CONCRETE QUALITY WITH MIX WATER AND ENVIRONMENTAL IMPACT OF CONCRETE

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ABSTRACT

The requirements to produce and specify more durable concrete in aggressive environments are increased to satisfy the demand for long-term economy and serviceability of concrete structure. These in turn need better quality concrete, which makes construction and the finished structure better. Considerable work has been done investigating various parameters, such as, water-cement ratio, cement content, admixtures including corrosion-inhibiting admixtures, air-entrainment, condensed silica fume (CSF), and has been reported in many places. This paper contributes through work done on the influence of mix water conditioner (MWC) on concrete behavior and includes the chloride permeability. Its effect on hydration product in the mix is emphasized, better concrete will be produced if proper hydration is accomplished. In addition, the paper deals with the environmental impact of concrete production. It has become increasingly important for the concrete industry to minimize the impact of a ready mixed concrete industry on the environment. The main idea is that concrete industry should be cognizant of such practice, which will need to be followed in the future if we want to expand the facilities and not get short-chained due to restrictions of Regulatory requirements to impact the production and therefore the use of concrete.

Keywords: Concrete, durability, hydration, admixtures, chloride permeability, environmental management, solid waste, sater discharge, air pollution

1. INTRODUCTION

Attempts have been made to develop a natural, economical, uncomplicated and consistently reliable method, which would significantly enhance Portland cement's overall quality criteria. Such development generally begins with the experience of the current technology prior to the development of synthetic admixtures, such as air entrainment, water reducers, plasticizers, super plasticizers, micro-silica, etc. But unlike many of these admixtures, which are added to already-mixed cement, the inventors determined that the most promising media for enhancing Portland cement was concrete's mixing water. The mixing water is important since certain reactions during hydration - when the water initially comes into contact with Portland cement, can be modified with benefits.

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Experiments with natural ingredients capable of enhancing the hydration abilities of Portland cement were conducted to determine their interaction. It was found that certain ingredients provided water with extraordinary molecular binding power to allow larger volumes of so-called water of convenience in concrete to be utilized, rather than evaporated, for additional hydration of cement. This action reduced the capillary void sizes, making them comparable to gel pore sizes, and created a significant increase in the concrete’s impermeability. This research resulted into a mix water “pre-conditioner” that would provide extraordinary benefits to Portland cement concrete through such improvement of mixing water.

2. UNIVERSAL NATURE OF CONCRETE

Concrete is one of the leading universal materials of construction. It is therefore of interest to the users and designers all over the world to improve its qualities. In the colder climate, there are more handicaps of making concrete. On the other hand, very high temperatures also create problem. Both of them result in developing admixtures, which have been mentioned earlier. This paper deals with an approach, which can be used in either condition in any country so that better concrete can be made and its application be further enhanced. Cost is another parameter, which has played role in the use of any material of construction and concrete is no exception.

Design based on the cost parameters needs to be developed and not only the strength criteria. It will then be truly economical to design and build concrete structures better than any other material of construction. If good concrete is made in the beginning and such concrete needs much less maintenance cost, it will be even more attractive material. This good concrete comes mostly from the ready-mix concrete plants and creates the environmental awareness in the public, which needs consideration.

3. ENVIRONMENTAL IMPACT FROM CONCRETE

Ready mixed concrete has reached such a level of production that one needs to think about its impact on the environment. This impact takes various forms. If minimized, it would help the industry in a long-term basis to achieve the most of it and at the same time, it would create a much better image of the industry in the society. Recommendations [1] are now available, which represent good industrial practices which are practical, realistic and economically viable from the US perspective, although they are applicable in any urban setting, where the public is becoming more cognizant of the concrete industry as part of their life. Eventually, Regulatory requirements may dictate plant upgrades regardless of the economic consequences. In short this may be considered as a wake-up call for the industry. Some of these aspects of environmental impact and its management are presented in appendix A. Thus, one would have considered all bases related to a good concrete practice leading to a construction material, which is not only universal, but is good and also environmentally friendly.

4. QUALITIES OF GOOD CONCRETE

Good concrete means durable concrete. The durability of a material is a 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. 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 various factors including alternate wetting-drying cycles, freezing-thawing cycles, aggressive sulfate 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.

