ELASTOMERIC BINDING COMPOSITIONS

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Compounds are provided which act as flexible binding or cementing compounds. These compounds comprise a substituted or unsubstituted polyvinyl alcohol, a hydrogen-bonding crosslinking agent and a water storage component. Additionally, methods for making and using these compounds are provided.
ELASTOMERIC BINDING COMPOSITIONS

FIELD OF INVENTION

This invention relates to novel hydratable compositions or in situ additive compositions which, when combined with particulate material, bind the particulate material and provide flexible and elastomeric mechanical grout or binder.

BACKGROUND

In the field of civil engineering, particularly when it relates to the construction of buildings or roadways, many materials can fulfill the function of securing, cementing or binding crushed aggregates used as primary basement to such constructions. These aggregates are typically any non-friable materials, that when mixed with an appropriate cement or binder retain and/or increase the strength of the aggregate/cement combination. Typical aggregate materials are, for example, polycrystalline construction sand (silicon oxide —$\text{O}_2\text{Si}$— CAS #87347-84-0), pea gravel, crushed rock, or decomposed granite, which are often mixed with typical cement materials like Portland-style cement, synthetic cements and clay. Once the cements and aggregates are mixed, water is usually added to the mixture and the cement begins hydration over anywhere between one hour to several days, until the mixture reaches several thousands of pounds per square inch (kpsi) of compression strength.

Still in other industries related to construction, like the commercial or domestic landscaping businesses, it is sometimes desirable to have binders admixed with the aggregates to impart flexibility and elasticity to the bound mass.

This flexibility and elasticity is sometimes necessary to impart specific properties to the aggregate plus binder combination to suit a specific use, for example in the installation of driveway or roadway prefabricated interlocking pavers. Due to the large variety of designs and installation combinations of interlocking pavers, it is sometimes desired to fill the spaces separating the pavers' vertical contact walls with sand. The sand acts as a shock absorbing material when the pavers are subjected to lateral forces applied by rolling vehicles as they pass across its surface, as well as preventing the pavers from coming loose from their abutment.

It was found through interviews with industry users, contractors and manufacturers of interlocking pavers, that one principal characteristic of interlocking pavers, and what makes them so appealing and desired in the construction of roadways and driveways, is the fact that about 90% of pavers are installed as a small block locked with an adjacent one by a spur or claw feature molded onto the paver. The pavers need to be able to move a minimal amount in all directions to absorb the heavy loads of vehicles running over any single paver. This ability to move slightly makes pavers impervious to cracking or crumbling under extreme loading while being able to remain relatively intact in appearance, even in regions of the world affected by earth movements, such as earthquake-prone California.

One common problem with the use of sand as a "gap filler" for the spaces between interlocking pavers, is that being very fine in mesh and light in weight, the sand is prone to being blown out of the interstitial spaces of the pavers by the action of wind, water runoff, rain and general settling due to random load changes on the pavers in their day-to-day use.

There is a limited variety of sand-based filling or binding materials available under various trade names, but which are commonly self-categorized as "polymeric sand", that act to bind sand in interstices, such as between concrete pavers. However, these "polymeric sands" either become rock-hard after application or, if pliable after application, do not remain pliable and flexible under various environmental temperature ranges. Other "polymeric sands" crumble back to a powder at some point after installation and activation. Still other "polymeric sands" require special physical conditions, like being perfectly dry, and/or require large or costly equipment in order to be mixed thoroughly.

Thus, there is a need in the industry for a composition which can provide a long-lasting flexible elastomeric grout or binder for construction materials, pavers or aggregates.

SUMMARY

In one embodiment, a flexible binding compound is provided comprising a polymer of the form:

$$\text{R}_2^2 \text{R}_1 \text{C-C} \text{R}_3 \text{OH}$$

where R’, R and R are each independently hydrogen or alkyl groups of five or fewer carbons; a hydrogen-bonding cross linking agent; a water storage component.

In another embodiment, a method for making a flexible binding composition is provided comprising combining a polymer of the form:

$$\text{R}_2^2 \text{R}_1 \text{C-C} \text{R}_3 \text{OH}$$

where R’, R and R are each independently hydrogen or alkyl groups of five or fewer carbons; a hydrogen-bonding cross linking agent; a water storage component.
In another embodiment, a method for fixing particulate material is provided comprising mixing the particulate material with a polymer of the form:

\[
\left( \begin{array}{c}
R^2 \\
R^1 \\
R^3 \\
\end{array} \right)
\]

where \(R^1, R^2\) and \(R^3\) are each independently hydrogen or alkyl groups of five or fewer carbons, a hydrogen-bonding cross linking agent, and a water storage component to form a mixture; depositing the mixture; and hydrating the mixture.

**DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS**

One of the embodiments of the present invention comprises modified aggregates used to fill inter-paver joints. It was determined that the minimum physical requirements demanded by the market for such a modified aggregate are as follows.

