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(19) **United States**(12) **Patent Application Publication**
Wallajapet et al.(10) **Pub. No.: US 2006/0147689 A1**(43) **Pub. Date: Jul. 6, 2006**(54) **ABSORBENT COMPOSITES CONTAINING
BIODEGRADABLE REINFORCING FIBERS**(52) **U.S. Cl.** **428/292.1; 428/369; 428/364**(76) Inventors: **Raj Wallajapet**, Neenah, WI (US);
Katie Veith, Fremont, WI (US);
Richard W. Tanzer, Neenah, WI (US)(57) **ABSTRACT**Correspondence Address:
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An absorbent composite contains a superabsorbent material and thermoplastic biodegradable reinforcing fibers, and may also contain pulp fibers. The superabsorbent material may be biodegradable, providing a biodegradable absorbent composite. The superabsorbent material may have a gel strength from about 500 dynes/cm² to about 80,000 dynes/cm². The biodegradable reinforcing fibers may contain fibers of a polyester such as poly(lactic acid). The biodegradable reinforcing fibers may be wettable, reducing or eliminating the need for treating the surface of the fibers with a wetting agent such as a surfactant, and may provide desirable performance without being bonded to the other components.

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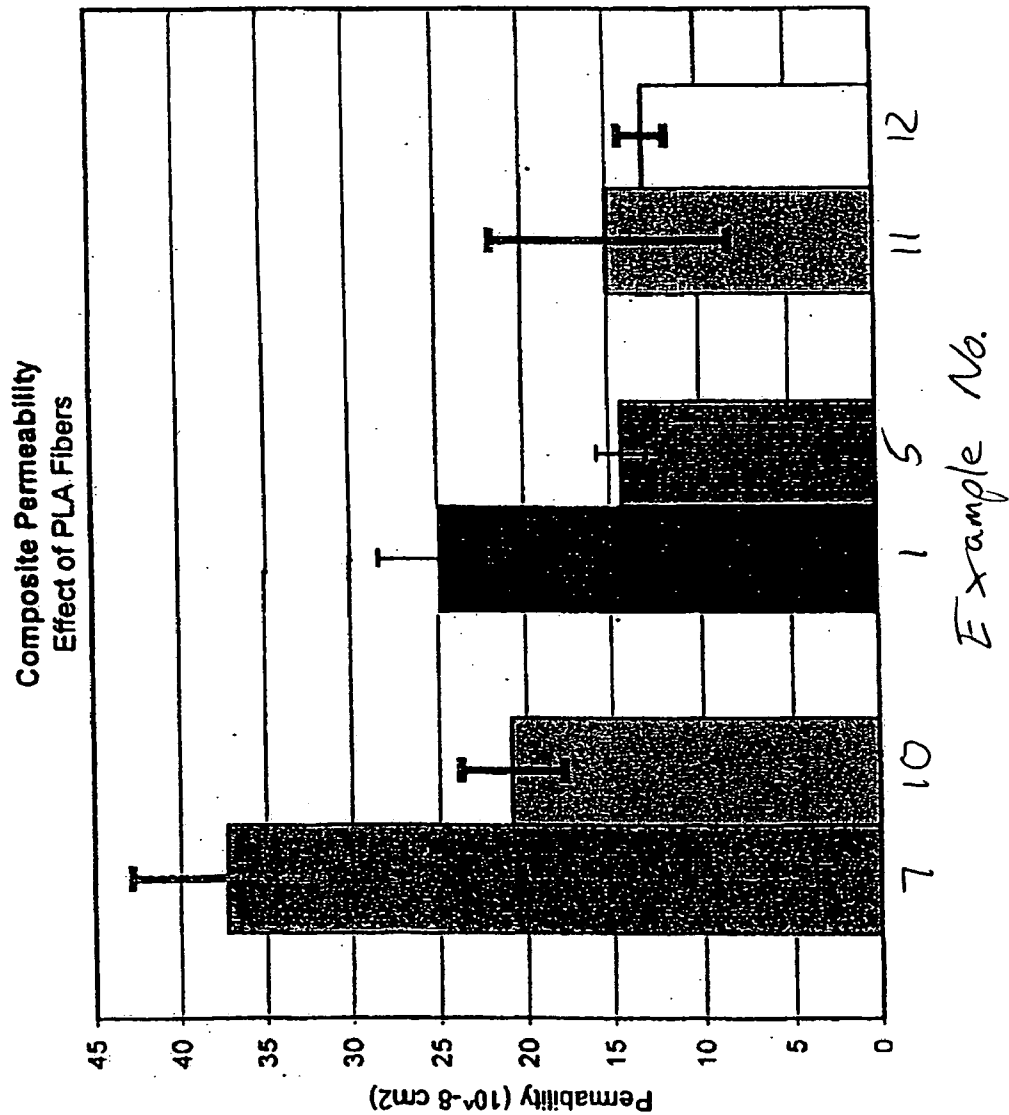