To make concrete durable, its permeability must be reduced. Ideally, one should produce defect-free finely textured cement paste, which is capable of improving concrete paste-aggregate contact zone areas. By accomplishing this, the microstructure around the aggregate is modified and thus, the cement contact zones from the weakest part of the concrete to the strongest. Current methods of improving the performance and durability of concrete (such as High Performance Concrete) are both expensive and complicated. However, by preconditioning the water with the right ingredients, you can achieve these goals simply and with minimal expense. It was found that concrete could be produced with no separation between the aggregate and water. This concrete had virtually no plastic shrinkage cracking and virtually no curling. Extensive laboratory work showed that the mix water conditioner's (MWC) conceptual goals were consistently achievable, without necessitating use of outside mineral or chemical admixtures, synthetic agents, water-reducers, or plasticizing agents.

5. ROLE OF WATER IN CONCRETE

Water is essential to Portland cement concrete performance to make the cement a good bonding agent. There are two ways in which Portland cement and its compounds react with water. The first is "hydration", which is the reaction created when water molecules contact dry cement. The second is "hydrolysis", which is the reaction as a result of hydration. Hydrolysis is directly responsible for the production of new products or compounds that are essential in freshly hydrated concrete. Both these products and compounds, which are created as a result of hydration and hydrolysis, are usually referred to as hydration products. They include calcium hydroxide, formed from released lime and freed through hydrolysis, as well as several other calcium hydrates, often referred to as calcium silicate hydrates.

The quality of internally produced products of hydration may vary greatly, depending on the quality and impurity content of the cement being hydrated, as well as the quality of mix water used. In concrete, the rate of hydration decreases continuously following initial hydration, and continues even after 28 days while amounts of cement still remain unhydrated. Tests show that cement grains in constant contact with water may only hydrate to a depth of 4 m, and even after a year may only hydrate up to 8 m. Water enhanced by mix water conditioner to improve its cement hydration abilities, consistently improved cement grain hydration percentages. Under
field conditions, concrete utilizing mix water conditioner has shown a 6 to 12 percent increase in cement hydration to prove the role of mix water in hydration.

During the hydration of Portland cement concrete reactions occur as the mix water initially contacts the dry cement and split off molecular portions of the dry cement’s compound components. These reactions result in some essential byproducts, such as Calcium Silicate Hydrates (C-S-H) and calcium hydroxide. These reactions, in combination with water dilution, temporarily lower Portland cement’s potency, causing the initial poor quality cement paste. This cement paste is initially absorbed by or coats the exterior of aggregates. The resultant concrete integrity is affected by weak paste-to-aggregate bonding quality, as well as the deposition of paste, which contains poor microstructure. It in turn affects paste-aggregate contact zone areas in concrete affecting permeability and thus its durability. However, the MWC effectively alleviates some of the reactions associated with hydration, and beneficially lowers heat evolution while promoting a smoother, gentle transition into the continuing phase of hydration. The MWC also greatly improves the hydration/hydrolysis byproduct quality (i.e., calcium hydroxide, calcium sulfoaluminate, and others). This allows an efficient use of the byproducts in production of beneficial C-S-H, leaving only minimal unused portions in the resultant concrete, as an end result.

6. ROLE OF ADMIXTURES IN CONCRETE PROPERTIES

Designers using admixture materials can tailor and adjust mixes to meet a wide variety of performance requirements. Most mix designs today include additional cementitious materials and admixtures. Natural pozzolans fly ash and slags supplement replace a portion of the Portland cement. Air entraining admixtures are used to improve freeze-thaw resistance. Chemical admixtures are used to accelerate or retard set, improve workability, reduce mixing water or increase strength. Adding these ingredients requires a thorough knowledge of mix designs.

In a much simpler way, MWC in water readily utilizes an additional 6 percent or more of already-included cement content in the mix, which in turn effectively increases the cementitious material content volume. It does this without increase of the originally designed dry cement volume (per-cubic-yard), which in turn lowers the water/cement ratio. This extraordinarily beneficial effect is due to the property of the preconditioned water in the mix to absorb more deeply the cement particles, posturing each cement particle to more readily and more often shed its mix water generated hydrate envelopes. It then allows new envelopes to be regenerated, which effectively causes the utilization of significantly increased percentages of each cement particle. It also uniquely generates additional volumes of cement paste, subsequently C-S-H or tobermorite gel per cement particle.