- The modified aggregate inside the filled inter-paver joint should remain pliable and elastomeric to allow movement of the pavers without cracking.
- Any cracking of the filled inter-paver joint should occur, the modified aggregate should be able to re-seal itself upon re-hydration.
- The modified aggregate should be activated at ambient temperature by application of plain water spraying or flooding.
- The use of the paver surface after application of the modified aggregate should be available within one to two hours after activation.
- The modified aggregate should have a very low shrinkage factor for temperature cycling from −10 degrees centigrade to 95 degrees centigrade.
- If possible the modified aggregate should be resistant to mildew, vegetation growth (lichens, moss, weeds) and pests (termites, ants).
- The modified aggregate should be available in pre-packaged waterproof bags or containers.
- The modified aggregate should be made with low cost and easily available materials.

These requirements can be met by using a polymer-based composition which can cross-link through non-covalent chemical bonds, is water activated, which provides a dynamic viscoelasticity (DVE) to the aggregate particles and which is hydrophilic (water absorbing).

In the initial experimentation, several low-cost and easily available inorganic chemicals were found that would provide some but not all the properties required by the market research. One of the most promising yet unsatisfactory formulations was the admixture of the aggregates with a solution composed of a colloidal suspension that would remain in a "gel" form as long as the water content of the admixture could be maintained constant and at a proper ratio. This initial colloidal suspension was provided by the combination of polyvinyl alcohol (PVA), borate salts and water.

Polyvinyl alcohol is one of the main ingredients in regular household white glue, like Elmer's®, which contains several ingredients, but the major constituent is always PVA. PVA is a polymer composed of a long hydrocarbon chain with hydroxyl (-OH) groups attached to every other carbon as shown in Formula I, below.

When PVA is in aqueous solution (actually a colloidal suspension), the hydroxyl groups become ready sites for hydrogen bonding, which increases PVA’s interaction with the water molecules, making it soluble as compared to polyethylene. This hydrogen bonding also allows the PVA molecules to interact slightly with each other, such that at higher concentrations, a PVA solution becomes slightly viscous. During plasticization of PVA, the hydroxyl groups are covalently cross-linked to create a solid mesh of connected chains.

However, if too much water is added, the mesh of connected chains remains fluid, forming link chains of up to 2,000 units, and the covalent cross-linking is not occurring. What is needed at this point is the addition of a compound or chemical with multiple hydrogen bonding sites that will form strong hydrogen bonds with PVA. It was discovered that many organic and inorganic forms of borate salts have the effect of forming hydrogen-bonded cross-links between the PVA molecules as shown in Diagram I below. Note that water is likely directly involved in at least some of the hydrogen bonding.

![Diagram I](image-url)
interfere with the ability of the polyvinyl alcohol to form hydrogen bonds with the crosslinking agent.

[0028] It was clear that this simple PVA-borate combination plus the aggregate would require a stabilization to maintain its moisture level at the optimal cross-linking of PVA and borate salts, without losing its elastomeric properties. It was also found that the presence of the hydroxyl (OH) groups on PVA makes it possible for PVA to form hydrogen bonds with other molecules, such as the ones formed with the borate ion, \( \text{B(OH)}_4^- \). The borate ion has a tetrahedral structure, as shown below in Diagram II. Other compounds with multiple (two or more) hydrogen bonding sites can also be used as hydrogen bonding crosslinking agents. Compounds which foster this crosslinking by hydrogen bonding include, but are not limited to, sulfates, molybdates, phosphates, and nitrates. Other suitable compounds for crosslinking PVA by hydrogen bonds will become apparent to one skilled in the art and are specifically included in the scope of the present disclosure.

![Diagram II](image)

[0029] Borates come from a rock called Kernite. Kernite is used in the production of boric acid and borax. Boric acid is used in the production of textile fiberglass (cars, boats, circuit boards, roofing shingles), ceramics (glasses), chemicals (corrosion inhibitors, insecticides, pharmaceuticals), and specialty glass (heat resistant glass, laboratory glass). Sodium borate, a white, anhydrous, crystalline salt with an alkaline taste, is used as a flux in manufacturing of glass, soap, enamel and artificial gems. Several borate ores include borax, colemanite and ulexite. For the purposes of this invention, it was found that borates and their other salts like sodium metaphosphate, sodium tetraborate, hydrated sodium borate, hydrated sodium metaphosphate, and hydrated sodium tetraborate (Borax), as well as non-borate salts such as magnesium sulfate, molybdenum sulfate, and sodium molybdate all interact in similar manner with PVA, while imparting somewhat different properties to the composition.