Figure 1

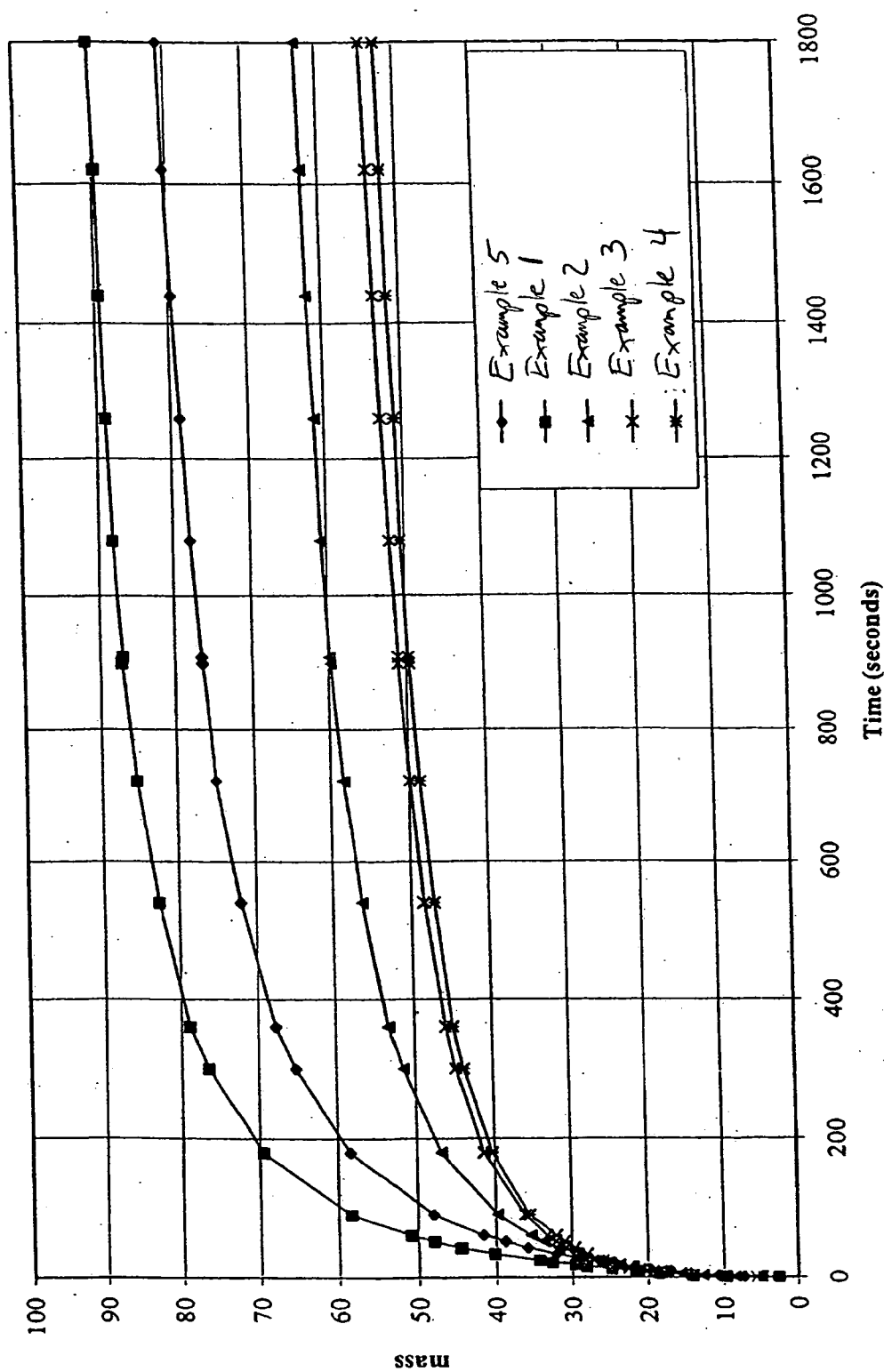


