The Gulf's demanding climate has sparked off a need to improve the reactive time between cement and water while simultaneously ensuring optimum moisture retention in the plastic state. We talk of micro-concretes in the repair industry and that title best describes the physical characteristic of fineness in raw material making up a repair mortar. Fine constituents in the mix and the corresponding effect of their large (high) surface area's influence on the pore water are important to the product performance and repair volume. Considering the high temperatures and drying winds, control of the pore water is extremely demanding.

The influence of increased surface area resulting from reducing particle size of raw materials (making up a repair mortar) will be discussed throughout this presentation.

Moisture control in the hardened state

To improve impermeability a low water:cement ratio is required. Volume stability is safeguarded by a constant supply of hydration (pore) water, while impermeability is ensured by minimising pore water. Losses in gel water drives the shrinkage action, while losses of capillary water from open ended pores drives the permeability activity.

Remembering the large surface area to be covered (serviced) by the moisture in the high fines mix of a repair mortar, brings to mind the importance for practical control of pore water during the plastic and hardening state. Internal and external curing is an aid to this end.

THE RELATIONSHIP BETWEEN WATER AND CEMENT

Water/Cement ratio

As has been previously mentioned, early interaction between cement particles in the pore water structure is imperative to control impermeability and encourage early strength gain. Repair mortar performance is based on distance of the binder particles from each other and the need to achieve early interlock between these particles to provide rapid strength gain. This early interaction of particles is inherent in permeability control and strength gain and is encouraged in mortar design. The reaction (being hydration of the cement particles) encourages ettringite crystal growth, described in various works as long needle like crystals, along with CH crystals on the cement surface.

Should the spaces between the cement particles be too great (ie too high a water content in the mix) the needles or crystals will not interact sufficiently quickly, nor will the water be effectively bound into the matrix. This results in rapid loss of moisture after curing and voids are created around the cement particles which is the cause of high permeability. Once the voids become large enough to be continuous in the hardened mortar the resulting effect is pore water losses . The concrete accepts and transports liquids through these channels easily, into the structures depths taking with it chemical contaminants such as chlorides and sulfates. It is often seen in renders on structures where moisture from ground water and garden sprays is transported within the structure upwards. This rising damp is often experienced in low performance renders mortars and in concrete structures at ground level

Repairs are expected to fix sensitive zones of structures permanently. As a result repair mortars have to have properties capable of withstanding moisture migration and resist pore water losses while simultaneously maintaining the fixed dimension of the wound.

Cementitious materials go through volume changes in both the plastic and throughout its life in the solid state. Volume changes in the solid state relate to shrinkage and creep. Loss of moisture leads to shrinkage and applied loads lead to moisture loss and subsequent creep. Mortars have extremely high potential for shrinkage due to the absence of the large dimension aggregate available in concrete, which have a practical influence on its dimension. Repair mortars are designed to overcome the obstacles described above by being impermeable, shrinkage controlled (or Volume Stable as we shall call it) in both the plastic and hardened state.

Surface area of cementitious content - A simplistic model

Powers[1] showed that one volume of cement hydrates and increases to a volume of 2.2 times its original dimension taking into account voids (porosity).
The principle hydratable cementitious products (cement included) in reaction with water, cause the development of gel (which form into platelets) and cement particles (still part of the gel) supplement the formation of crystals which are described as needles growing from the surface of the cement particles. Grains of cement react with water (they hydrate) and form needles (or crystals) which gradually increase in length, all the while encroaching on the surrounding passages containing water, see Fig. 1. This growth then ensures interlinking with the surrounding crystallizing cement particles while simultaneously penetrating the capillaries and pores of the developing cement paste matrix. These needles intertwine through surrounding platelets penetrating and forming an extremely rigid cross-linked matrix also locking into the irregularities of the aggregate shapes, Fig. 2.