[0030] Since the water content of this "aqueous polyvinyl alcohol colloidal borate cross-linking" would eventually evaporate after long periods of thermal cycling or exposure to the environment, it was necessary to find additional constituents that would replenish water to the PVA-borate combination. It was found that mucilages, which are substances belonging to a class of gelatinous compounds chemically called 'colloidal polysaccharides' that are produced and extracted from certain plants could provide such hydrophilic function by the action of adsorbing water.

[0031] Typical high-yield plants that have parts composed or containing mucilage are preferably quince seeds, flax seed, konjac glucomannan, guar gum, locust bean gum, carob bean gum, and more preferably aloe acemannan, xanthan gum, psyllium seed, carrageenan, gum arabic. Typical low-yield plants and seeds that would be viable for the purposes of this invention are nonionic or cationic saccharides such as: agarose, amylopectins, amyloses, arabamides, arabinogalactans, arabinoxylans, carageenans, gum arabic, carboxymethyl guar gum, carboxymethyl(hydroxypropyl) guar gum, hydroxyethyl guar gum, carboxymethyl cellulose, cationic guar gum, cellulose ethers including methyl cellulose, chondroitins, chitin, chitosan, chitosan pyrrolidone carboxylate, chitosan glycolate chitosan lactate, cocomodinium hydroxypropyl oxethyl cellulose, colomonic acid (poly-[N-acetyl-neuraminic acid]), corn starch, curdlan, dextrin sulfates, dextrins, fucellarans, dextrans, cross-linked dextrins, dextrin, emulsan, ethyl hydroxethyl cellulose, galactoglucomannans, galactomannans, glucomannans, glycogens, hydroxy ethyl starch, hydroxypropyl methyl cellulose, hydroxy ethyl cellulos, hydroxy propyl cellulose, hydroxypropyl starch, hydroxypropylated guar gums, gellan gum, gellan gum, gum ghatti, gum karaya, gum tragacanth (tragacanth), heparin, hyaluronic acid, inulin, keratin sulfate, modified starches, laminarans, laurdininum hydroxypropyl oxethyl cellulose, okra gum, oxidized starch, pectins, acids, pectin, polydextrose, polyquaternium-4, polyquaternium-10, polyquaternium-28, potato starch, propectins, pullulan, sodium hyaluronate, starch diethylaminoethyl ether, steardimonium hydroxyethyl cellulose, raffinose, rhamnose, tapioca starch, whelan, levam, scleroglucan, sodium alginate, starchlyose, sucingoglycan, wheat starch, xylans, xyloglucans, and mixtures thereof.

[0032] These colloidal polysaccharides, in turn contain mostly xylene, arabinose and galacturonic acid which are used in many commercial over-the-counter (OTC) intestinal laxatives for human consumption, the most famous of which is sold under the trademark Metamucil but also they are the active compound in Benefiber, Fiberall, Hydrocil, Konysyl, and Perdiem, among others. The main effect for humans is the relief of chronic constipation because the mucilage's polysaccharides hydrophilic activity acts as a soothing lubricant by absorbing toxins and holding water in the digestive tract.

[0033] It was discovered empirically that the well-known husk from the Plantago psyllium seeds (Plantago ovata, Plantago psyllium, Plantago arenaria) contains a high percentage of mucilage and is mainly composed of xylene, arabinose and galacturonic acid. Said husk also contains substantial amounts of rhamnose and galactose. Thepowdered husk is broadly utilized throughout the world as an emollient and laxative, being particularly useful in the treatment of chronic constipation. Psyllium has an extraordinary hydrophilic nature capable of absorbing 15 to 25 times its weight in water.

[0034] While colloidal polysaccharides and mucilages work well as water storage components, other compounds that store and slowly release large quantities of water will work as well, including various types of hygroscopic polymers.

[0035] An embodiment of the present invention, which will be used as additives to construction aggregates will be formed by ternary dry mixtures of:

[0036] a. a water storage component as described herein, in ground powder form in mesh sizes of 100 to 600 and preferably 200 to 400 and more preferably 250 to 300;

[0037] b. a polyvinyl alcohol (PVA) provided in ground powder form in mesh sizes of 150 to 600, preferably 250 to 450, and more preferably 300 to 400 and with PVA average molecular weight of 85,000 to 220,000, preferably 95,000 to 150,000, and more preferably 105,000 to 110,000 where the PVA may be fully or partially saponified or internally plasticized polyvinyl alcohols with an average degree of polymerization of 150 to 10,000, preferably 300 to 2000;
[0038] c. a hydrogen bonding crosslinking agent such as boric acid, sodium borate or hydrated sodium tetraborate (Borax), sodium metaborate, hydrated sodium borate, hydrated sodium metaborate, magnesium sulfate, molybdenum sulfate, and sodium molybdate provided in ground powder form with mesh sizes of 150 to 500 and preferably 200 to 400 and more preferably 240 to 330.