FIGURE 2

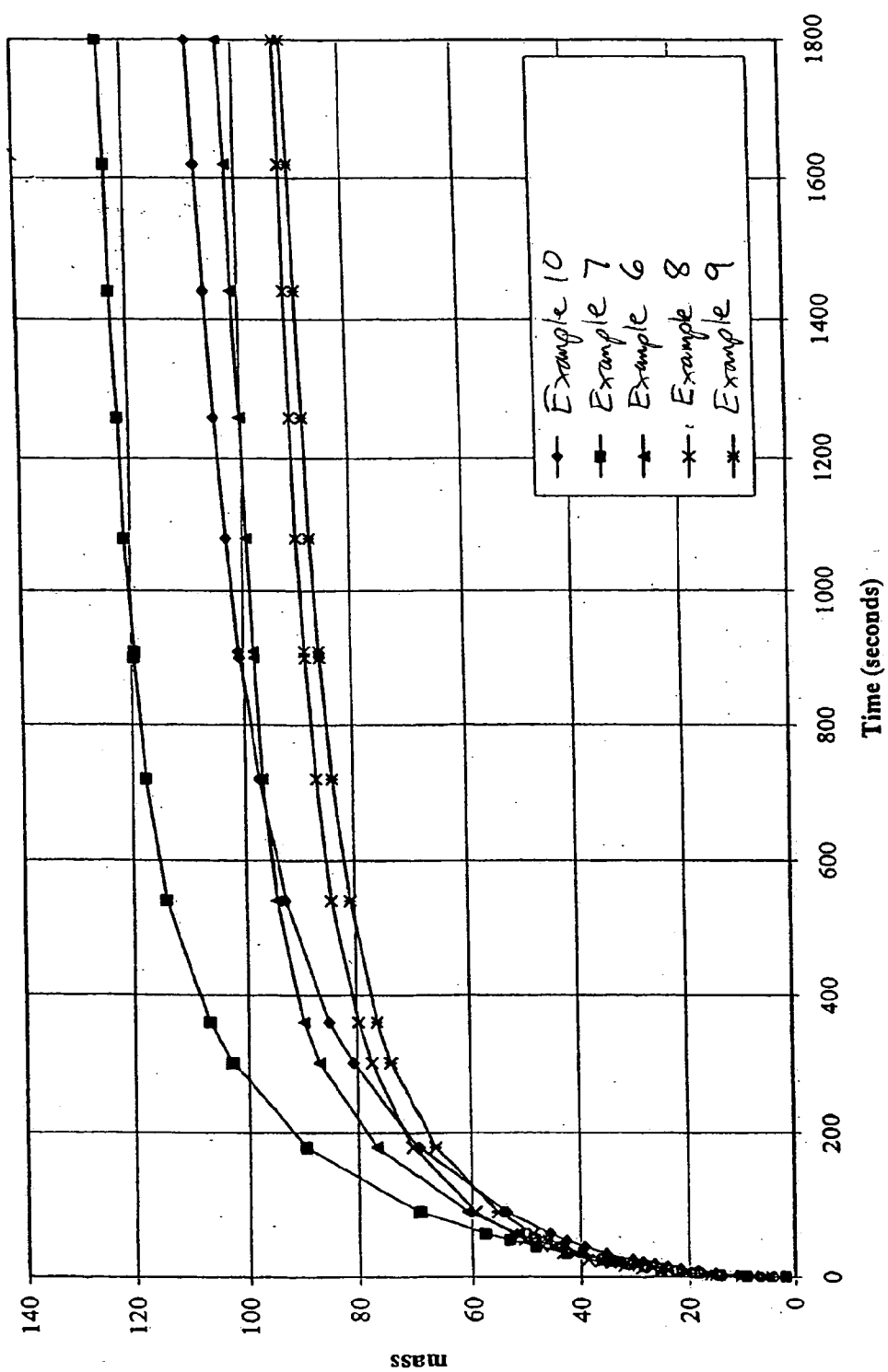