The more they grow over a period of time the stronger the interlock or bond becomes between adjacent particles. The quicker these needles come in contact with their opposing platelets and become interlocked the greater the advantage of the cement in the strength growth development. It then becomes obvious that the closer these cement particles are the greater the opportunity for early strength gain, Fig. 3. Of course water plays a key role, as the crystals cannot form without the presence of moisture

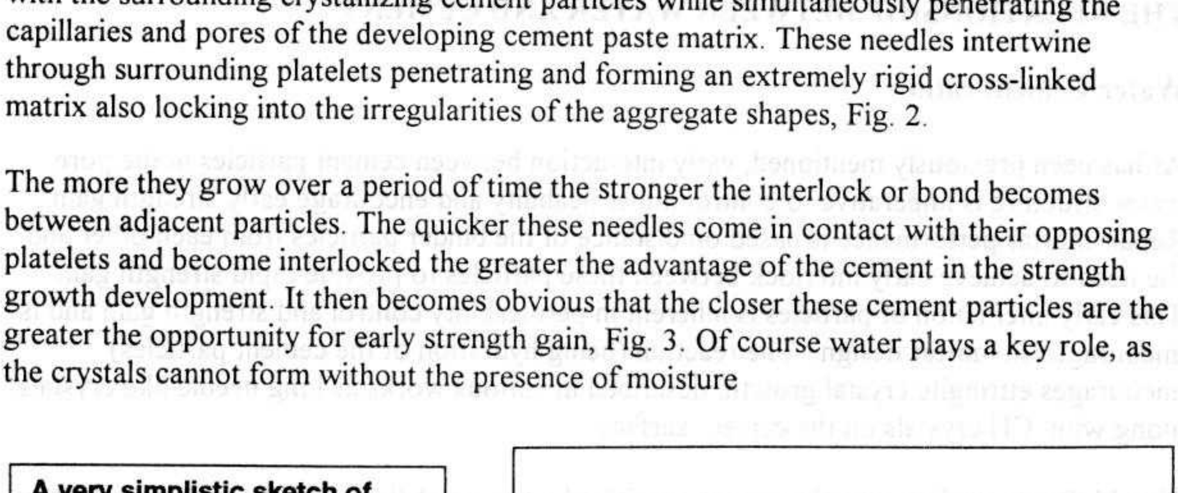

Fig. 1: Crystal growth from cement particles

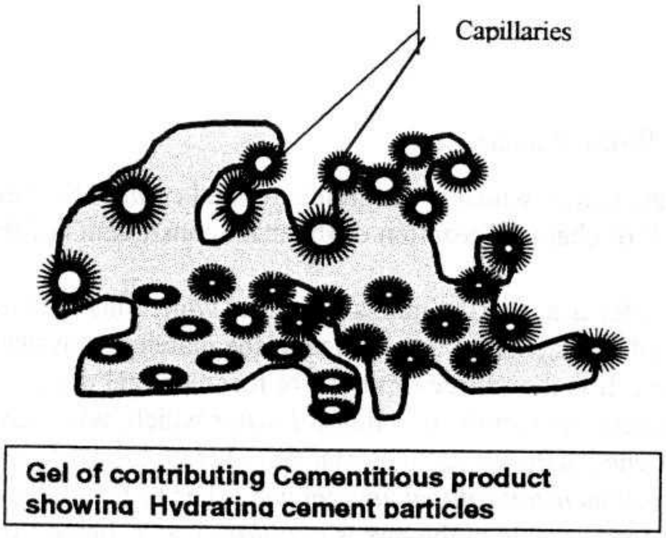

Fig. 2: Sketch showing gel platelets and cement crystals

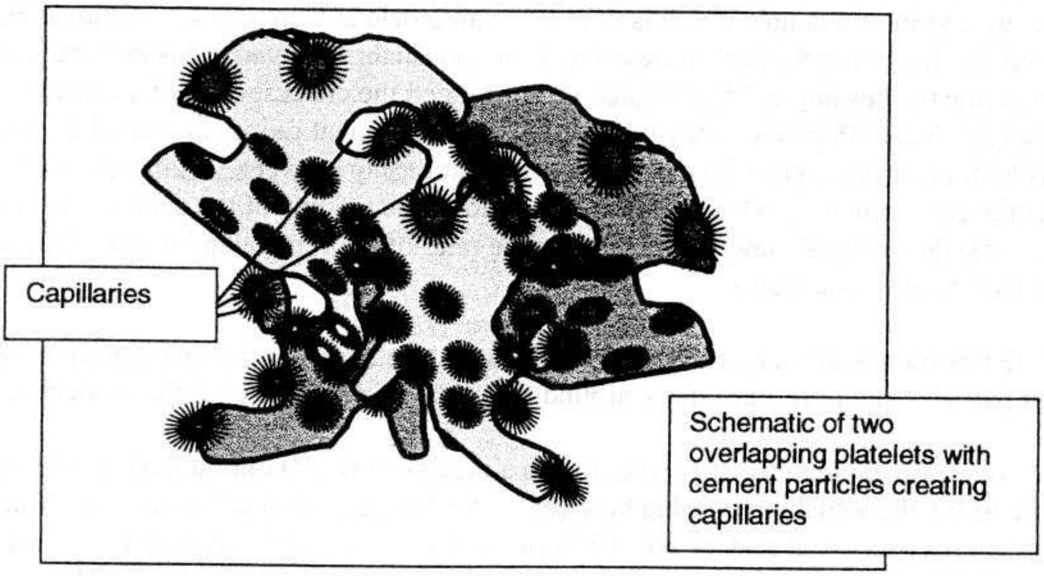

Fig. 3: Two overlapping platelets showing gel pores forming, the larger spaces around the platelets would signify capillaries

Water in the mix.

Water is present in three forms in a mix.

- First as non-evaporable water, which is commonly termed *combined water*. This water is held tight as a result of chemical reaction of the main constituents of the hydration process.
- The second state of water usage in the mix is the water which fills the voids between the particles of cement and is attached to the surface of the platelets, physically held or adsorbed by the matrix. It is the source of moisture for initial gel platelet development and later the development of crystals. It is this *gel water* which, when lost, causes the dimension of the hardened state concrete/mortar to reduce (shrinkage results). For structural stability this *dimension influencing* gel water has to be controlled.
- The third state of water available in the mix is *capillary water*, being the space around the solids, consisting entirely of water, which contributes minimally to the concrete solid matrix development. This water is the source of plastic state moisture losses and is most active. It is likely to dissipate out of the matrix in the plastic state causing voids within the concrete in the form of continuous channels (capillaries). This is the water, which is first lost through the 'wind cracks' in the concrete surface.