It is a known fact that when water is added in any mix, it reduces its strength. The objective, then, is to transform the water into a better product, such as cementitious material that produces even a lower water-cement ratio and not influencing the strength. Introducing selected natural ingredients into the mix water will generate increased utilization of water of convenience, in the mix producing virtually no bleed water. Following example will illustrate the use. Let's assume that 5 gallons of water fully hydrates 100 pounds of cement with a water ratio of 0.42. Only 2.88 Gallons of normal mix water actually combines with the cement, while the remaining 2.1 gallons of water occupies capillary spaces following the surface finish until it is used for
production of the hydration products or is later evaporated, which leaves the void capillaries. When the mix water is preconditioned, however, virtually all of the normal mix water is used due to the increased cement particle saturation schematically shown in Figure 1.

Using the ACI standard that in a given mix design of 470 pounds of Type 1 Portland cement, only 80% (376 pounds) of the cement is hydrated. Mix water conditioner produces a minimum of 6-8% (28-38 pounds) more cementitious material from that remaining 18-20% (84-94 pounds) of unhydrated cement. This results in a very homogeneous ready mix as shown in Figure 2.

7. PROPERTIES OF CONCRETE

Based on the extensive testing, several MWC showed the following enhanced properties from utilization of increased percentages of the already-included Portland cement content in the concrete mix.

1. The usual (leftover) cement particle cores were much smaller, which increased impermeability and density. These particle cores became different sized through increased cement utilization resulting in the leftover cores to act as sand/aggregate binder. This was tested extensively [2].
2. The cement paste was finely textured and homogenous. It provided with the same charged-particle effect and greatly reduced the potential for internal voids, shrinkage, excessive external bleed water, internal micro-cracking, crazing, plastic/settlement cracking, etc.
3. The concrete was extremely homogenous with the increased workability due to increased lubricity [2].
4. Cementitious material waste was reduced and water utilization was increased. This resulted in the increased volumes of cementitious material utilization per cement particle, effectively lowering water/cement ratio of finished concrete.
5. It generated 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 permeability and thus increasing durability shown in Figure 3.
6. It produced true shrinkage-compensating concrete, compensated by production of increased volumes of C-S-H, the hydration product, which also virtually eliminated curling.

![Graphs showing untreated and treated samples](image)

**Figure 3**

### 8. DISCUSSION

From the durability standpoint, it is of crucial importance to achieve the lowest possible permeability in the shortest period of time possible. This was achieved when the MWC was used. If less pollutants or contaminants were allowed to penetrate in the interior of concrete, it would be less permeable [1]. The degree of permeability dictated whether these pollutants/contaminants would readily - or sparingly - allow ingress. Therefore, permeability effectively and directly affected concrete’s durability and translated in to a longer service lifespan. For concrete made using normal weight aggregate, permeability is governed by porosity of the cement paste and pore-size distribution. In fact, its permeability is generally controlled by the capillary porosity and not by the gel porosity. Paste capillary porosity size is governed by water-cementitious material ratio in the mix and the degree of hydration. Mix water conditioner was designed to significantly enhance increased cementitious material...
volumes and improved hydration rates and processes through re-organizing the mix water's hydration abilities.

9. EXAMPLES

Examples presented here from different jobs to illustrate a wide variety of applications of MWC in practice.

Figure 4

Figure 4 shows the Dally Center in Chicago, in which a 4.5 x 96 meters section was poured during the rehabilitation work at the center. The MWC treated mix was poured over the irregular bitumen surface. Bonding was excellent and there was no cracking except in one corner of the inset, which was probably due to deflection.

Figure 5
Figure 5 shows an Exxon filling station, where the whole area was decked with 28 MPa concrete. It used 227 Kg. of cement, 1-in. aggregate and 23-cm. slump. The yard after several years is in very good condition with no distress (cracking) and the cores taken at our random location at 28 days showed the strength of over 41 MPa.