FIGURE 3

FIGURE 4

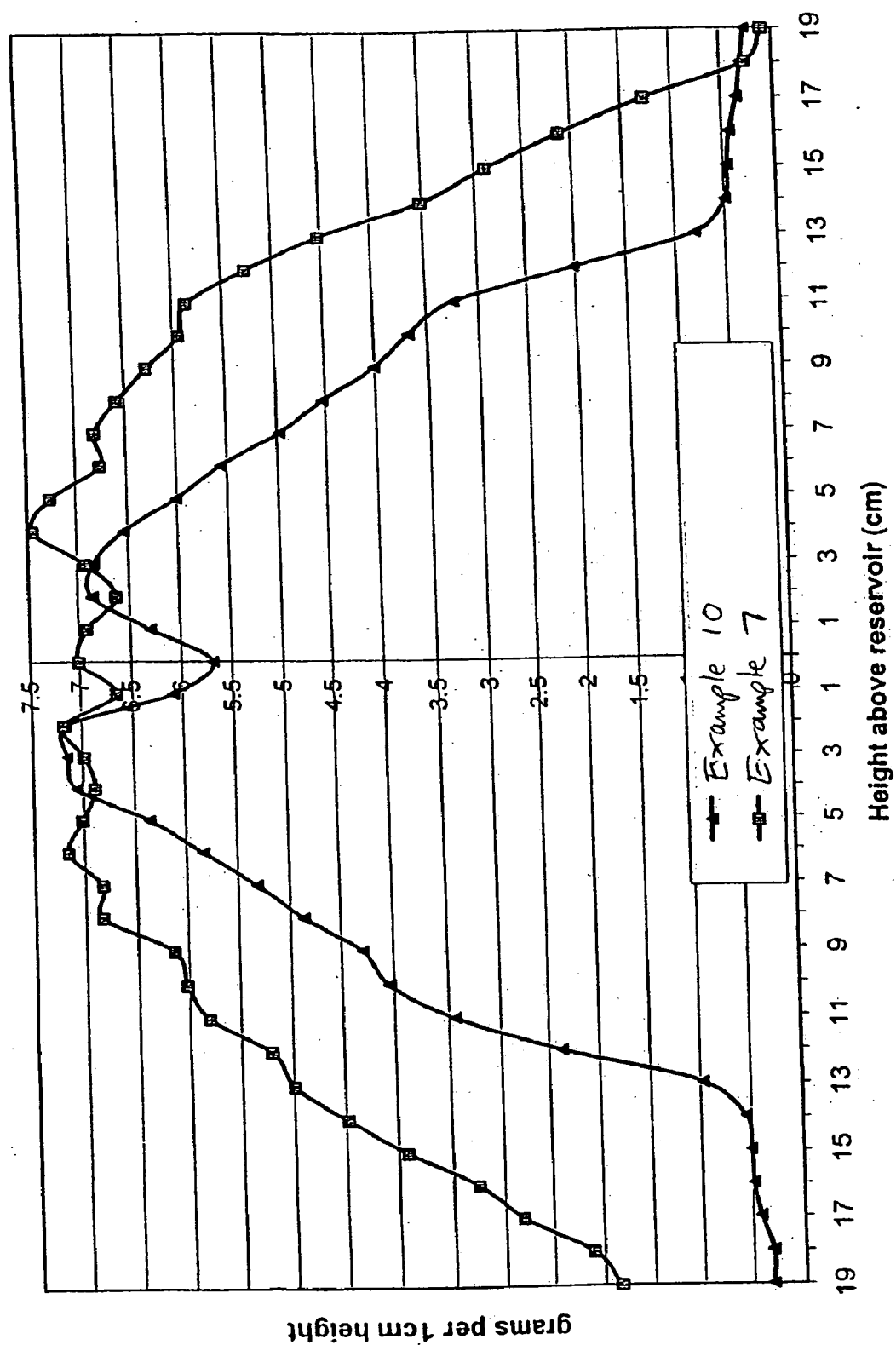