Money, Cement and Water

The dimension of these pores (capillary and gel pores) are best described in a less academic manner by a graphic example which is covered in an article in Concrete International and authored by Hover and Stokes[2]. It describes how to visualize the variations in water cement ratio in a practical example. They "scaled up" or related the cross section of a cement particle to a single US penny. They related single water cement ratios (measured by weight then volume) and then applied the mathematical relationship between volume and surface area of the pore structure, which says that the ratio of the volume of the cement and water (in the three dimensional view) is the same as the ratio of the cement and water of the areas (in the two dimensional view).

By using this framework they could give a practical scale model of the relationship between cement particles and pore size (space around the particle) in any given water cement ratio.

To lay out any given number of pennies (up to a maximum of 27) onto a Dollar note it is possible to see the visual relationship between water and cement in any given mix. Nine pennies in cross-sectional surface area laid near each other on the equivalent size of a US Dollar bill would equate the water cement ratio over that area to 1 (equate to a W:C = 1:1), see Fig. 4. In other words an equal *volume* of cement and water in the mix or an equal *area* of water and cement in cross section.

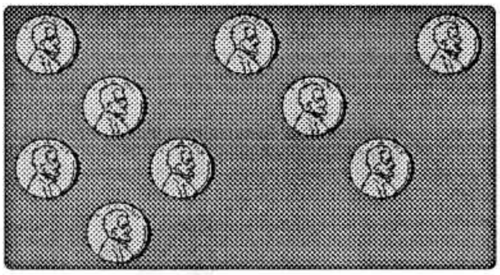

Fig. 4 : Shows 9 "cement particles" in relation to a Dollar bill which is the equivalent of a water cement ratio of 1

If we look at what we consider to be a water:cement ratio of approximately 0.4 the surface area on the bill would be taken up by 16 pennies. The cement takes up *less than half* of the surface area of the bill . In actual fact for the particles of cement to be close enough to be almost touching together they would need 27 pennies to cover the Dollar bill that would represent a 0.13 water: cement ratio by volume. At this stage the particles of cement being in such close proximity would ensure that shrinkage would be controllable.