[0039] Proportions for these components by weight are as follows:

[0040] Water storage component → in the range of 19 to 88 percent, and preferably 19 to 75 percent;

[0041] PVA → in the range of 2.7 to 45 percent, and preferably 4.8 to 45 percent;

[0042] Hydrogen bonding crosslinking agent → 8.3 to 67 percent, and preferably 15 to 67 percent.

It is often desirable to maintain a PVA to crosslinking agent ratio of approximately 3:1.

[0043] Another embodiment encompasses pre-formulated mixture of binder and aggregates provided to consumers in fractioned packaging like bags or totes, where the ternary mixture of the components of the present invention shall be present in the total net weight of the contents with a percentage by weight for each ternary component in the following ratios:

[0044] Water storage component → in the range of 1 to 45 percent and preferably 3 to 28 percent and even more preferably 3 to 12 percent, of the total weight of the aggregate composition;

[0045] PVA → in the range of 0.2 to about 10 percent and preferably from about 1 to about 5 percent, of the total weight of the aggregate composition;

[0046] hydrogen bonding crosslinking agent → in the range of 1 to about 25 percent and preferably from about 3 to about 8 percent, of the total weight of the aggregate composition;

with the balance being the aggregate material.

[0047] It is understood that the multiple combinations possible of water storage component, PVA, hydrogen bonding crosslinking agent and aggregate percentages will provide for a final hydrated texture and elastomeric properties that will vary in accordance with the application requirements. Without limitation, the uses of more than one water storage component in any ternary mixture is also possible in order to add different water absorption and retention properties to the whole composition. It is also further understood that a desire to use naturally occurring polysaccharides are preferred, so as to provide more economical and ecologically-friendly sources of said material (e.g. from other industries’ waste products).

[0048] It will be obvious for those skilled in the art, that there will be many combinations of the ingredients that will be suitable for specific uses outside the field of construction materials for the building industry.

[0049] As an example, a specific combination of the ternary admixture of the components can be used to ameliorate loose landscaping soil while providing moisture retention, preventing excessive water irrigation and soil erosion. In this example the aggregate will be plain, common landscaping or agricultural soil and the function of the novel invention is purely for improving the performance and economy of soil or soil amendment (fertilizer, pH correction, humidity) additives.

[0050] As another example, the admixture of the components can be used to bind elastomeric aggregates such as shredded rubber, silicone particles or other flexible materials. This bound composition can be used to form cushioned surfaces such as running tracks or playground landscaping.

EXAMPLE 1

[0051] A 2-litre beaker was filled with a 1,000 grams of dry construction sand used for filling interlocking spaces between interlocking pavers, commonly designated in the industry as type ASTM C-136 by the American Society for Testing of Materials.

[0052] A 1-litre beaker was charged with 7.8 grams of PVA with a mesh size of ~220 and an average molecular weight of 95,000 grams/mole which was then mixed with 12.5 grams of sodium perborate (Na2(B2O3)(OH)4(8H2O)) with a mesh size of ~300 and an average molecular weight of 300 grams/mole. Thirty grams of ground psyllium husks mucilage (Plantago psyllium), produced in India under the trade name “Kha-Kha” with a mesh size of ~150, was added to this mixture.

[0053] The above ingredients represent a mixture with respect to 1,000 grams of sand, containing: 1.25% Borax by weight, 0.78% PVA by weight, and 3.00% Psyllium by weight. All ingredients were mixed in their dry form with a 3,000 grams-capacity sealed rotating-tumbler mixer for 15 minutes.

[0054] A test framed box was constructed in wood with dimensions of 21.25 inches wide by 26.25 inches long, to hold a 5 by 5 grid of standard concrete interlocking pavers, sized 4 inches wide by 5 inches long and 3 inches high and separated from each other by a 0.25 inch gap, which is subsequently referred to by the term “inter-paver gap.”

[0055] The pavers were dusted with the mixed dry sand mixture described above, and the mixture was brushed into the inter-paver gaps by the aid of a stiff brush to fill as much of the entire depth of the paver height with the mixture as possible.

[0056] A small water hose affixed with a fine sprayer nozzle was used to spray tap water over the entire assembly until a slight pool of water was observed remaining on top of the admixture of the inter-paver gaps, at which point the water spraying was stopped.

[0057] The whole assembly was left to cure for 60 minutes at ambient temperature.

[0058] After the curing time had elapsed, the entire test frame was placed on a vibrating table and given a shake test for 20 minutes with an excursion of 20 millimeters and a frequency of 4 Hertz, in order to establish the adhesion and cohesiveness properties between the inter-paver gaps filled with the mixture described above and the walls of the adjacent pavers.

EXAMPLE 2

[0059] A 2-litre beaker was filled with a measured amount 1,000 grams of dry ⅛ to ⅜ inch diameter pea gravel such as that used for filling ornamental walk paths in open gardens.

