# Bentonite Clay Waterproofing

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### ABSTRACT

Bentonite waterproofing is a unique and interesting water protection material. This Monograph describes its use, limitations, chemical makeup, and the various products it is contained in for waterproofing purposes. Several typical waterproofing details illustrating how bentonite is used in practice will also help the reader understand its uniqueness in the below¬grade waterproofing industry.

### INTRODUCTION

This monograph provides background information on bentonite clay as a waterproofing material for below-grade applications. It is important that specifier's recognize the unique physical characteristics of bentonite clay. Each projects technical requirements should be reviewed with the manufacturer, or his representative, before any specifications are written.

### MINERALOGICAL COMPOSITION OF BENTONITE CLAY

Bentonite is a clay mineral with expansive characteristics. It is a natural material that is mined in the Black Hills regions of Wyoming, Montana, and South Dakota.

Approximately 50 to 80 million years ago volcanoes laid down an ash which time has changed into one of the most unique minerals in the universe. Its mineralogical name is sodium montmorillonite, but, it is commonly known as bentonite. This inorganic mineral is about 1/100,000 of an inch thick and it has many unique physical characteristics. Its most significant features are:

. The ability to expand and contract as it absorbs and expels water; . It can expand and contract an infinite number of times; . It can swell to 10 to 20 times its volume; . It will absorb five times its weight at saturation in water; . It is inorganic and does not break down with time; and . In thicknesses of 3/16- to 3/8-inch, it has a coefficient of permeability of 1 X 10(-8) to 1 X 10(-10) centimeters per second (cps). Its physical size and shape is sometimes hard to conceptualize. Imagine a one-inch square sheet of paper; this small piece of paper would represent a bentonite flake magnified 400 times. Bentonite flakes are very thin with large surface areas. The ratio of their surface area to physical volume is large and this characteristic enables them to absorb large quantities of water. One cubic inch of bentonite clay contains almost ten trillion individual flakes, and laid side-by-side would have a surface area equivalent to one and a half football fields. These characteristics, coupled with its swelling ability, give bentonite clay tremendous water impedance qualities.

Each bentonite flake is about 9.5 angstroms thick and has three layers bonded together; they consist of a gibbsite layer (aluminum octahedron) sandwiched between two silicon-oxygen layers (tetrahedron). Isomorphous substitution of magnesium or iron for aluminum in the gibbsite layer is common, and it will change the electrical balance and electrical charge of the plates.

The forces holding the three layers of a bentonite flake together are quite weak. Layers are held together by secondary valence forces and an exchangeable ion linkage. When trivalent aluminum is replaced by magnesium or iron, an imbalance is created and an exchangeable ion exists. This loosely attached ion may be sodium, calcium, or magnesium, and sometimes hydrogen. When the exchangeable ion is sodium, sodium montmorillonite is formed; in the case of calcium, calcium montmorillonite is formed. These two types are the most common montmorillonites. Sodium types are often mixed with calcium types. Sodium montmorillonite is much more expansive than either the calcium or magnesium montmorillonites. High grade waterproofing bentonites are sodium based; much of the expansive clays in the southern United States are calcium bentonites, while western bentonites are a mixture of mostly sodium bentonites.

The interesting phenomenon about bentonite clay chemistry is that an electrical imbalance exists in the gibbsite layer, which causes the flake to be like a magnet with a strong positive (+) charge in its center, and a negative ( - ) charge on the flake surface.

Water molecules tend to bond with the exposed oxygen atoms on the flake's surface, causing the mass of flakes to expand as more and more bonded water molecules crowd in between the individual flakes and surround them. Expansion of the mass will continue as the dipole water molecules align themselves upon each other. As water interacts with the bentonite flakes, it tends to displace the attached sodium ions on the flake's surface. Water then, by osmosis, seeks to equalize the displaced sodium ion concentration between the flakes.

As more water enters it crowds between individual flakes, forming layers upon layers in semi-rigid positions, pushing apart the flakes and causing the mass to swell. These water layers tend to bind the flakes together. This process continues to attract water molecules into the spaces between the flakes and causes expansion until equilibrium is achieved. Expansion will cease when all the excess water is consumed, or when the external pressures exceed the expansive pressures. Based on estimated pressure calculations, it is generally accepted that a minimum pressure of 30 to 60 pounds per square foot (psf) is necessary to keep bentonite from free-swelling.