Graphically it becomes important to provide as much of an opportunity for early interaction of the cement particles as possible (by minimizing space around the cement particle) thereby ensuring efficient use of water and minimizing shrinkage in the repair mortar due to the high solid content.

As a direct result of this factor, for repair mortars to have a sufficient dimensional stability and resist shrinkage the w:c ratio should be as close to the magical 0.13 (by volume) as possible which would then ensure the cementitious binder has as early a start as possible to develop strength.

DRYING SHRINKAGE AND VOLUME STABILITY

The richness of the mix (in any given water cement ratio) has a great deal to do with the shrinkage potential of any mortar. When increasing the water content to maintain the w:c ratio in mixes containing increasing proportions of cement the potential for shrinkage increases.

For a repair mortar to be effective it should fill the cavity of the repair zone and maintain that dimension as closely as possible, so as to distribute the applied loads and stresses equally throughout its volume.

Dimensional stability and stress relaxation through tensile and compressive creep would ensure the mortar was compatible with the host concrete.

Short term moisture loss

A volume stable material has to counteract *plastic state* shrinkage, and *hardened state* shrinkage, which we call dual shrinkage. A mortar during the plastic state (first 4 hours) must overcome the pronounced initial shrinkage resulting from water lost from the capillaries during this time (see Fig. 5). First stage shrinkage compensation must be designed to last for at least 4 hours to allow the mortar to harden and stabilize (see Fig. 6).

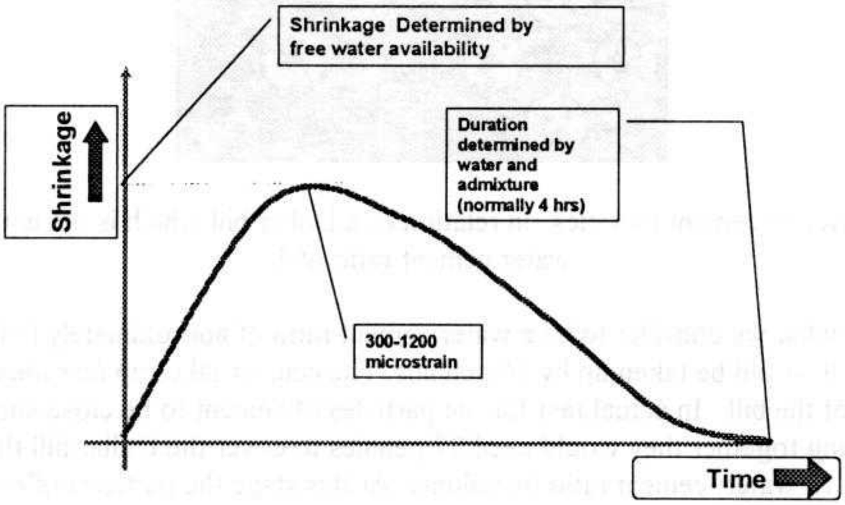

Fig. 5: Shows schematic of capillary (wind crack) moisture losses during mortars' plastic state generally during the first 4 hours.

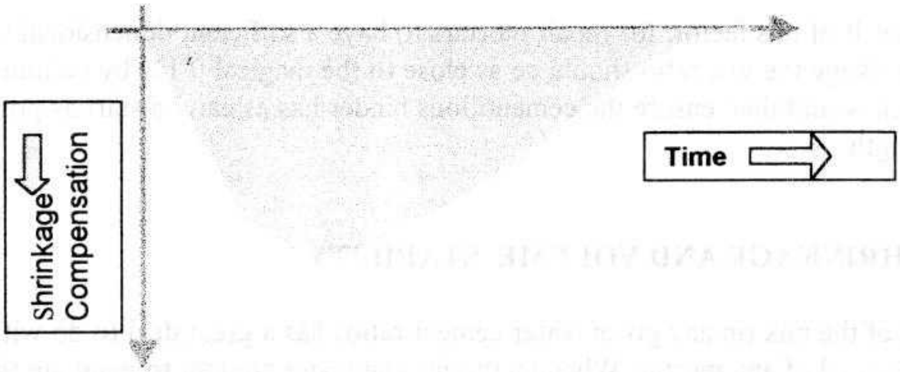

Fig. 6: Shows shrinkage compensation properties required to counteract moisture losses during the mortars plastic state generally during the first 4 hours.