[0060] A 1-litre beaker was charged with 12 grams of PVA with a mesh size of ~300 and an average molecular weight of 105,000 grams/mole which was mixed with 15 grams of sodium perborate (Na2(B2O3)(OH)4(8H2O)) with a mesh size of ~300 and an average molecular weight of 300 grams/mole. To this was added 45 grams of ground guar
gum extracted from the seed endosperm of the legume plant *Cyamopsis tetragonolobus*, an annual plant, grown in arid regions of India as a food crop for animals, with a mesh size of ~250. Finally, 10 grams of Xanthan gum powder, which is a gel produced by the bacterium *Xanthomonas campestris*, with a mesh size of ~200 was added. The backbone of Xanthan gum is similar to cellulose, but the tri-saccharide side chains of mannose and glucuronic acid make the molecule rigid, and allows it to form a right-handed helix which makes it interact with itself and with the other long chain molecules in the guar gum to form a thick mixture or gel in combination with water.

**[0061]** The above ingredients represent a mixture with respect to 1,000 grams of pea gravel containing: 1.50% Borax by weight; 1.20% PVA by weight; 4.50% Guargum by weight (water storage component 1); and 1.00% Xanthan gum by weight (water storage component 2).

**[0062]** All ingredients were mixed in their dry form with a 3,000 grams-capacity sealed rotating-tumbler mixer for 15 minutes.

**[0063]** A test framed box was constructed in wood with dimensions of 20 inches wide by 25 inches long by 3 inches high and filled with the whole volume of the admixture so it could be contained while curing.

**[0064]** A manual tamper disk attached to a long wooden handle was used to compact the pea gravel admixture to a uniform level.

**[0065]** A small water hose affixed with a fine sprayer nozzle was used to spray tap water over the entire assembly until a slight pool of water was observed remaining on top of the admixture.

**[0066]** The whole assembly was left to cure for 60 minutes at ambient temperature.

**[0067]** After the curing time has elapsed, the entire test frame was placed on a vibrating table and given a shake test for 20 minutes with an excursion of 30 millimeters and a frequency of 8 Hertz, in order to establish the adhesion and cohesiveness properties between the pea gravel individual rocks and the whole mass assembly.

**[0068]** Examples 1 and 2 were repeated in a large scale for actual installation of interlocking pavers on a household driveway and a garden walkway with pea gravel, respectively. Both large scale tests were conducted for 12 months and periodic evaluation was made of the conditions of admixture surface hardness, shrinkage, vegetation growth, pest infestation, run-off, extended water flooding and high wind erosion.

**EVALUATION OF EXAMPLES**

**Test Results**

**[0069]** The test examples detailed above were repeated with many combinations of hydraulic and different ratios of PVA, borate salts and aggregates with the goal of finding the most stable and consistent elastomeric formulation that would satisfy long-term and wide-range environmental temperature and humidity after curing.

**[0070]** Two of the most common industry standards for measuring elastomeric properties are tests used to measure the hardness of plastics called the Shore® (Durometer) test or Rockwell hardness test. Both methods measure the resistance of plastics toward indentation and provide an empirical hardness value. Shore Hardness, using either the Shore A or Shore D scale, is the preferred method for rubbers/ elastomers and is also commonly used for ‘softer’ plastics such as polyolefins, fluoropolymers, and vinyls. The Shore A scale is used for ‘softer’ rubbers while the Shore D scale is used for ‘harder’ ones.

**[0071]** The Shore hardness is measured with an apparatus known as a Durometer and consequently is also known as ‘Durometer hardness.’ The hardness value is determined by the penetration of the Durometer indenter foot into the sample. Because of the resilience of rubbers and plastics, the indentation reading my change over time—so the indentation time is sometimes reported along with the hardness number. The ASTM test method designation is ASTM D2240-00 and is generally used in North America. Related methods include ISO 7619 and ISO 868; DIN 53505; and JIS K 6301, which was discontinued and superseded by JIS K 6253.

**[0072]** The results obtained from this test are a useful measure of relative resistance to indentation of various grades of polymer mixtures and in the case of these examples, it provided the correct and repeatable measure of flexibility of the cured admixtures, as Shore hardness is often used as a proxy for flexibility (flexural modulus) in specifying elastomers. The correlation between Shore hardness and flexibility holds for similar materials, especially within a series of grades from the same product line, but this is an empirical and not a fundamental relationship.

**[0073]** Durometer tests for various combinations of water storage compounds, PVA and cross-linking salts and kiln-dried sand, were made utilizing a Shore-A Durometer benchtop tester with a modified 30° included-angle titanium tip. The results of the tests is tabulated in Table-1.

