PROTECRETE

Mix Water Conditioner

A technical paper submitted to the ACI Committee 201, Durability of Concrete, describing what it is, what it does, and why you need it

How Mix Water Conditioner came into being

When we initiated MWC development, we began research in a prior era . . . the era just before development of chemical/synthetic admixtures. Our research objectives were to find a consistently achievable way of further enhancing portland cement concrete using only natural ingredients.

MWC development began with the knowledge that to achieve its objectives, which were to significantly improve concrete performance and durability, two critical goals were imperative. The first goal was to produce concrete with significantly reduced permeability. The second was to improve the concrete microstructure. This improvement would consistently produce defect-free, extraordinarily textured cement paste, which is capable of improving concrete paste-aggregate contact zone areas. Through long hours of in-house testing, we learned that MWC's conceptual goals were consistently achievable, without necessitating use of outside mineral or chemical admixtures, synthetic agents, water-reducer, or plasticizing agents.

After discussing whether MWC should be designated an admixture or not, we ultimately decided that it was not an admixture and should not be construed as one. This is because MWC was designed to enhance mix water's cement hydration abilities and not affect its status otherwise. In other words, should water already be considered suitable to use as portland cement concrete mixing water (according to ASTM requirements), the subsequent addition of MWC does not alter that status.

Furthermore, MWC enhancements to concrete are not limited to only one or two facets, but encompass several facets. MWC utilization significantly and beneficially affects concrete's overall quality/integrity.

We subsequently learned that the most advantageous and workable avenue to success was to utilize concrete's mix water as the media into which we would introduce natural ingredients into the concrete mixture. We carefully selected ingredients that were capable of revolutionarily enhancing water's portland cement hydration abilities. Furthermore, we learned that these same ingredients would generate prolific utilization, instead of evaporation, of concrete's "water of convenience." This remarkable series of discoveries slowly developed into a unique product, which we call Mix Water Conditioner. MWC provides extraordinary benefits for concrete through the reposturing of its mix water hydration abilities.

In an economical way, MWC significantly improves concrete quality and therefore its useful lifespan/durability. Infrastructural installations will also greatly benefit from MWC use, especially where MWC benefits and cost are compared to the complexity of use and cost of High Performance Concrete (HPC).

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What happens during the manufacturing of portland cement concrete without Mix Water Conditioner

During the manufacturing of portland cement concrete, immediate violent actions and reactions occur as mix water initially contacts portland cement. These actions are necessary and important, since they result in the by-product production of a variety of calcium compounds in the concrete, i.e., calcium hydroxide, calcium sulphate, etc. This occurs as molecular portions of cement's tricalcium and dicalcium silicate are split off due to these initial hydration actions and/or reactions.

These initial hydration actions and reactions, combined with mix water dilution, immediately and effectively lower portland cement's potency factor, causing the cement paste which is initially produced to be of extremely poor to fair quality. The initially-produced portland cement paste, almost immediately following initial hydration, begins to absorb into or coat concrete aggregates. This happens even though later on, due to the quality of the cement paste, it may deleteriously affect finished concrete integrity. The resultant concrete could have weak paste-aggregate bond strength and/or have low quality cement paste in the paste-aggregate contact zone areas, possibly adversely affecting permeability, durability/useful lifespan, etc.

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How manufacturing is different when you use Mix Water Conditioner

MWC, however, alleviates the extreme violence normally associated with initial portland cement hydration. The use of MWC also lowers heat evolvement and allows for a smoother, more gentle transition from initial hydration to full-blown hydration. This significantly and beneficially affects hydration by-product quality, i.e., calcium hydroxide. MWC provides ingredients to mix water that will minimize portland cement potency factor loss ascribable to actions/reactions of initial hydration and mix water dilution. MWC also provides ingredients to mix water that insure that only the highest attainable quality cement paste is being produced, both initially and subsequently.

Mix Water Conditioner lowers heat evolvement while allowing a smoother, more gentle transition into portland cement hydration.

Mix water which has been conditioned with MWC readily utilizes 6 percent or more of the mix's already-included portland cement content, which in turn increases its volume of cementitious material content. This happens without increasing the originally designed per-cubic-yard dry cement volume, which lowers the mix's water-cement ratio. These extraordinarily beneficial effects are due to MWC-conditioned mix water's ability to more readily and deeply absorb portland cement particles, posturing each particle to more readily and more often shed its mix water generated hydrate envelopes, allowing new ones to be quickly regenerated. This action alone generates utilization of significantly increased percentages of each cement particle which, in turn, generates increased volumes of cement paste/tobermorite gel/C-S-H (calcium silicate hydrate) per cement particle.

Mix Water Conditioner readily utilizes 6 percent more of concrete's already-included portland cement content.