When bentonite is allowed to free¬swell in standing water it will expand anywhere from 10 to 20 times its original volume. If exposed to external pressure, its swell will be less. When the bonded water molecules are removed by evaporation, the mass contracts and the flakes reassume approximately their original spacing. Movement of the flakes is in only one direction, but, because of the random nature and orientation of the flakes, shrinkage of the mass occurs in three dimensions. As water leaves, external forces along with internal forces within the flakes, work in unison forcing even more water out until pressure equilibrium is achieved and the flakes go back to their original positions.

This process can be repeated indefinitely because of the electromotive nature of clays; they do not wear out with time. Clay-swelling activities, however, can be damaged by the addition of salt or certain impurities in the water. Introduction of impurities tends to displace sodium ions and to lower the electrical imbalance in the flakes. If calcium or iron attach to the flake's surface, the electromotive charges are less and the water is not as strongly attached and absorbed onto, or in between, the flakes.

In practice bentonite clay is used as a 200 to 325 mesh powder, or, as granules that typically pass through a #10 sieve. Some products use both gradations of powder and granules. Just as in cement chemistry; the finer it's ground the faster it hydrates, similarly, bentonite that is ground to a fine powder reacts more quickly to the water. The increased surface area of powder allows for faster hydration than granules.

Imagine bentonite flakes, which have a length-to-width-to-thickness ration of 500-to-100-to-l, as sets of stacked plates or dishes with each stack in the range of 100 to 10,000 units. Also, imagine that these stacks are all intertangled and fused together. As the bonded water molecules enter the maze of stacked benetonite flakes, they first align onto the edges of the perimeter stacks. They then slowly work their way into the interior of the maze of stacked flakes and produce expansion of the mass. This expansion, between the flakes is in one direction, and is created by water layer buildup on the large flat surface areas of each flake.

The total mass grows in three directions, because of the random alignment of stacked flakes in all directions, but, the individual flakes do not absorb any water or swell. The total mass increases in volume only because of the electrical attraction of the bonded water molecules to each flake's interior. As more and more water is aligned with the flakes' surfaces, the mass of water and bentonite flakes, because of their own generated weight, tend to limit further expansion due to the induced back pressure to the system.

In the field, bentonite clay systems impede water flow because the external ground pressure on walls from earth backfill, or the weight from various building components (floor slabs or decks) creates a resisting pressure on the foundation that only allows a small amount of expansion of the bentonite system.

The bentonite waterproofing system takes on only enough water to form a pressurized gel which cannot absorb more water unless the confining pressure is reduced. Therefore, the system expands with water until it creates its own back pressure that limits its own further expansion and water absorption. When the clay is pressurized, it cannot absorb water, nor will it pass excess water, thus it becomes a waterproof coating.

A recent innovation by some bentonite suppliers and producers is the introduction of water reactive organic polymers to montmorillonite clays. These polymers tend to intertangle themselves throughout the bentonite flakes and attach to the flakes when water is added. As polymers attach and swell they act like springs and disperse the bentonite flakes. This swelling and gelling causes bentonite to react faster to water, and helps protect the bentonite flakes from stray ion contamination. This means that polymer treated bentonite is much mqre resistant to contaminant attack. Polymer treated bentonites also tend to have lower permeabilities, and they are not as sensitive to pressure gradient requirements. This is because polymers tend to limit the bentonite flakes from free-swelling due to their spring-like restraint when they are stretched.

There has been some concern that organic polymers will break down with time and allow the bentonite flakes to be attacked when placed in contaminated environments. However, it has been verified, in a laboratory environment, that once polymer treated bentonites become activated and remain in a swelled condition, they maintain an effective seal against contaminants, even though the polymers may slowly break down with time.

When bentonite clay is mined, it has about a 30 to 35 percent moisture content. It is then ground and kiln dried to a moisture content of about 6 to 10 percent; it is then processed through sieves ranging from a pellet size down to 325 mesh, a powder much like cement or flour. The most common sieve sizes are 40 to 200 mesh. There are different qualities of bentonites, each with different swelling capacities in fresh water. Bentonites can also range in color, although this should not be associated with quality. Bentonites used for waterproofing should generally have a minimum permeability coefficient of 1 X 10( -8) cps based on a 3/16-inch thick layer at a four foot constant head.