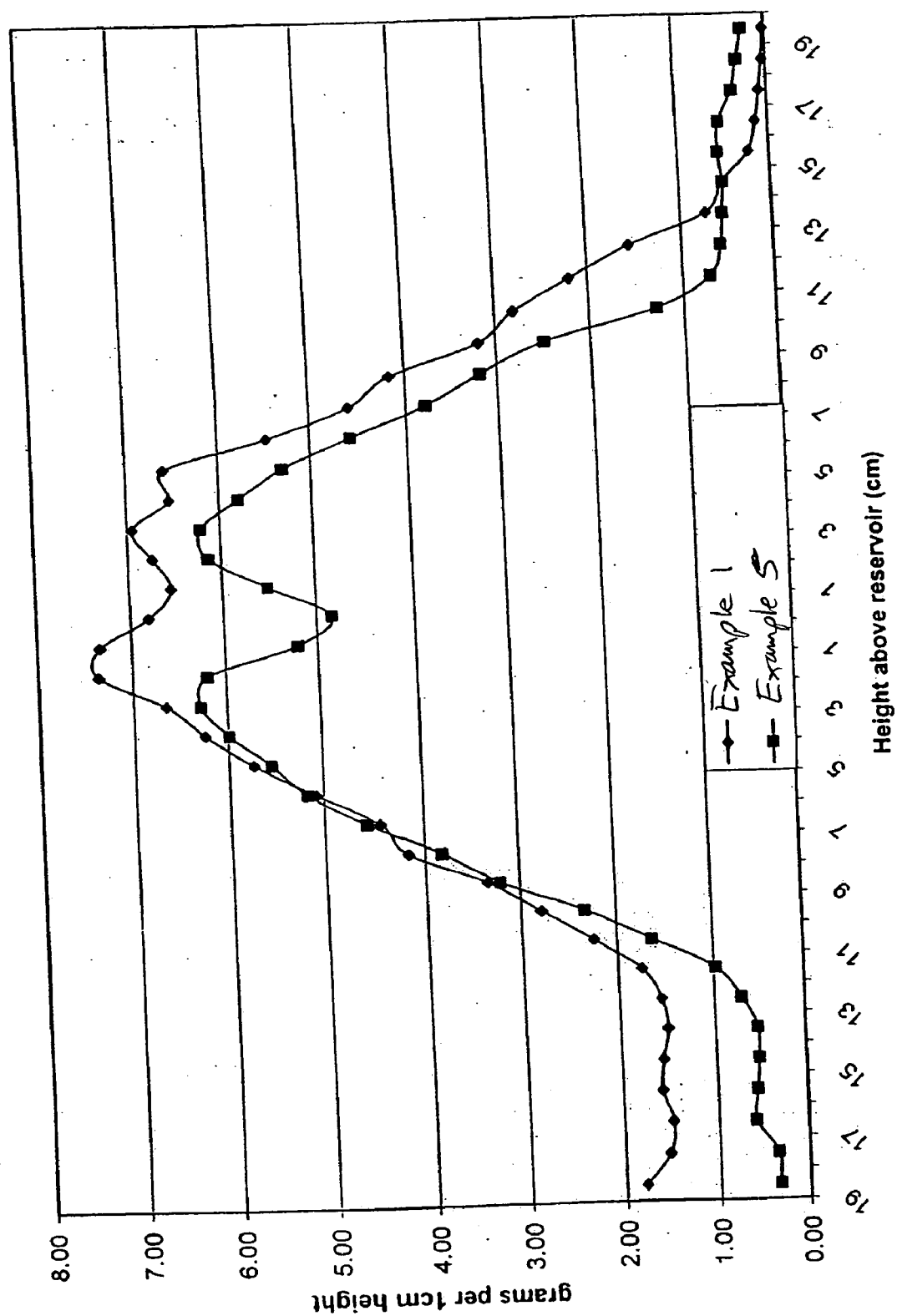