Some significant benefits achieved with Mix Water Conditioner

Listed below are several MWC-derived benefits gained from utilization of increased percentages of concrete mix's already included portland cement content:

1. ***Resultant concrete employs the smaller than usual leftover cement particle cores***, which became variously sized through increased cement utilization, producing smaller than usual

leftover cores to act as sand/aggregate. The smaller cement particle cores increase impermeability and density.

2. ***Produces cement paste that is extraordinarily fine-textured and homogenous,*** provided with same charge particle effect, greatly reducing potential for internal voids, shrinkage, excessive bleedwater, internal microcracking, external checking, crazing, plastic/settlement cracking, etc.
3. ***Extraordinarily homogenous concrete with increased workability*** due to increased lubricity, etc.
4. ***Reduced cementitious material waste and increased water utilization,*** which results in increased volumes of cementitious material utilization per cement particle, effectively lowering water/cement ratio of finished concrete.
5. ***Generation of more finely textured cement paste consisting of smaller-size gel pores with excellent uniformity and smaller than usual capillary pores/voids.*** This is due to total mix water utilization, which results in increased hydration product volumes. These actions significantly lower total void percentages and, thus, permeability.
6. ***Production of a true shrinkage-compensating concrete,*** compensated by production of increased volumes of internally generated hydration product/C-S-H, which also virtually eliminates curl.

Mix Water Conditioner achieves the lowest possible permeability

From a durability viewpoint, it is of crucial importance to achieve the very lowest possible permeability in the shortest period of time possible, a feat achieved each and every time when utilizing MWC. Using MWC consistently produces concrete with smaller, more segmented capillaries than usual.

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Permeability in concrete means that pollutants or contaminants are allowed to penetrate inside its interior. The degree of permeability dictates whether these pollutants/contaminants are readily—or sparingly—allowed ingress. Therefore, permeability, as well as the degree of permeability, effectively and directly affect concrete's durability, which translates to useful lifespan.

Concrete permeability is of critical interest because the integrity disintegration/deterioration of concrete is usually caused by either (1) external agents arising from concrete's environment or (2) internal agents from within the concrete itself. Permeability of concrete is very often increased further than required by inadvertant use of porous aggregates or placement without proper cure in a timely manner.

For concrete made using normal weight aggregate, permeability is governed by cement paste porosity and pore-size distribution. For example, for a cement paste whose total gel pore porosity is low, its permeability is very low. However, the permeability of hydrated cement paste as a whole is usually greater than its gel porosity indicates because of larger capillary pore presence. In fact, its permeability is generally controlled by the capillary porosity and not gel porosity.

Concrete paste capillary porosity size is governed by concrete water-cementitious material ratio and degree of hydration. Therefore, MWC was

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designed to enhance both factors (increased cementitious material volumes and improved hydration rates and processes) through reposturing of mix water's hydration abilities. MWC can enhance already-existent conventional mix designs with minimal change and without hassle or undue complexity.

Simply by utilizing MWC to condition a concrete's mix water, increased volumes of the already-included cement content are utilized, effectively raising the volume of concrete's cementitious material (cm) content and further lowering its water/cement ratio.

Using MWC also accelerates the portland cement's hydration rates and process, which generates additional volumes of hydration product, or C-S-H, in a shorter than normal time period. The faster the cement hydrates, the faster the hydrate product/C-S-H is subsequently produced to fill capillary voids, or original water spaces. This action alone effectively causes concrete permeability to decrease even further than usual. A reduction in permeability also becomes even faster with the lower than usual water-cementitious material ratio, created by utilization of MWC.

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Mix Water Conditioner and defect-free cement paste

Crack prevention of newly-placed concrete is extremely important in preserving long-range integrity. In newly-placed concrete, there are three intrinsic surface-visible types of cracking to be concerned with: (1) plastic cracks, (2) early age thermal cracks, and (3) drying shrinkage cracks. All three of these leave concrete more vulnerable to contaminant ingress. MWC provides ingredients to mix water that will effectively counteract root-causes of these three types of surface-visible early-age cracking.

Surface-visible cracking is not the only type of cracking that can result in portland cement concrete integrity inferiority, however. There are also internal defects and cracks to be concerned with, such as microcracking in aggregate-cement paste contact zone areas. Along with what would have been concrete's normal permeability, aggregate-cement paste zone area cracking (not surface-visible) has tremendous effect on final concrete permeability and vulnerability to embedded steel corrosion, thus durability/useful lifespan. Very often concrete will unsuspectingly develop internal defects/microcracks in areas between aggregates and cement paste, causing concrete to be weaker and more permeable to free moisture/water, oxygen, and other forms of aggressive media. The aggregate-cement paste contact zone areas are very often the weakest link in a concrete structure because of surface-invisible bleed water voids, as well as microcracking due to shrinkage and elastic mismatch between cement paste and the aggregates.