## HISTORY IN CONSTRUCTION

In the late 1920's bentonite clay was used to seal dams and contain water as a pond liner. One of its earliest noteworthy uses came in the 1930's when it was used, during construction of the Grand Coulee Dam, to seal off water that was preventing construction of a cofferdam. Upon installation, the bentonite clay swelled and filled open water-bearing seams. Water flow was reduced from 30,000 gallons per minute to 250, and work on the Dam was then completed.

Bentonite clay soon gained wide acceptance as a liner for lagoons and lake bottoms. It was widely used as an earth stabilizer, as "drilling mud" for removal of tailings during oil well drilling, and as a lubricant for driving pilings and caissons. In the mid-1960's bentonite clay was introduced as a waterproofing membrane for below¬grade building structures. Its successful performance and low cost led to large waterproofing applications including subways, tunnels, and building foundations.

## SYSTEMS AVAILABLE

There are several bentonite clay waterproofing methods presently in use. Over the past 20 years, bentonite has been mixed with other chemicals and containerized in many forms to achieve an economical application. There are basically seven types of systems that use bentonite in some form for waterproofing. They are: 1. Raw bentonite mixed with or without sand; 2. Spray bentonite with an asphalt binder in dry format; 3. Spray polymer enhanced bentonite with binder in dry format; 4. Bentonite placed in flutes of cardboard panels; 5. Bentonite adhered to geotextile in the form of a mat; 6. Trowel or spray grade bentonite in liquid/gel format; and 7. Bentonite adhered to high density polyethylene in sheet and panel form. (Bentonite/HDPE)

### Raw Bentonite Mixed With or Without Sand

In either powder or granulated form, raw bentonite is inexpensive when compared to other bentonite waterproofing materials. Because of its form, it is only usable for horizontal applications such as pond liners. When used, care must be taken to avoid application during high winds or rain. A void foot traffic on the material after application since displacement of bentonite is highly probable. A six to ten mil polyethylene sheet should be placed over raw bentonite after application.

It is very important to eliminate all voids in subsequent layers over the bentonite application. If large voids exist above the bentonite, these areas become avenues for the material to swell and gel into, thus losing its pressurization and seal. It is extremely important to realize that bentonite must be pressurized at all times by a pressure of 30 to 60psf, or more, to effectively seal it. It is best to mix powder and granulated bentonites together when used in the raw form.

Granular or powdered bentonite clay, mixed with clean coarse silica-sand, is also used for waterproofing horizontal surfaces or substrates. Generally a 200 mesh powdered bentonite is mixed in a ratio of 5 to 18 percent bentonite to sand. The sand should approximate 10 to 15 percent moisture content before bentonite is added. Application thickness is usually 2 to 4-inches, with 2-inches being a minimum. The bentonite clay/sand layer should be compacted and covered with a 6-mil polyethylene cover sheet.

The advantage of a bentonite clay / sand matrix is that as the bentonite swells and fills the void spaces between the sand, it forms an effective seal without introducing external movements or pressures to overlying materials. A concern in this type of application is in not getting a thorough and proper bentonite clay /sand mix, thus, having intermittent porous sand pockets that could allow water migration. Another concern with this matrix, when the bentonite content is low, is that large void spaces in the sand matrix could allow for excessive free¬swelling of the bentonite.

When a bentonite clay /sand matrix waterproofing material is installed beneath a concrete slab, quality control must be carefully controlled. The optimum quantity of bentonite will just fill the interstices in the sand when expanded. This percentage is usually about 10 to 13 percent depending upon the sand texture. If the bentonite is mixed with moist sand, some swelling takes place during application, and controlled compaction of the mixture will reduce the formation of porous sand layers.

When raw bentonite is placed on or under a substrate, it typically has a moisture content in excess of four to eight percent. If raw bentonite is placed on the jobsite substrate drier than two to three percent, uplift problems could occur. During the first one or two molecular layers of water absorption of bentonite, a pressure of over 140,000 psi can be generated. After those first few water layers are built up, water enters by osmosis and pressures generated are very small, perhaps ten psf (0.069 psi) or less. It is important to realize that the stress (pressure) created by swelling bentonite is insignificant when it is compared to the induced strain (movement), generated by expansion, if the confining material is not of proper weight. What this means is that as bentonite swells it conforms into the surrounding soil, rather than creating an added lateral or uplift pressure on the wall or retaining system. The strain created, under a floor or between slabs, by 3/16- to 3/8-inch of bentonite swelling is generally not a concern if external pressures, from the 4- to 6¬inches of concrete, of 30 to 60 psf or more are present. Placing very dry bentonite one-inch thick, or more, may require more than a 30 to 60 psf pressure gradient on the material to contain uplift pressures and movements.