The time during which the largest volume change takes place is during the plastic state when losses in moisture from the structure are unlikely to be recaptured. Tensile stresses are developed during this plastic state and should the tensile strength be exceeded during this very weak state then cracks will form. These cracks generate an even greater surface area of the structure to atmosphere which exposes even more capillaries to drying. It is therefore important to bear in mind that curing should begun within the hour of completion of the repair. In the case of shuttered repairs the formwork plays an extremely useful part in maintaining the moisture balance in the repair zone. In this case curing should begin on the formwork being stripped .

Long term moisture losses

The w:c ratio has direct bearing on pore dimension (space between cement particles). For every change in water :cement ratio there is a corresponding change in pore dimension and permeability. The degree of hydration also has an influence on the pore structure. Ramachandran V S (Concrete Science), Feldman and Sereda[3] have indicated that movement of water into or from the spaces between platelets of gel will cause volume changes as a result of the dimension between layers changing. Apart from this model there are a number of alternative models to refer to, but the final conclusion is that the dimension of the mortar does change with moisture losses. The effect from moisture loss (as we have covered earlier) relates to two distinct conditions arising in the structure.

- Shrinkage
- Permeability.

As a result of long term moisture losses in mortars leading to shrinkage, it stands to reason that well designed pre-bagged materials should compensate for these losses by building in stabilizing properties in the mortar, Fig. 7. We term this property solid state shrinkage accommodation. The purpose of the property is to provide equal and opposite forces within the mortar to ensure that mortar dimensions will remain stable in the repair site.

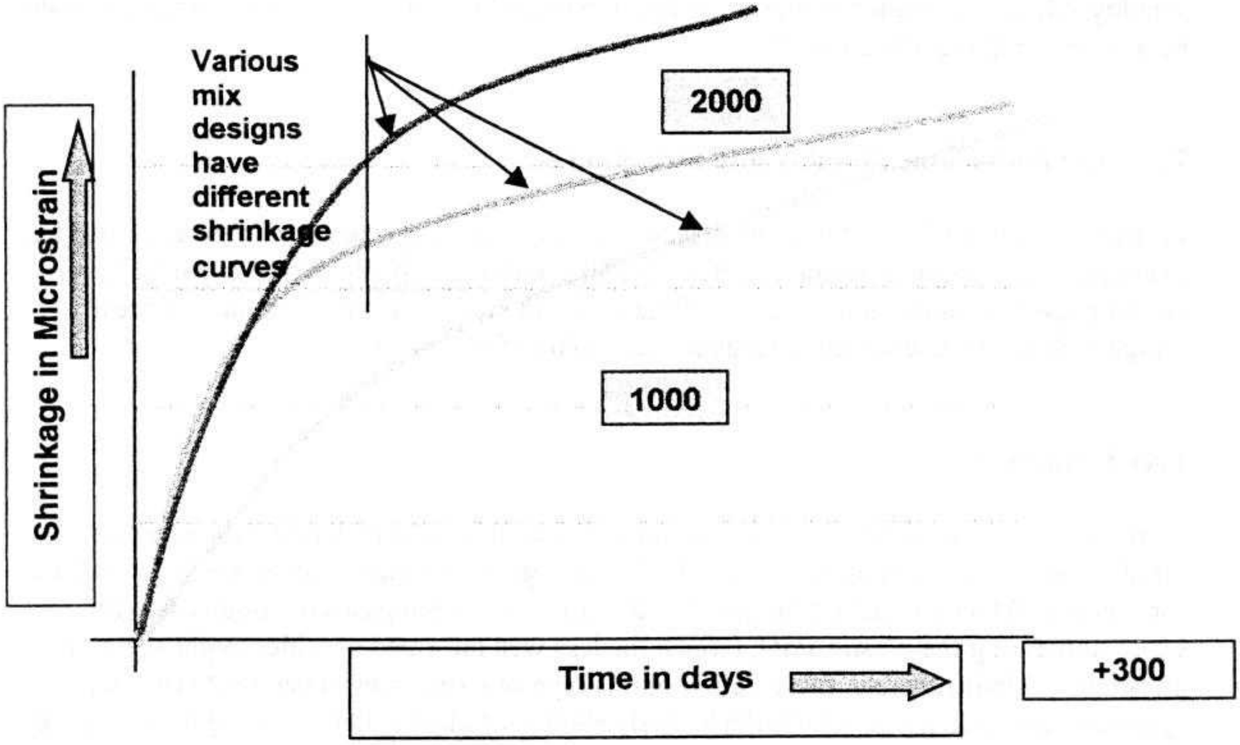

Fig. 7: Showing schematic of long term shrinkage generated by capillary moisture loss