**[0074]** It was found, through in-situ testing of actual test site installation of driveway interlocking pavers, that an average of 33 Shore-A Durometer flexural modulus was the best match for the small movement between joints of typical installations of interlocking pavers, as this flexibility allowed for the admixture plus aggregate to physically bind to the internal edge of the pavers and maintain cohesion throughout a wide range of water content in the air and substrate of the pavers. Additionally the Durometer value of about 25 to 45 Shore-A proved to be the best “hardness” required to survive temporary flooding of several days without compromising the integrity of the grout mechanical and chemical stability.
TABLE I

<table>
<thead>
<tr>
<th>PVA %</th>
<th>Cross-Link Salt %</th>
<th>Mucilage-1%</th>
<th>Mucilage-2%</th>
<th>Example 1</th>
<th>Example 2</th>
<th>Shore-A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formula-1</td>
<td>0.78</td>
<td>1.25</td>
<td>3.0-PP(^1)</td>
<td>0</td>
<td>X</td>
<td>N/A</td>
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<tr>
<td>Formula-2</td>
<td>1.4</td>
<td>3.0</td>
<td>5.0-PP</td>
<td>0</td>
<td>X</td>
<td>N/A</td>
</tr>
<tr>
<td>Formula-3</td>
<td>2.0</td>
<td>1.5</td>
<td>1.0-PP</td>
<td>7.0-XG(^2)</td>
<td>X</td>
<td>N/A</td>
</tr>
<tr>
<td>Formula-4</td>
<td>7.0</td>
<td>5.8</td>
<td>0</td>
<td>6.0-XG</td>
<td>X</td>
<td>N/A</td>
</tr>
<tr>
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<td>5.5</td>
<td>3.0</td>
<td>11.0-PP</td>
<td>0</td>
<td>X</td>
<td>N/A</td>
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<td>1.20</td>
<td>1.50</td>
<td>4.5-GG(^3)</td>
<td>1.0-XG</td>
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<td>X</td>
</tr>
<tr>
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<td>2.0</td>
<td>7.0-GG</td>
<td>3.0-XG</td>
<td>N/A</td>
<td>X</td>
</tr>
<tr>
<td>Formula-8</td>
<td>8.0</td>
<td>13.0</td>
<td>5.3-PP</td>
<td>2.5-XG</td>
<td>N/A</td>
<td>X</td>
</tr>
<tr>
<td>Formula-9</td>
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<td>6.5-GG</td>
<td>2.5-PP</td>
<td>N/A</td>
<td>X</td>
</tr>
</tbody>
</table>

\(^{1}\)Plantago Psyllium  
\(^{2}\)Xanthan Gum  
\(^{3}\)Guar Gum

[0075] It should be emphasized that the above-described embodiments are merely possible examples of implementations, merely set forth for a clear understanding of the principles of the invention. Many variations and modifications may be made to the above-described embodiments of the invention without departing substantially from the spirit and principles of the invention. All such modifications are intended to be included herein within the scope of this disclosure and the present invention and protected by the following claims.

1. A flexible binding compound comprising a polymer of the form:

   \[
   \begin{array}{c}
   R^2
   \end{array} \begin{array}{c}
   C
   \end{array} \begin{array}{c}
   C
   \end{array} \begin{array}{c}
   R^1
   \end{array}
   \]

   wherein \( R^1, R^2, \) and \( R^3 \) are each independently hydrogen or alkyl groups of five or fewer carbons; a hydrogen-bonding crosslinking agent; and a water storage component.

2. The binding compound of claim 1, wherein the water storage component comprises a mucilage.

3. The binding compound of claim 1, wherein the water storage component comprises a colloidal polysaccharide.

4. The binding compound of claim 1, wherein the water storage component is selected from the group consisting of quince seed, flax seed, konjac glucomannan, guar gum, locust bean gum, carob bean gum, aloe acemannan, xantham gum, psyllium husk, carrageenan, gum arabic, agarose, amylopectins, amyloses, arabinans, arabinogalactans, arabinoxylens, carageenans, carboxymethyl guar gum, carboxymethyl cellulose, cationic guar gum, cellulose ethers, chondroitin, chitosan, chitosan derived carbohydrate, chitosan-glycolate, chitosan lactate, cocodimonomium hydroxypyropyl oxyethyl cellulose, colominic acid, corn starch, curdlan, dermatan sulfate, dextran, furcellaran, cross-linked dextran, dextrin, emulsan, ethyl hydroxyethyl cellulose, galactoglucomannan, galactomannan, glucomannans, glycogens, hydroxy ethyl starch, hydroxypolmethyl cellulose, hydroxy ethyl cellulose, hydroxy propyl cellulose, hydroxypropyl starch, hydroxypolmethyl guar gums, gellan gum, gellan, gum ghatti, gum karaya, gum tragacanth, heparin, hyaluronic acid, inulin, keratin sulfate, modified starches, laminarans, laurdimonium hydroxypropyl oxyethyl cellulose, okra gum, oxidized starch, pectin acids, pectin, polydextrose, polyquatemium-4, polyquatemium-10, polyquatemium-28, potato starch, proteopectins, pullulan, sodium hyaluronate, starch diethyl aminoethyl ether, steardimonomium hydroxyethyl cellulose, raffinose, rhamsan, tapioca starch, whelan, levan, sclero glucan, sodium alginate, stachylose, succinoglycan, whey starch, xylans, xylitoglucans, and mixtures of said compounds.

