

# The Durability & Solubility of Plaster

A series of e-mail articles from the research group onBalance, March 2006

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## The Durability & Solubility of Plaster #1

Two years ago, onBalance performed experiments to learn more about the durability of pool plaster. We specifically wanted to study the effects associated with the length of time one waits after a new plaster pool's final troweling, until the time water is turned on to fill the pool.

For the experiment, plaster (cement and aggregate) was mixed, and coupons were formed and placed in water at various time delays (30 minutes, 2 hours, 6 hours, and 24 hours) after the final hardening.

Each plaster coupon was placed separately into a five-gallon tank of balanced water, having a starting pH of 7.7, an alkalinity of 110 ppm, a calcium hardness of 180 ppm, and a temperature of 70 degrees.

Since this water was balanced according to the Langelier Saturation Index, does this mean nothing from the plaster surface should dissolve into the water?

Of course, we all know that "plaster dust" forms in the water, and on the walls and floors of pools soon after newly finished plaster pools are filled. And the primary source of this "plaster dust" is, well, the plaster!

But why does the plaster come off the walls when the water is balanced to begin with? And why do some pools have more "dust" than others? What can be done to reduce this problem? Answers to these questions and other results of this study will be shared in this update series.

## The Durability & Solubility of Plaster #2

For the first phase of our experiment, plaster coupons were placed in balanced water at four different time intervals (30 minutes, 2 hours, 6 hours, and 24 hours), and then the chemistry of the water was monitored over time. We assumed that if the chemical levels changed, it would be a result of plaster components dissolving and influencing the water chemistry. We also wanted to know if those changes varied according to the "fill delay".

The first thing we noticed was that the pH of the water rose in all four tanks. But the pH rose to 8.5 in one tank, and went as high as 9.2 in another. We also noticed some "plaster dust" settling at the bottom of the tanks.

Why did the pH rise so high?

Why did the pH rise to different levels in the different tanks?

Why didn't the pH stop increasing once the pH reached 8.3, as it would in "natural" water?

Since at a pH of 8.3 the calculated Saturation Index of the water would be +0.6, the water shouldn't have been aggressive to the coupons, yet the pH continued to go even higher! Where did the pH-increasing influence come from?

### **The Durability & Solubility of Plaster #3**

The reason for the continuing pH rise in this experiment is the compound *calcium hydroxide*, a component of hardening plaster, which has an extremely high pH – in the 12 range. It is somewhat soluble even in what we would consider balanced water, since water balance and calcium saturation is relative to *calcium carbonate*, a lower-pH compound.

After reacting with the alkaline components of the water, soluble calcium hydroxide is converted to insoluble calcium carbonate, which we know of as the chemical makeup of both plaster dust and deposited scale.

This experiment demonstrates that calcium hydroxide will be dissolved by "balanced" water from the surface of relatively hard plaster. However, calcium carbonate, also a component of a plaster surface, requires aggressive water to dissolve. The Saturation Index indicates when water has the ability to dissolve calcium carbonate, not calcium hydroxide.

CONCLUSION #1 – The rising pH levels indicated the loss of *calcium hydroxide* from the plaster surface and into the water.

CONCLUSION #2 – When calcium hydroxide dissolves from the plaster surface into the water, it predominately reacts with existing bicarbonate (alkalinity) in the water and becomes calcium carbonate (also known as "plaster dust" or scale).

### **The Durability & Solubility of Plaster #4**

After placing plaster coupons into water at different time intervals after final hardening, we tested the pH of each tank 24 hours after placement. We found that the *lowest* pH increase (to about 8.5 from a beginning pH of 7.7) was the tank with the coupon that had hardened the *longest* (24 hours) before placement in water.

The six hour coupons (placed in water after six hours) resulted in a pH increase to about 8.7.

The coupons placed in water after two hours resulted in a pH of about 9.0.

The *highest* pH increase (to about 9.2) was recorded in the water tanks that received the first plaster coupon in the *shortest* time, after only 30 minutes after final hardening.

CONCLUSION #3 – Since the water's pH change varied progressively from tank to tank, from fill delay to fill delay, we can conclude that the sooner the plaster is placed under water, the more plaster material is dissolved off the surface and into the pool water – even positive saturation water.

It should be reasonable to assume that when plaster loses some of its material (such as calcium hydroxide) from the surface, this loss creates porosity in the plaster surface. Increasing porosity reduces the long-term durability of the plaster surface, since it allows greater water penetration and movement. Greater porosity also increases the likelihood, severity, and permanence of staining discolorations.

Unfortunately, there is no current pool industry standard or guideline limiting how soon water can be started to fill a new plastered swimming pool. The filling of some pools is often started before the finishing crew has even left the job site. This is an area where onBalance thinks scientifically-derived standards could improve the consumer product.