Combining plastic and hardened state shrinkage control

Taking into account the nature of plastic shrinkage and solid state shrinkage and stabilizing both of these factors of shrinkage we commonly term Dual State shrinkage accommodation.

MORTAR PROPERTIES

Improvement in mortar designs

Repair mortars in the last 10 years, have improved considerably in volume stability. Orchard[4] indicates that a 100m long concrete wall may move (by very approximately) 42mm in length through moisture movement. In earlier years repair mortars would develop a factor of shrinkage in the order of 600-1200 micro-strain or 0.06 - 0.12%. In later years the development of shrinkage compensating properties has reduced the shrinkage value of a 0.4 water: cement ratio concrete to 0.03 - 0.06%. For repair mortars recent technology has mimicked this shrinkage control during the wet cure period. (In the most up to date technology even this performance is improved on). It is possible to maintain the initial volume for its full wet cured period . This ensures that during the most crucial time of strength development the mortar provides positive contact to all faces of the repair zone. This void filling property can be seen as self stressing in the wound.

With the advent of new innovation (which is continuos in the Fosroc / Fosam laboratories) Dimensional Stability is becoming more and more an achievable goal. Some shrinkage control systems rely upon expansive cements. Others rely upon controlling surface tension. Neither approach is adequate. Fosroc uses multiple control systems to ensure dimensional stability. More information of the latest developments in products with these properties will be available in the coming months.

Restraint for Volume Stability and Strength Gain

Flowable grade repair mortar in the plastic state requires complete restraint to eliminate free expansion. The property which counteracts initial shrinkage (if allowed to expand freely) would cause the unrestrained surface of the repair to swell in a similar fashion to bread dough rising. This phenomenon leads to weakening of the mortar.

Free Expansion

There is a further element to this plastic state shrinkage accommodation, which relates to rapid expansion predominantly present in the early grouts (which at times are still specified for repairs) . Many grouts are designed to generate Hydrogen gases to compensate for expansion during the *plastic state*, (which the less well informed specifier might see as an advantage). Unfortunately the duration of this type of gaseous expansion is fairly short (generally less than 20 minutes) which barely allows for placing before losing its expansive properties. The result is that this early expansion cannot ensure physical contact with the load bearing sides of the repair area before initial set. This property does not satisfy the volume stable requirement of a repair mortar even in the first plastic stage of application

Long term dimensional control

During the curing stages a secondary volume control comes into action counteracting the loss in dimension initiated by moisture losses from the pore structure during the hardening state. The sections described above have indicated the importance of moisture required for the cement hydration to assist crystal growth and reduce the dimension of capillaries and thereby increase impermeability. It is even more important for the shrinkage compensating properties in a repair mortar. Neville [5]states that the use of expanding cement cannot produce "shrinkless" concrete, as shrinkage occurs after moist curing ceases. The products used for this stage of dimensional management demand the presence of water in the capillaries to feed the shrinkage-compensating portion of the repair mortar thereby ensuring controlled expansion during curing.

MOISTURE CONTROL WITHIN THE REPAIR

Primers and Bonding agents and internal curing

There are many types of polymer emulsions available for bonding and these are described as follows

Commonly PVA (polyvinyl acetate), SBR (styrene butadiene rubber) and acrylic emulsions are used. All three types have their limitations but are extensively used.

Epoxy bonding aids provide the best bond of all when assessed by the pull off test. They perform well on site, particularly the slow setting versions, which give a long 'open' time.

All the above products will also have a secondary function to perform during the bonding process.