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Ironically, this cement paste, which ultimately winds up in aggregate-cement paste contact zone areas, is initially produced during the effects of initial hydration. Also, this cement paste is the paste which initially absorbed into or coated the aggregates. However, the aggregate cement paste absorption/coating is frequently interfered with by bleed water coming from within the aggregates.

MWC ingredients create extraordinarily homogenous portland cement paste which significantly minimizes internal/external bleed water production, attributable to particle/aggregate segregation. During concrete hardening/setting where internal bleed water is present, there is always the possibility that bleed water migrating upward may become trapped in horizontally-stratified grain surfaces of the aggregates, leaving voids to contribute to permeability. Excessive water bleeding and inefficient packing of the cement paste around affected aggregates may also cause voids to be formed. These types of voids will not become filled with hydration product, or C-S-H, during hydration. This creates internal void situations that potentially could be more porous than the entire matrix of the concrete would have been without creation of the surface-invisible voids.

Internal void creation and its root causes even further promote the existence of initial bond microcracks at the interfaces between cement paste and aggregates. Where concrete defects/microcracks remain localized and are not contiguous, this is not initially an extremely serious situation, except from a probable low strengths (flexural, compressive) viewpoint. However, over time, with the inevitable occurrence of volume changes, freeze-thaw cycles, wetting-drying cycles, fatigue, alkali-aggregate reactions, etc., there is a tendency to greatly increase interior and possibly exterior cracking. These widening cracks serve to further facilitate permeation of liquids, pollutants, contaminants, ions, gases, etc., all of which can potentially destroy concrete's integrity and corrode its reinforcement steel.

Where MWC is utilized to reposture/condition concrete's mix water, enhancing its portland cement hydration abilities, it consistently produces virtually defect-free cement paste, as well as additional volumes of paste per cement particle. MWC-produced cement paste addresses every imaginable concrete ailment that is associated with portland cement concrete and its manufacturing, and it alleviates and/or eliminates all of the aforementioned problems, including internal void creation and cement paste-aggregate contact zone defects, including microcracks. MWC utilization effectively increases concrete impermeability, a tremendously important factor in increasing concrete durability, which translates to useful lifespan.

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The problem of etteringite and how it occurs

It is essential that hardened cement paste not undergo appreciable expansion, especially expansion under conditions of restraint, since this type of expansion may result in disruption, or cracking, of the hardened cement paste. One cause for such expansion is late-development etteringite in the hardened paste, produced by reactions with excess gypsum or calcium sulphate in the cement. Calcium sulphate along with calcium hyroxide are produced in portland cement during initial hydration. These are difficult, if not impossible, to distinguish one from the other.

Normally, in concrete produced using high strength cement, which generally contains up to 11-12 percent tricalcium aluminate and 1-3 percent of gypsum (such as ordinary Type I and Type III portland cement), the calcium sulphate/calcium sulphoaluminate content that is produced in concrete during initial hydration becomes utilized in generation of beneficial C-S-H (calcium silicate hydrate), and the calcium sulphate or calcium sulphoaluminate never adversely affects the concrete. However, where MWC is not utilized, the possibility always exists that total volume amount of produced calcium sulphate/calcium sulphoaluminate may not get utilized in beneficial C-S-H creation. This is caused by one or more of the following reasons: (1) an excessive amount of gypsum was ground in during cement production, (2) inadvertant sulphate contamination of the concrete through its mix water or aggregates, or (3) a combination of both circumstances, resulting in varying volumes of calcium sulphate hydrates being leftover and unused in the hardened concrete to potentially later on detrimentally react, which results in the creation of highly destructive internal forces. Leftover calcium sulphates in hardened concrete potentially will create internal expansion pressures through formation of calcium sulphoaluminate (etteringite), by combination with the cement's hydrated tricalcium alumi-

Leftover calcium sulphate in concrete is liable to cause hardened cement paste expansion through formation of calcium sulpho-aluminate (etteringite).

nate content, in the presence of water or free moisture. Concrete exhibiting this form of expansion is usually classified as unsound.

Etteringite is formed in other ways, such as in expansive cements. All types of expansive cements produce calcium sulphoaluminate hydrate (etteringite) which causes expansion in plastic cement. Expansive cements are used in special applications, such as prevention of water leakage. It should be noted, however, that the use of expanding cement cannot produce shrinkless concrete, as shrinkage will still occur following a wet curing, but magnitude of expansion can be adjusted so expansion and subsequent shrinkage are equal and opposite. Etteringite formation is created in concrete under sulphate attack. Concrete under attack by aggressive sulfates usually takes on a whitish appearance. Damage usually starts at corners and edges, followed by cracking and spalling of the concrete.