#### **The Durability & Solubility of Plaster #5**

The plaster coupons used for the first phase of the study were made with a water-to-cement ratio w/cm of .44. This means that .44 pounds of water was used for every pound of cement. The aggregate in plaster is not counted as part of the w/cm. A .44 ratio would be considered a fairly low w/cm for the pool industry, and results in a beneficial and desired thick mix for plastering pools.

For the second phase of our experiment, we formed plaster coupons using a higher w/cm of .56, which results in a more watery mix. This scenario can sometimes happen if the plaster mixer person adds too much water to the mix.

We placed these newly formed plaster coupons in water at the same time intervals, or fill delays as in our first phase. The pH was tested again after 24 hours of coupons being placed into the water. As before, the pH rose in all tanks, but this time it rose even slightly higher than before. The water with the 24 hour coupon rose to a pH of 8.7, slightly higher than the pH of 8.5 recorded in the first phase. The 30 minutes coupon rose to 9.5, also slightly higher than the pH of 9.2 that was recorded in the first phase.

After recording the pH, a little acid was added to lower the pH again to 7.7 in all of the tanks, and the alkalinity was also adjusted back to 110. After another 24 hours had passed, the pH in all four tanks had risen again nearly to the same level as before. This process was repeated, with the same results for several days. After nearly a week, the pH began to stabilize – or stopped rising significantly from day to day.

CONCLUSION #5 – The wetter the original mix, the more plaster material is dissolved off the surface and into the pool water. This is an additional factor to the fill delay issue itself.

Again, the loss of material from this plaster surface creates porosity and will shorten its life-expectancy.

The fact that increasing water content is a direct influence in decreasing a cement-based product's durability is established, fundamental cement science.

Unfortunately, there is no current pool industry standard or guideline limiting how much water can be used in a plaster mix. This is another area where onBalance thinks scientifically-derived standards could improve the consumer product.

### **The Durability & Solubility of Plaster #6**

We continued maintaining the water balance in all of the tanks for 30 days. After being in the water for 30 days, the plaster coupons were removed from the water tanks. Remember the plaster dust in bottom of the water tanks? Could dissolving this dust and measuring the calcium increase from the starting point be another way of evaluating the effects of fill delay and of water-to-cement ratio?

Sufficient acid was added to the water tank to dissolve all of the precipitated "plaster dust" at the bottom. Then the water was tested to determine the total amount of calcium (as hydroxide) that had dissolved out of the plaster coupons and into the water.

First we tested the water from the coupons with the *lower* w/cm of .44 and the *longest* fill delay of 24 hours. The calcium increase from the dissolution of calcium hydroxide was 40 ppm. Since the ratio of plaster surface to water volume in this experiment was similar to that in a pool, this can be equated about 3 to 4 pounds of calcium hydroxide dissolved away from the surface of a 20,000 gallon swimming pool.

Next we tested the water that had the plaster coupons with the *higher w/cm* of .56 and the *shortest* fill delay of only 30 minutes. The calcium level in these tanks increased about 180 ppm in just thirty days!

This 180 ppm of calcium increase is the equivalent of a 22 pounds of calcium hydroxide lost from a new plaster pool surface into the water of a 20,000 gallon swimming pool!

Quite a difference! We learn from this study that although calcium hydroxide can be dissolved by balanced water, proper construction and curing practices can reduce the amount of this material that is dissolved away from the surface – resulting in a better product.

### **The Durability & Solubility of Plaster #7**

As a third variable in this study, we repeated the process using various amounts (1%, 2%, 3%, and 4%) of calcium chloride (for hardening acceleration) in the making of the plaster coupons. Testing the water for chloride two days after the coupons were submerged in water showed that some of the calcium chloride from the plaster coupons was dissolving

into the water. We learned that 15% to 25% of any calcium chloride that is added to a plaster mix will eventually (within 30 days) dissolve out of the plaster paste and into the swimming pool water.

Consistent with the calcium hydroxide loss, the **highest** amount of calcium chloride loss came from the coupon with the **highest** w/cm and placed into water the **shortest** time (30 minutes).

And of course, the **least** calcium chloride loss was from the most durable coupons – with the **lower** w/cm in the plaster mix and with the **longer** hardening time before submersion in water.

Losing yet another paste component, this time chloride, from the plaster surface into the water leads to yet more porosity. In combination with hydroxide loss, a significant level of additional porosity can be created in a plaster surface.

Past industry standards recommended a limit of 2% of calcium chloride in plaster mixes. There is even a move to allow greater levels as a result of (inaccurate) conclusions from other research. This potential increase in the standard is contrary to existing cement science, and contrary to our research applying known science specifically to pool plaster.

The results of this pool plaster durability study indicate a need for the pool industry to set scientific standards and limits for:

- minimum times for hardened plaster to set and dry before filling the pool with water
- water-to-cement ratios
- calcium chloride content

### **The Durability & Solubility of Plaster #8**

The American Concrete Institute's *Guide to Durable Concrete (201.2R-01)* "describes specific types of concrete deterioration" and "contains a discussion of the mechanisms involved and the recommended requirements for individual components of concrete, quality considerations for concrete mixtures, construction procedures, and influences of the exposure environment, all important considerations to ensure concrete durability".