The first group are all water based primers. On drying out the water content in the film is absorbed into the host concrete or repair mortar. In this process the water molecules leave hardened passages behind for further moisture (and along with it chloride ions) to migrate into the repair zone *through the intended barrier* created by the water based bonding agent. Therefore where chloride ions are resident in the host concrete behind the reinforcing an epoxy resin bonding agent should be considered which has the ability to form an impermeable barrier capable of preventing the migration of any remaining chloride ions from the host concrete back into the repaired areas.

Remembering that generally the cover between the host concrete and the reinforcing back face is approximately 20mm, much less than the cover to the exposed front face of the repair. Such a material must be formulated to have an 'open' life sufficiently long after it has been applied to the concrete substrate to allow for the erection of formwork. Relative to the function of the repair mortar system one can view bonding membrane as internally curing the repair mortar. The bonding membrane stops the passage of pore water from within the mortar outwards into the host concrete and visa versa stops the passage of chloride ions from the concrete into the repair mortar.

Curing

Cementitious repairs should always be cured in line with good concreting practice. This is crucial under hot, windy or low humidity conditions. Curing with water is often impractical due to cost, potable water availability, or the maintenance of a minimum of 7 day curing regime. During the early stages of hydration losses in pore water of 0.2 to 1liter / m^2 /hour is possible(Payne and Dransfield[6]).

Payne and Dransfield[7] indicate that hydration stops at RH80% in the pore structure. Fresh concrete with moderately severe exposure to the top 6mm may reach this level after one day and the top 20mm could reach this condition after 7 days.

Low grade curing aids are often expected to provide quality curing of equal performance to a high grade curing membrane. A convenient method, especially where subsequent overcoating is required, is to use the acrylic emulsion bonding primer as a curing aid. The products are purposefully referred to as curing *aids* as the base constituent of most of the acrylic and polymer curing compounds is water. In drying the *curing aid* releases the water molecules making up the basic product.

These avenues of escape of the water molecules are also avenues through which the pore water of the repair mortar can escape, Fig. 8. This then reduces the moisture content in the surface of the repair and knowing the need to maintain the optimum moisture content in the repair zone the drying effect will rob the repair mortar of its ability to maintain dimensional stability. The curing efficiency of these water based products are not as high as solvent based curing membranes or well-fixed polythene, but it is a practical solution and can provide curing for short durations particularly where structural protection with an acrylic protective surface coating is anticipated. Of course deeper or multiple applications will improve these properties by blocking the underlying layer pores. In particularly adverse drying conditions, the additional use of polythene sheeting, taped down at the edges, is recommended.

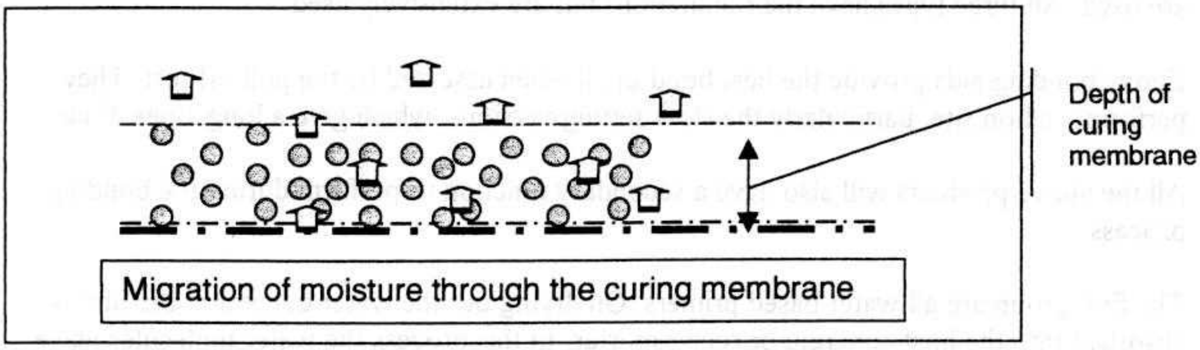

Fig. 8: Permeability of Water-based curing aids

Most mortars have the ability to be “Volume Stable” during the period of moisture control. Should moist curing stop the volume controlling properties of the mortar would stop. Practically shrinkage would be seen in the form of cracks in the middle or disbondment around the perimeter which immediately exposes the reinforcing to corrosion making the repair worthless. Therefore curing is essential to good repair practice and should be a measurable part of the bill of quantities. Curing should then be followed by an appropriate breathable protective coating.

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