5. The binding compound of claim 1, wherein the crosslinking agent is selected from the group consisting of borax, boron acid, orthoboric acid, metabolic acid, tetraboric acid, boron oxide, sodium borate, potassium borate, sodium orthoborate, potassium orthoborate, sodium metaborate, potassium metaborate, sodium tetraborate, potassium tetraborate, sodium perborate, potassium perborate, sodium boronic acid, lithium boronic acid, potassium boronic acid, sulfate salts, molybdate salts, phosphate salts, and nitrate salts.

6. The binding compound of claim 1, wherein \( R^1, R^2, \) and \( R^3 \) are hydrogen.

7. The binding compound of claim 1, wherein the water storage component comprises 19 to 88% by weight of the compound, wherein the polymer comprises 2.7 to 45% by weight of the compound, and wherein the crosslinking agent comprises 8.3 to 67% by weight of the compound.

8. A composition comprising the binding compound of claim 1 and a particulate material.

9. The composition of claim 8, wherein the particulate material comprises a non-friable aggregate.

10. The composition of claim 9, wherein the non-friable aggregate is selected from the group consisting of sand, gravel, crushed rock, crushed concrete, crushed brick, and decomposed granite.

11. The composition of claim 8, wherein the particulate material comprises an elastomeric material.

12. The composition of claim 8, wherein the water storage component comprises 1 to 45% by weight of the composition, wherein the polymer comprises 0.2 to 10% by weight of the composition, and wherein the crosslinking agent comprises 1 to 25% by weight of the composition.
13. A method for making a flexible binding compound which comprises combining a polymer of the form:

\[ \begin{array}{c}
\text{R}^2 \\
\text{R}^1 \\
\text{R}^3 \text{OH}
\end{array} \]

wherein \( \text{R}^1, \text{R}^2, \) and \( \text{R}^3 \) are each independently hydrogen or alkyl groups of five or fewer carbons; a hydrogen-bonding crosslinking agent, and a water storage component.

14. The method of claim 13, wherein the water storage component comprises a colloidal polysaccharide.

15. The method of claim 13, wherein the water storage component comprises a mucilage.

16. The method of claim 13, wherein the water storage component is selected from the group consisting of quince seed, flax seed, konjac glucomannan, guar gum, locust bean gum, carob bean gum, aloe acemannan, xanthan gum, psyllium husk, carrageenan, gum arabic, agarose, amylopectins, amyloses, arabins, arabinogalactans, arabinoxylans, carageenans, carboxymethyl guar gum, carboxymethyl cellulose, cationic guar gum, cellulose ethers, chondroitins, chitin, chitosan, chitosan pyrrolidone carboxylate, chitosanglycolate, chitosan lactate, cocodimonomium hydroxypropyl oxethyl cellulose, colominic acid, corn starch, curdlan, dermatin sulfate, dextrins, fucellarans, cross-linked dextrans, dextrin, emulsan, ethyl hydroxyethyl cellulose, galactoglucomannan, galactomannan, glucomannan, glyco-gens, hydroxy ethyl starch, hydroxypropyl methyl cellulose, hydroxy ethyl cellulose, hydroxy propyl cellulose, hydroxypropyl starch, hydroxypropylated guar gums, gellan gum, gellan, gum ghatti, gum karaya, gum tragacanth, heparin, hyaluronic acid, inulin, keratin sulfate, modified starches, laminarans, laurdinunmonium hydroxypropyl oxethyl cellulose, okra gum, oxidized starch, pectin acids, pectin, poly-dextrose, polyquatemium-4, polyquatemium-10, polyquatemium-28, potato starch, protepectins, pullulan, sodium hyaluronate, starch diethyl aminoethyl ether, steardimunium hydroxyethyl cellulose, rafinose, rhaman, tapioca starch, whelan, levan, scleroglucan, sodium alginate, starchlyose, succinoglycan, wheat starch, xylans, xyloglucans, and mixtures of said compounds.

17. The method of claim 13, wherein the crosslinking agent is selected from the group consisting of borax, boric acid, orthoboric acid, metoboric acid, tetaboric acid, boric oxide, sodium borate, potassium borate, sodium orthoborate, potassium orthoborate, sodium metaborate, potassium metaborate, sodium tetraborate, potassium tetraborate, sodium perborate, potassium perborate, sodium goric acid, lithium borate, potassium salt, sulfate salts, molybdate salts, phosphate salts, and nitrate salts.