When portland cement is ground from clinker, gypsum is added in order to prevent flash setting as water contacts cement's tricalcium aluminate ingredient. Tricalcium aluminate is added to cement during its grinding process because it is beneficial to cement production and facilitates the combination of lime and silica. Free lime is in cement clinker, intercrystallized with other compounds. Consequently, free lime hydrates very slowly and requires a larger volume of space than the original calcium oxides. The volume of gypsum added to cement is crucial and depends on tricalcium aluminate and alkali content of cement. Increasing cement particle fineness has the effect of increasing its tricalcium aluminate quantity, available at early stages of hydration, raising the gypsum requirement. An excess of gypsum added to clinker can lead to expansion and consequent disruption of hardened cement paste, especially if sulphates are present. The essence of sulphate attack is the formation of calcium sulphate (gypsum) and calcium sulphoaluminate (etteringite), with both products requiring greater space volumes than compounds they replaced. Thus, subsequent disruption (cracking) of hardened concrete occurs.

Gypsum is able to prevent flash setting of cement, as hydration takes place, because gypsum quickly reacts with tricalcium aluminate to produce etteringite. The etteringite is harmless at this stage because the concrete is still plastic and expansion can be accommodated. However, similar reactions take place in hardened concrete when exposed to sulphates or excess gypsum. Sulphates react with both calcium hydroxide and hydrated tricalcium aluminate to form gypsum and etteringite, respectively. The extent of sulphate attack depends on concentration and permeability of concrete, i.e., ease with which sulphate can travel through the concrete pore system. If concrete is very permeable and water can percolate right through its thickness, then calcium hydroxide will be leached out. Subsequent evaporation at the far surface of concrete leaves behind calcium carbonate deposits, formed by reaction of free lime with carbon dioxide. This whitish deposit is generally known as efflorescence. Extensive leaching of calcium hydroxide gradually increases porosity so concrete becomes progressively weaker and more prone to attack. Sulphates, salts, chemicals, etc. only attack concrete when present in solution. The vulnerability of concrete to sulphate attack can be reduced through the use of sulphate-resistant cements; however, the type of cement should be of secondary importance, or of no importance, unless concrete is dense and has low permeability. Water-cementitious material content is a vital factor since a high cementitious material content facilitates full compaction.

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Mix Water Conditioner creates mixes so extrordinarily homogenous that during mixing, existing calcium sulphate residue is totally utilized as beneficial C-S-H.

Why Mix Water Conditioner prevents etteringite

Late-development etteringite cannot exist where MWC is utilized in portland cement concrete mix water for many reasons. The first and most important is extraordinarily low permeability, since without ingress from airborne sulphates or ground transmission sources, late-development etteringite cannot exist. Even if leftover—or not utilized—calcium sulphate were to exist, reaction cannot take place without the presence of free water/moisture.

MWC begins preventing possibility of late-development etteringite at the earliest possible moment, during hydrolysis, creating smoother less volatile transition into hydration. It thus avoids the possibility of overproduction of calcium sulphate hydrates, significantly improving hydrolysis by-product quality, translating to greatly improved final C-S-H quality. MWC effectively creates mixes so extraordinarily homogenous that during mixing, existing calcium sulphate residue is totally utilized as beneficial C-S-H.

MWC provides ingredients that greatly enhance mix water's portland cement hydrating abilities, resulting in production of extraordinarily hard, sound, low permeability, and truly shrinkage-compensated concrete that effectively resists cracking, crazing, internal microcracking, and every ailment that could detrimentally affect permeability, and thus vulnerability. MWC virtually eliminates the potential for adverse internal chemical reactions and the need for expansive or other special cements.

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Mix Water Conditioner and durability

The durability of a material is that certain property which indicates whether or not the material will endure, even though it may not be subjected to loads sufficient to destroy it. Durability of portland cement concrete, then, is defined as its ability to resist weathering action, chemical attack, abrasion, or any other process of deterioration.

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Durable concrete retains its original form, quality, and serviceability when exposed to its environment. Durability of concrete is its most important property since it is essential that concrete be capable of withstanding conditions for which it was designed, throughout the useful lifespan of the structure. Durability of concrete can be affected by innumerable factors such as alternate wetting-drying cycles, freezing-thawing cycles, aggressive sulphate exposure, heating-cooling cycles, capillary water invasion, abrasion, corrosion of imbedded steel reinforcement/other imbedded materials, chemical contaminant reactions, alkali-aggregate reactions, salt deposition by percolating water, dissolving of calcium hydroxide and/or certain other constituents by percolating water, dissolving of cement by certain acids, etc.

MWC added to portland cement concrete mixing water, prior to concrete manufacturing, significantly alleviates/eliminates all of the above-mentioned durability deterioration factors in concrete and more. MWC in mix water consistently produces concrete that is extraordinarily strong, hard and impermeable.

Mix Water Conditioner significantly alleviates/eliminates durability deterioration factors in concrete.