USG Performance Flooring Solutions

GYPSUM MISCONCEPTIONS

This white paper reveals the misconceptions and inherent features and benefits of gypsum cement by exploring the basic science behind it. For the sake of clarity and time, we have taken a few short-cuts with the descriptions of science and may have used literary license to keep the extremely technical information to a minimum. First, a few basic terms and definitions:

Binder A binder is defined as "something (as tar or cement) that produces or promotes cohesion in loosely assembled substances."[1]
Cement Cement is defined as "a binding element or agency: as a substance to make objects adhere to each other."[2]

Therefore, for all practical purposes, "binder" and "cement" can be used interchangeably.

Concrete A word often misused. Concrete is defined as "formed by coalition of particles into one solid mass."[3] The definition does not specify what binder is used to create the mass, nor does it specify the types of particles. Aggregates can be sand or gravel or a combination of both. *Therefore, a product such as gypsum, when mixed with sand (such as USG Levelrock® Brand Floor Underlayment) is, in fact, a concrete (i.e. gypsum concrete).*

1. Binder [Def. 3]. 2016. In *Merriam-Webster.com*, Retrieved May 17, 2016, from http://www.merriam-webster.com/dictionary/binder.
2. Cement [Def. 2a]. 2016. In Merriam-Webster.com, Retrieved May 17, 2016, from http://www.merriam-webster.com/dictionary/cement.
3. Concrete [Def. 2]. In *Merriam-Webster.com*, Retrieved May 17, 2016, from http://www.merriam-webster.com/dictionary/concrete.

GYPSUM BASICS

Gypsum offers unique physical characteristics that other binders cannot. By definition, gypsum is a "mineral of crystalline structure composed of calcium (Ca), sulfate (SO_4) combined with two molecules of water." The chemical equation is: $CaSO_4 \cdot 2H_2O$. **Gypsum** is also commonly known as **calcium sulfate dihydrate** (di meaning two and hydrate meaning "contains water").

Natural gypsum is pH neutral – neither acidic nor alkaline. It is a very common mineral found around the world. **Limestone** is commonly known as **calcium carbonate**, and is also a calcium-based mineral, represented by the chemical equation: $CaCO_3$, where Ca is calcium and CO_3 is carbonate.

GYPSUM SOURCES

Gypsum occurs in sedimentary depositional basins in many parts of the United States and Canada including the Permian age strata and the Mississippian strata that contains gypsum mined in Nova Scotia.

USG and Gypsum
Historically, United States Gypsum (USG) built manufacturing plants at the site of natural gypsum sources. USG continues to quarry and mine gypsum plants such as Sweetwater, TX, Southard, OK and Ft. Dodge, IA, to name a few. Mined gypsum is not the only gypsum USG uses for wallboard and USG Levelrock floor underlayment; for more than a decade, USG is also a consumer of Flue Gas Desulfurization (FGD) gypsum to manufacture products. In fact, USG's newest plant is located near electric power plants that burn coal. It is there that FGD gypsum is created.

FGD Gypsum
Flue Gas Desulfurization is one of the processes of 'cleaning' the combustion gases of coal-burning power plants. The result of the cleaning process produces fly ash and FGD gypsum in two distinctly different places within the cleaning process. In simple terms, the cleaning of the exhaust gases from a power plant is done in this two-step process:

Step 1 involves the removal of the coal 'soot' which uses dry filters to capture the exhaust. The soot that is extremely fine in size and floats in the exhaust air is called 'fly ash.'

Step 2 is to eliminate as much of the sulfur dioxide from the exhaust. This is done by passing the filtered exhaust gases through a 'wet' scrubber. This scrubber is a mixture of finely ground limestone mixed with water to create a thick soup. As noted before, limestone is calcium carbonate. As the gas passes in the scrubber, the soup is sprayed into the gas and a chemical reaction takes place – the sulfur dioxide reacts with the calcium carbonate and the calcium carbonate becomes calcium sulfate dihydrate (aka gypsum).

THE MIRACLE MINERAL

Ground gypsum in and by itself will not get hard when mixed with water. Gypsum has to be converted to a "hemihydrate" by first cooking it. The process of cooking gypsum is called "calcination." As previously mentioned, two molecules of water are part of the gypsum (dihydrate) crystal. The calcination process removes 75% of the water, yielding a crystal composition known as calcium sulfate hemihydrate. Adding water to hemihydrate converts it back to the original form, calcium sulfate dihydrate. As you can see, the process is reversible.