Other precautions, for the use of raw bentonite with or without sand on horizontal areas, are: avoid wetting the material before it is covered; provide a protective board over it before application of subsequent material layers; and avoid calcium carbonate, chlorides, and other reactive materials from contaminating the sand and neutralizing the sodium montmorillonite. A further consideration against the use of raw bentonite is that without a container, or an adhesive to hold it in place during construction, workmen installing cover sheets, protection board, insulation, or backfill tend to damage and displace it. Ra w bentonite has been known to fall through small cracks and joints, while still in its dry state, when no means is used to bind it together as a membrane. There have been many waterproofing applicators who have created severe problems for themselves by using raw bentonite on vertical walls. The most serious concern arises when water is mixed with bentonite to make it trowelable. This typically requires a nine to one mixture of water to bentonite to make it soft and plastic; it also damages the bentonite's re¬sealing and long-term sealing characteristics. To form a positive seal on a wall it takes two to three-inches, or more, of this pre-activated material to equal the performance of 3/16- to 3/8¬inch of dry material. In time the pre¬activated material placed on the surface will shrink back to its originat dry volume. Upon shrinking it will crack and create many void spaces, as well as cause settlement in and around the structure. This in itself could damage both the waterproofing integrity and the structure.

Raw bentonite applications should only be used for pond and lagoon liners, where bentonite clay Isoil thicknesses are approximately four to six inches thick, and two to four pounds of bentonite per square foot is used. In conclusion, this system is not recommended for residential or commercial waterproofing. It is not actively promoted by any manufacturer, and the description of the system was only included for information.

### Spray Bentonite With an Asphalt Binder in Dry Format

This system is a two-component process in which dry granulated bentonite is blown through a two-inch air line and intermixed with an asphalt emulsion at the end of a spray gun. As the partially asphalt-coated bentonite hits the substrate, it adheres and forms a monolithic-seamless membrane. Thicknesses can be varied from 1/8¬inch for damp proofing to 3/8-inch, or more, for extreme situations where severe hydrostatic conditions may exist. The standard membrane recommended by applicators has an average thickness of 1/4-inch, with a bentonite clay content of 11/4- to 11/2-pounds per square foot. Permeability tests have shown that this system will perform well at head pressures of 80-feet.

The system is sprayed on horizontal substrates at a ratio of 80 to 90 percent bentonite with 20 to 10 percent asphalt emulsion; and a 50/50 mix is used on vertical surfaces. At grade line terminations, where bentonite interacts with the air, a protection material must be placed over the bentonite to insure its pressurization. At the grade line, and for about 12-inches below, an applicator will typically increase the asphalt content to a 30/70 mix.

This system has been used successfully for many years, but, it has some drawbacks. Quality control remains essential for its effectiveness. Problems can occur when the asphalt emulsion content is too high and it completely coats the bentonite granules. Water tends to find its way through the asphalt; bypassing the bentonite and thus not activating it. In time the asphalt emulsifies, and exposes the bentonite which then begins to develop its waterproofing qualities. Another difficulty with this system is that during cold weather the asphalt emulsion has to be heated in order to be properly sprayed. During extremely hot weather the asphalt emulsion tends to creep, which could lead to product fall off or spalling. The system also tends to be quite messy.

Another concern with this spray system is the rebound of uncoated bentonite hitting the substrate and dropping to the ground. This occurrence makes it important that drain tile, filter fabric, and porous rock not be in place before the waterproofing application. Many times the bentonite rebound can be left on the footing because it forms a good seal at the construction joint between walls and footings. On horizontal applications no rebound is generated.

This system appears to have the ability to withstand normal field abuse without a costly protective coating. The material takes on a tough resilient set, shortly after being applied, and can remain on the wall for several weeks in this condition. If rainy weather is a concern, the applicator can spray a light asphalt coat over the system to offer some protection.

This system is not widely used. It requires the use of specialized application equipment, and there is only one applicator available in the United States. A newer spray bentonite system replaces the asphalt binder with a latex emulsion, see the next section.

http://wiki.csinet.org/index.php?title=Bentonite_Clay_Waterproofing_2

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