This guide provides the following recommendations for obtaining abrasion resistant concrete surfaces and **resistance to mild acid attacks**:

- Use a low water-to-cement ratio at the surface which will reduce permeability. Tests indicated that w/cm of .40 provided significantly better protection than w/cm of .50 and .60, and a w/cm of .62 provided little protection.
- Avoid the use of supplemental water when troweling. Do not finish concrete with standing water because this will radically reduce the compressive strength at the surface (by increasing the surface w/cm).

Other documents from the ACI and Portland Cement Association also advise against using more than 2% of calcium chloride to the weight of cement due to the detrimental effects of drying shrinkage and discoloration.

All of these recommendations are consistent with the results of our study.

### **The Durability & Solubility of Plaster #9**

Since the Cal Poly research center (NPIRC) has performed experiments that included these three variables, what were their conclusions, and are they valid?

As for the fill-delay aspect, Cal Poly did not compare similar plaster mixes on pools filled with water within 30 minutes and 24 hours after final troweling. However, they did make plaster that had 2% calcium chloride added (which hardens quickly), which was also allowed to harden for over six hours before submerging under water. They then **compared it** to plaster that did not have any calcium chloride (0%) added, (which as a result needed and should have had 24 hours to dry to sufficiently and properly harden), and submerged it under water within minutes after final troweling!

So the skew was twofold – the chloride accelerator addition and the fill delay difference both favored the one type of plaster over the other. Not a very fair comparison and you can guess from reading the previous updates what happened as a result. The plaster that had the longest to harden was the densest – even though it contained the chloride. There was no cross-check to see the best result – using no chloride and a long fill delay. Yet Cal Poly claimed that their study proved plaster with calcium chloride added **is a benefit and reduces etching!**

(Incidentally, why is the term “etching” being used here? Of course calcium chloride doesn’t cause etching! But high calcium chloride amounts do cause shrinkage and increased porosity, which reduces the durability of plaster surfaces.)

As far as the water-to-cement issue, Cal Poly used w/cm ratios of .425 and .50 in their first phase. They announced that this water variable would probably “**not affect the etching deterioration of the samples significantly.**” Again, what does a high w/cm have to do with **etching?** But a high w/cm will affect the solubility and durability of smooth cement finishes. The Cal Poly study did not address this issue any further in their report.

### **The Durability & Solubility of Plaster #10**

Some people misunderstand cement chemistry and the relationships between pool plaster (a cement-based product) and pool water. As an example, the Cal Poly pool research study suggests that calcium hydroxide (which is contained in plaster) is only dissolved by aggressive or unbalanced water. This is not true, as demonstrated in our experiment.

More importantly, we have learned that some improper plastering practices lead to larger amounts of calcium hydroxide dissolving off the plaster surface - which leads to more porosity and reduced durability of that plaster surface.

In order to justify filling pools with water soon after completion, some industry people make the claim that the sooner plaster is submerged in water, the greater the ultimate strength. However, pool plaster is used mostly for its cosmetic or aesthetics properties, not for structural strength. The concrete (or gunite) shell is what provides structural strength. Additionally, plaster must be more dense than the gunite, since it must hold water in the pool. Our work shows that a proper fill delay, coupled with minimal calcium chloride and a proper water/cement ratio results in a smooth, hard, and dense cement finish to withstand the discoloration and staining effects from water year after year. That is what our customers want.

We have recommended that the industry consider establishing standards in three areas – fill delay, water-to-cement ratio, and chloride content. If considered, these standards need to be based on actual, valid science – not misunderstandings or invalid research such as some of that coming out of the NPIRC.

### **Durability & Solubility of Plaster #11**

We have received questions from many of you regarding problems with the Cal Poly studies, such as the fill delay issue, the calcium chloride issue and the issue of water/cement ratio and supplemental water use. Some of you have asked why we do not simply join efforts with them to improve their work.

Please note that we have been members of the NPC for 15 years. Que Hales and Doug Latta (from onBalance) were members of the NPC research committee and Tech Manual committee at one time before being forced off along with Jerry Wallace (another independent service company member).

In spite of that, we communicated with the Cal Poly research professors a year ago, offering constructive comments. Two months ago, we contacted Cal Poly research director Dr. Kachlakev, and volunteered to assist him and Cal Poly to help improve its research efforts. However, Dr. Kachlakev stated that he “cannot not see any clear benefit from our involvement on the Advisory Board.” He also did not acknowledge the problems which have been pointed out regarding his previous research, some of which we believe are significant enough to require scrapping some conclusions made to-date.

A lot of money has been donated by many contributors for the purposes of conducting research on swimming pool issues. The Cal Poly Research Center is a tremendous facility to conduct such research. We would hope that the powers-to-be would consider encouraging Cal Poly to revisit and research the issues raised in this update series. Pool plaster durability should be a prime focus of pool industry research.

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