The conversion from hemihydrate back to dihydrate is fascinating. When water is added to calcium sulfate hemihydrate, the hemihydrate crystals immediately go into solution and as fast as they go into solution, gypsum crystals begin to grow. The crystals grow in every direction and into each other. Once each crystal has re-hydrated, growth of the crystal system stops. Due to the crystal growth, the developed mass expands ever so slightly. This is a powerful mechanism for products made from gypsum as the expansion helps in several ways:

1. Eliminate shrink cracks normally associated with other types of cements (such as Portland cement (PC) and calcium aluminate cement (CAC)).
2. As expansion occurs, the mass finds every nook and cranny to grow into. Unless the surface is perfectly smooth like glass, the dihydrate will "lock" itself into place. This feature of gypsum provides a very important benefit in the underlayment marketplace. Therefore there is no need to create a host surface via shot-blasting or scarifying.
3. Thickness indifference. CAC and PC require water for proper hydration throughout the curing process. If a pour has variations in cross-sectional thickness (from thick to thin), the thin areas may evaporate quicker than the thick areas, thereby creating differential shrink over the entire mass. Gypsum only requires water for hydration until it has set (gets hard), therefore the cross-sectional thickness is not susceptible to differential shrink.

USG AND GYPSUM MANUFACTURING

Calcium sulfate hemihydrate, as described above, is the base binder for USG Levelrock floor underlayments, as well as many other USG products including, USG Moulding Plaster (Plaster of Paris), USG Hydrocal® Brand Gypsum Cements, USG Hydro-Stone® Brand Gypsum Cements and USG Sheetrock® Brand wallboard.

Through the marriage of base hemihydrate (via unique manufacturing process sciences) and chemical formulation, USG can formulate products to suit a wide variety of applications with specific features. As an example, USG Durock™ Quik-Top™ self-leveling underlayment will not only develop a compressive strength range from 8,000 – 10,000 psi and have self-leveling properties, but has been designed to be 'self-drying' in that the rehydration process will consume almost all the water used to create the slurry.

GYPSUM CONCRETE STRENGTH

Two factors have the most profound effect on the final strength of rehydrated gypsum – the amount of water and the aggregate used in the hemihydrate mix.

WATER

A hemihydrate crystal only requires about 18.6% water to rehydrate and become gypsum. This is often called "theoretical water." Using math, this means that 100 pounds of pure hemihydrate powder requires 18.6 pounds of water to convert into gypsum. However, in the real world, 18.6% volume of water will not be enough to create a fluid slurry. It is not uncommon that some hemihydrate products require up to 4-5 times theoretical water.

The rule of thumb about the effect of water with respect to hemihydrate is simple: The more water used to create a slurry (greater than the actual hemihydrate theoretical need), the weaker the hardened mass will be. This is because the excess water has no effect on the hydration process and literally takes up space. This 'free' water, sometimes referred to as 'water of convenience' ultimately sits in the hardened mass and then later evaporates, leaving behind tiny air voids. The more air voids the lower the density and the lower the strength, be it compressive, flexural or tensile strength.

The excess water has to leave the system through natural evaporation or through forced drying. The more water in the system, the longer it will take for it to be removed. Excess water will result in a lower strength mass. Once the mass has 'set up' and is fully hydrated, it is imperative that the hardened mass begin to dry. Last but not least, the ultimate strength of gypsum occurs only after the gypsum mass has completely dried.

Important to note – this is totally different than Portland cement (PC) or calcium aluminate cements (CAC). PC and CAC materials require water for an extended amount of time while the cement sets. This is often referred to as moist curing. Gypsum cements only require water to form new crystals as explained earlier. Once formed (usually within a few short hours), the system **no longer requires water**. This is counter-intuitive to those that work with or develop PC and CAC products. Note that all PC and CAC products provide strengths at different intervals up to 28 days to develop maximum strength. Gypsum's final strength can be accomplished as soon as the free water has evaporated from the set mass.

GYPSUM CONCRETE STRENGTH CONT.

AGGREGATES

The rule of thumb regarding the use of aggregates such as sand is: the addition of anything other than hemihydrate to a slurry will reduce the strength of the hardened mass. This is because the sand keeps the new hydrated gypsum crystals apart. Sand also prevents the new hydrated gypsum crystals from growing into each other. Further, the sand does not chemically bond to the newly formed crystals; instead, the sand becomes trapped and locked within the crystal matrix. One way to maximize how sand integrates with the slurry is to make sure the particles are not all the same size.

Particles of like size create space between each particle. By adding particles of various sizes, the spaces become smaller and more compact, providing a more efficient ‘nesting’ of aggregate. The shape of the sand is also very important. Sand that is too angular and flat is not as good as sand that has some rounded shape. Sands that have a more rounded shape tend to “roll” more than sand that is flat, which improves slurry flow. Sand to be used in USG poured gypsum underlayment products must be selected based upon maximizing the physical properties of the sand with the base formulation. It should also be noted that sand is not the same around the country and can contain impurities that have a negative effect on gypsum.

Given the rules as described above, one can deduce that excess water and the resultant negative effects on crystal growth etc. will result in an inferior dihydrate mass. It should be recognized that there are additives that are used in gypsum, PC and CAC-based formulations to make water more efficient. By using these chemicals, also known as ‘consistency reducers’ less water is required to create a flowable slurry.