Figure 6

Figure 6 shows a subway system floor in Chicago Transit Authority in 1995. The floor used another form of MWC. concrete identifier-sealer (CDS) which was used for protection in the rehabilitation of concrete. The CDS was spray-applied, which penetrated to a substantial depth. In this manner, it reduces significantly rust producing reactions. It did not alter concrete surface or appearance or its physical characteristics. The traffic was opened within a few hours without impairing traction or bonding.
Figure 7 shows a Riverwalk project in Aurora, IL. The original walk started showing distress of saponification. With a major investment for the city, they used CDS for protecting it with some type of sealer to stop the deterioration and increase service life. The treatment helped by forcing the CDS into capillaries, where the bleed water came out and reacted with free alkali to form a silica-hydrate gel to help healing of concrete internally. The treatment also eliminated the freeze-thaw problem since the free water also was used with the CDS action.

10. CONCLUSIONS

It is shown that the mix water pre-conditioner added to Portland cement concrete mixing water, prior to concrete manufacturing, significantly eliminates all of the deterioration factors in concrete and more. Water in the mix, which has been preconditioned with the right amount of MWC will consistently produce concrete that is very strong, hard, impermeable and durable. It should be stressed that we can learn from our past experience to develop better concrete for the future. While doing so, one must recognize the need to preserve the environment and a good relationship with the community to improve the image of our industry as well as engineer in general.

Environmental impact should be considered during the production of ready-mix concrete. This will allow a better image of concrete and more useful applications of concrete.

Another point must be made related to concrete as universal material and its industry needs to promote it from developed world with all the good experience with new materials to the to developing world. This will bring the two worlds together to benefit everyone.

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REFERENCES

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APPENDIX A: DETAILS OF ENVIRONMENTAL IMPACT AND MANAGEMENT

National Ready Mix Concrete Association (NRMCA) (Ref. 1) has prepared recommendations for environmental management, which represent good industrial practice. They are practical, realistic and economically viable from the US perspective, although they are applicable in any
urban setting, where the public is becoming more cognizant of the concrete industry as part of their life. Eventually, Regulatory requirements may dictate plant upgrades regardless of the economic consequences. In short this may be considered as a wake-up call for the industry.

Other available environmental management tools include corporate mission statements, corporate policies and procedures, and internal plant audit inspections. The NRMCA Plant Audit Checklist was developed to serve as an internal guide for concrete plant managers. It should also be mentioned that Canadian Environmental code of Practices (1993) is available, which should be referred to as more detailed background version of this presentation.

Ready mixed concrete industry should be responsible environmentally and be nuisance-free and operate without causing such problems; it is then imperative that concrete producers maintain a positive image of their plants and equipment. As a manufacturing facility, ready mixed concrete plant operation is not a significant threat to the environment. However, main concerns may stem out of discharges due to the use of water and other ingredients, which may find their way into public facilities, and some pollution due to air and noise disturbances to the community. Thus, we need to address such issues and let the public be aware of our share of the problem and to make our industry a model to others in the vicinity.

Concrete producers can significantly impact the perception of their neighbors and others in their community. This perception, whether positive or negative, can be improved by the company’s involvement in community affairs. From technical perspective, this involvement can take several forms, such as the contribution of goods or services for worthwhile community projects, supporting local student projects, etc. The other sore problem is with concrete truck mixers, which are the advertising billboards for the concrete industry. They must be kept clean, freshly painted and well maintained to present a positive industry image. Use attractively designed company logos on truck mixers and other company vehicles. Consider using community logos or slogans on truck mixers, for example "Just Say No to Drugs." Concrete plants and related buildings must be well maintained and present an attractive appearance. Truck and equipment parts, tires, empty drums, solid waste and other debris should not be in public view at the plant. Concrete has a number of components, which are known to every one; it is time to see which of these in one form or the other may create a problem environmentally that one needs to manage.

- Cementitious material (cement, fly ash etc.)
- Sand
- Aggregate
- Water
- Admixtures (water-reducer, air-entertainment agent etc.)