19. A method for making a flexible fixable composition comprising combining a polymer of the form:

\[ \begin{array}{c}
\text{R}^2 \\
\text{R}^1 \\
\text{R}^3 \text{OH}
\end{array} \]

wherein \( \text{R}^1, \text{R}^2, \) and \( \text{R}^3 \) are each independently hydrogen or alkyl groups of five or fewer carbons; a hydrogen-bonding crosslinking agent; a water storage component; and a particulate material.

20. The method of claim 19, wherein the water storage component comprises a colloidal polysaccharide.

21. The method of claim 19, wherein the water storage component comprises a mucilage.

22. The method of claim 19 wherein the water retention component is selected from the group consisting of quince seed, flax seed, konjac glucomannan, guar gum, locust bean gum, carob bean gum, aloe acemannan, xanthan gum, psyllium husk, carrageenan, gum arabic, agarose, amylopectins, amyloses, arabins, arabinogalactans, arabinoxylans, carageenans, carboxymethyl guar gum, carboxymethyl cellulose, cationic guar gum, cellulose ethers, chondroitins, chitin, chitosan, chitosan pyrrolidone carboxylate, chitosanglycolate, chitosan lactate, cocodimonomium hydroxypropyl oxethyl cellulose, colominic acid, corn starch, curdlan, dermatin sulfate, dextrins, fucellarans, cross-linked dextrans, dextrin, emulsan, ethyl hydroxyethyl cellulose, galactoglucomannan, galactomannan, glucomannan, glyco-gens, hydroxy ethyl starch, hydroxypropyl methyl cellulose, hydroxy ethyl cellulose, hydroxy propyl cellulose, hydroxypropyl starch, hydroxypropylated guar gums, gellan gum, gellan, gum ghatti, gum karaya, gum tragacanth, heparin, hyaluronic acid, inulin, keratin sulfate, modified starches, laminarans, laurdinumionium hydroxypropyl oxethyl cellulose, okra gum, oxidized starch, pectin acids, pectin, poly-dextrose, polyquatemium-4, polyquatemium-10, polyquatemium-28, potato starch, protepectins, pullulan, sodium hyaluronate, starch diethyl aminoethyl ether, steardimonium hydroxyethyl cellulose, rafinose, rhaman, tapioca starch, whelan, levan, scleroglucan, sodium alginate, starchlyose, succinoglycan, wheat starch, xylans, xyloglucans, and mixtures of said compounds.

23. The method of claim 19, wherein the cross-linking agent is selected from the group consisting of borax, boric acid, orthoboric acid, metoboric acid, tetaboric acid, boric oxide, sodium borate, potassium borate, sodium orthoborate, potassium orthoborate, sodium metaborate, potassium metaborate, sodium tetraborate, potassium tetraborate, sodium perborate, potassium perborate, sodium goric acid, lithium borate, potassium salt, sulfate salts, molybdate salts, phosphate salts, and nitrate salts.

24. The method of claim 19, wherein the particulate material comprises a non-friable aggregate.

25. The method of claim 24, wherein the non-friable aggregate is selected from the group consisting of sand, gravel, crushed rock, and decomposed granite.

26. The method of claim 19, wherein the particulate material comprises an elastomer.

27. The method of claim 19, wherein the water storage component comprises 1 to 45% by weight of the composition, wherein the polymer comprises 0.2 to 10% by weight.
of the composition, and wherein the crosslinking agent comprises 1 to 25% by weight of the composition.

28. A method for fixing particulate material comprising mixing the particulate material with a polymer of the form:

\[
\begin{array}{c}
\text{R}^1 \\
\text{C} \\
\text{R}^3 \text{OH}
\end{array}
\]

wherein \( \text{R}^1 \), \( \text{R}^2 \), and \( \text{R}^3 \) are each independently hydrogen or alkyl groups of five or fewer carbons, a hydrogen-bonding crosslinking agent, and a water storage component to form a mixture; and hydrating the mixture.

29. The method of claim 28, wherein the particulate material comprises a non-friable aggregate.

30. The method of claim 28, wherein the non-friable aggregate is selected from the group consisting of sand, gravel, crushed rock, crushed concrete, crushed brick, and decomposed granite.

31. The method of claim 28, wherein the particulate material comprises an elastomer.

32. The method of claim 28, wherein the mixture is deposited between bricks, stones, flagstones, concrete pavers, concrete blocks, rocks or boulders.

33. The method of claim 28, wherein the mixture is hydrated before hydration.

34. The method of claim 28, wherein the mixture is hydrated before deposition.

35. The method of claim 28, wherein the water storage component comprises 1 to 45% by weight of the composition, wherein the polymer comprises 0.2 to 10% by weight of the composition, and wherein the crosslinking agent comprises 1 to 25% by weight of the composition.