USG FORMULATION ROBUSTNESS

USG has determined the range of water and sand that is required for every formulation manufactured by USG. Using more water or sand than is recommended will not only reduce compressive strength, but may create soft, chalky surfaces. However, USG gypsum cement formulations have been created to be extremely robust and can account for moderate user variations. Further, all of our formulations are designed so that they require less water than competitive products, yet maintain high fluidity. All USG gypsum-based underlayments use state-of-the-art technology that is protected by intellectual property rights.

Additionally, USG has developed manufacturing processes that optimize calcination processes resulting in engineered hemihydrate crystal structures that are well defined – sort of ‘designer’ crystals. Current technology can create hydrated products whose compressive strength approach 20,000 psi. The combination of formulatory and manufacturing technology advancements are unique and are protected by intellectual property rights.

THE TRUTH ABOUT WATER AND GYPSUM

Perhaps the biggest fallacy and certainly the one most used by adversaries of gypsum-based products is that gypsum underlayments will ‘dissolve’ or ‘melt’ when exposed to water. Gypsum is slightly water soluble, but so is limestone which is used as a building material. Gypsum is soluble in water at a rate of *2 grams per liter of water*. So what does this mean?

At a solution rate of 2 grams per liter of water, one pound of gypsum therefore will require 227 liters of water to go into solution (as there are 454 grams per pound). 227 liters is equivalent to about 60 gallons of water.

An example: If 60 gallons of water were poured onto a floor that was being supported by a gypsum underlayment (such as in a bathroom or kitchen) in no way does this mean that that one pound of gypsum would “melt” away. Assuming the floor had a floor covering, be it tile or vinyl as an example, how much water would actually be able to saturate the gypsum underlayment?

Now let’s say the flooring had not been applied, what then? The majority of the water will probably be absorbed by the gypsum underlayment. Even if the water is completely soaked into the gypsum underlayment, erosion will not take place because the water solution will be saturated at a rate of 2 grams/liter and will just soak into the gypsum underlayment. Assuming the water source is eliminated, the underlayment will dry. The water will simply evaporate, leaving the gypsum that had been in solution to reside within the interstitial spaces of the crystal structure. As a matter of fact, there could even have been a small portion of hemihydrate in the hydrated mass that was not rehydrated during the original pour. The intrusive water then reacts with the hemihydrate and is consumed as the hemihydrate rehydrates into dihydrate, further reducing the effects of water.

If however the water source is not eliminated, there is a possibility that surface erosion can take place. Keep in mind though that the volume of water would have to be extreme and the fact is that under circumstances enough to cause significant surface erosion, the effect of the water intrusion will also have an effect on other parts of the structure such as the plywood or OSB underlayment, or even the framing members of the structure. Water will probably cause the wood fibers of the plywood or OSB to swell, resulting in a floor/ceiling assembly that has been compromised to some degree.

In extensive lab tests conducted by USG CIC (Research), results proved that the gypsum structure did not lose physical strength or basic integrity.

IS GYPSUM CONCRETE A HYDRAULIC CEMENT?

ASTM C219-14a *Standard Terminology Relating to Hydraulic Cement* defines hydraulic cement as "a cement that sets in water and is capable of doing so under water." Gypsum completely fulfills this definition and it is totally proper to call all USG Levelrock products a "gypsum cement" (as it comes from the bag) and a "gypsum concrete" (after it is sets up and is on a floor).

GYPSUM REVIEW

- The setting of 'gypsum' is the result of the rehydration of the hemihydrates.
- The action of setting is also known as re-crystallization or hydration.
- Hemihydrate is the result of calcining (cooking) calcium sulfate dihydrate.
- Calcium sulfate dihydrate is the chemical name for gypsum.
- As hemihydrate converts to gypsum via crystal growth, the resultant mass expands slightly upon set.
- Hemihydrate requires about 18.6% water (by weight) to rehydrate.
- Water in excess of 18.6% is called 'free moisture' or 'water of convenience'.
- Too much water is bad because it keeps rehydrated crystals apart and the free moisture resides in the mass taking up space that ultimately becomes air voids once the free water evaporates.
- Adding sand dilutes the hydrated mass, reducing strength.
- Sand is not the same around the country and can contain impurities that have a negative effect on gypsum.
- Sand particle size and shape are important.
- Gypsum is slightly soluble at a rate of 2 grams per liter of water.
- Gypsum will not 'melt' when exposed to water. In some cases, the mass may become stronger.
- Soft, chalky poured gypsum underlayment is a result of too much water, too much sand or a combination of the two. Under mixing can exacerbate the problem.
- Once set, gypsum no longer has a need for water and develops ultimate strength once the gypsum mass is fully dry. The drying can be through normal evaporation or aided by forced drying.
- Through manufacturing and formulation techniques, gypsum concrete can achieve compressive strengths approaching 20,000 psi.

PRODUCT INFORMATION
See usg.com or pourlevelrock.com for the most up-to-date product information.

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