These are familiar, but once they make "Concrete" and most of the concrete is used for the purpose it was made for, the remaining part, which needs to be discarded need to be managed properly. The various management aspects from the concrete plant operation of interest, are specified as follows:

Water Management
Noise Management
Solid Materials Management
Admixture, Chemical and Fuel Management
Air Quality Management
Plant Closing (either temporary or permanent)

**Water** is used in the operation of a ready mixed concrete plant in several ways from mixing it in the batching concrete to rinsing the truck after loading and cleaning it at the job site and at the end of the day. It also includes dust suppression in the yard, on roadways, on stockpiles and at the point of loading mixers, heating, cooling and soaking aggregates and finally rinsing the reclaimed aggregates from leftover concrete.

Water is an irreplaceable commodity in any of these applications, but it can be even more expensive resource unless its use is properly controlled. It can be of short supply in some regions and can make a significant impact on operations and cost efficiency of the plant. Wasting water in the operation of plant during mixing it for batching should be avoided by eliminating the overflow during filling and reducing it for rinsing trucks after loading. On the other hand, the exterior of the truck mixer must be rinsed free of aggregates and cement dust after loading so that dust is not tracked out of the yard, which may give rise to dust or air pollution problem. Rinsing should be done on a paved area with slopes toward the water collection basin so water may be captured at the end of the day. Some of this water can be reused.

Rinsing chutes and the mixer drum at the job site can be a problem in some areas. Producers should make sure that the clean up take place in an area approved by the customer/owner. Mixer trucks should never wash into catch basins or streams, as this is a criminal violation of the Clean Water Act. A bag or diaper can be placed over the chute to prevent spillage and allow the truck to return to the plant to cleanup.

If possible, recycled water should be used for rising truck mixers at the end of the day. The rinse water should first be drawn from a settling pit, holding tank or reclaiming equipment. An effective alternative is to use recycling admixtures to stabilize the concrete residues in the drum. Use only 40 to 50 gallons of fresh water and the suggested dosage of recycling admixtures to rinse mixer drums. The resulting slurry is then held on the truck and then incorporated into the first batch the following day.

In some states the EPA is the sole regulator. In other states the EPA has delegated its responsibility to the state government. Regardless of the minimum standards set by the EPA, State or local governments may enact higher standards for compliance. The minimum standards for discharge of industrial process water were enacted in the 1972 amendment to the Water Pollution Control Act (referred to as the Clean Water Act). The Clean Water Act prohibits discharge of industrial process water into waters of the state without the issuance of an NPDES permit.

Water Management also includes other waters, such as industrially processed water, storm water, etc., which are discussed here.

**Noise** is a common complaint of neighbors located near a concrete plant. Ready mixed concrete plants and related equipment sometimes generate noise that may be unacceptable to neighbors. Plant managers must take steps to minimize noise levels due to plant operation or due to truck, so as not to create a nuisance.

**Solid** waste generally is concrete in the hardened or plastic state and reclaimed solids from mechanical recycling equipment or rinse water settling systems. These solids may be used for landfill but there are less and less sites available and one may have to find an alternate to reuse it as byproduct rather than disposing it. Some methods of using returned waste include:
- production of precast products, such as highway barriers, etc.
- paving yard surfaces or use it around the plant as fill
- if hardened, then breaking it and re-cycling it
- re-cycling it into cement manufacturing
- discharging into wash water collection system

**Admixtures** are widely used in concrete industry as ingredients. Most of them are liquids and are supplied in bulk. Fortunately, they have more than 50% water and inorganic salts, wood sugars or resins. Most of these are non-toxic from environmental point of view, but there is a trend to have a secondary containment to bulk storage tanks, which have foundation on concrete base slab. CaCl₂ is one of the admixtures, which is in powder form and delivered in bags. It is easier to deal with them by storing them indoors, without causing any environmental problems.

**Air quality** problem is generated through the dust through the normal plant operation. The principal concern is the release of small particle dust (less than 10 μm in diameter). They pose a health and safety risk to persons who may breathe these particles. While there are several sources of dust, such as cement and fly ash during filling, stockpiling of aggregate and their use in different places truck mixer loading and charging, etc. It is best to minimize dust, and if not it should be suppressed. Often dust can be collected, (filtered) and bagged and stored in a safe place for final disposal. Concrete Plants are usually required to have "air quality" permits for the entire plant to ensure that emissions from plant falls below the minimum threshold limit.