FIGURE 5



ABSORBENT COMPOSITES CONTAINING BIODEGRADABLE REINFORCING FIBERS

BACKGROUND

[0001] Disposable absorbent products are used extensively for body waste management. These disposable absorbent products include one or more absorbent structures to manage body waste effectively. The absorbent structure within the disposable absorbent product takes up and retains the body waste within the absorbent product. A variety of other components may also be present in a typical absorbent product, including liquid impermeable backing sheets, liquid permeable liners, wicking layers, and components for securing the product to the user. The particular combination and configuration of components in an absorbent product will depend on the intended use of the product.

[0002] Absorbent structures typically include a superabsorbent material, which can absorb large amounts of water or other aqueous liquids. One ongoing effort in the development of superabsorbent materials has been to increase the stiffness of the gel formed when the superabsorbent material has absorbed an aqueous liquid. Increased gel stiffness, also referred to as gel strength, can increase the porosity of the absorbent structure, thereby increasing the liquid intake rate and distribution within the structure. These and other factors can provide for better utilization of the entire absorbent capacity of the structure.

[0003] When superabsorbent materials are to be employed in personal care products such as diapers, it is generally desirable to employ a superabsorbent possessing both a high absorbent capacity and a high gel stiffness. High capacity is desired because it allows for the use of a smaller mass of superabsorbent material. High gel stiffness is desirable to prevent the formation of flowable gelatinous masses of superabsorbent, which may leak from the product or form a barrier to the transport of liquids through the matrix in which such superabsorbent materials are generally located. Superabsorbent properties such as gel stiffness and absorbent capacity are described, for example, in U.S. Pat. No. 5,082,723.

[0004] One approach for compensating for low gel stiffness of a superabsorbent material is to reinforce the absorbent structure with thermoplastic binder fibers. A common thermoplastic binder fiber for this application is a fiber having a sheath/core structure of polyethylene and poly(ethylene terephthalate) (PET). Polyethylene is used as the sheath polymer due to its low melting point, good rheology and low cost. PET is used as the core due to its higher melting point and overall stability. These stabilized absorbent composites containing reinforcing fibers can be used as absorbent structures in disposable absorbent products.

[0005] One potential drawback to stabilized absorbent composites is that conventional thermoplastic binder fibers tend to have low wettability due to their hydrophilic surfaces. This low wettability can reduce the overall liquid intake and distribution of the absorbent structure, despite increasing the porosity. The wettability of thermoplastic binder fibers can be increased by treating their surfaces with a wetting agent such as a surfactant or a fiber spin finish agent. However, these wetting agents can be dissolved in water, reducing the surface tension of the absorbed liquid

and actually decreasing both the wicking of liquid into the composite and the subsequent distribution of the absorbed liquid.

[0006] Another ongoing effort in the development of superabsorbent materials has been to make the superabsorbent biodegradable, such that the material either can be disposed of by composting or can be recycled into useful raw materials. Examples of biodegradable superabsorbent materials are disclosed in U.S. Pat. Nos. 4,952,550; 5,847,089 and 6,540,853; and in U.S. Patent Application Publication No. 2004/0157734 A1.

[0007] Biodegradable superabsorbent materials typically have less desirable absorbent properties relative to conventional non-biodegradable superabsorbent materials such as polyacrylates. This difference in absorbent properties is believed to be related to the lower gel stiffness of the hydrogels formed from biodegradable superabsorbent materials. Typically, absorbent composites made with biodegradable superabsorbents have tended to exhibit inferior intake, distribution and retention of liquids relative to absorbent composites based on polyacrylate superabsorbents. As with conventional superabsorbents, the gel stiffness of biodegradable superabsorbents can be increased by reinforcement with thermoplastic binder fibers. However, reinforcing a biodegradable superabsorbent material with non-biodegradable fibers would undermine the goal of constructing a completely biodegradable absorbent product.

[0008] There is thus a need for improved absorbent structures for disposable absorbent products. Improved absorbent structures may have improved wicking and distribution of aqueous liquids, while exhibiting other absorbent properties that are at least as good as those of conventional structures. Ideally, the structures could be made completely of biodegradable materials to help provide biodegradable absorbent products.

BRIEF SUMMARY

[0009] In an embodiment of the invention, there is provided an absorbent composite, comprising a biodegradable superabsorbent material, and a plurality of thermoplastic biodegradable reinforcing fibers.

[0010] In another embodiment of the invention, there is provided an absorbent composite, comprising a superabsorbent material having a gel strength from about 500 dynes/cm² to about 80,000 dynes/cm², and a plurality of thermoplastic biodegradable reinforcing fibers.

[0011] These embodiments may further include absorbent composites wherein the thermoplastic biodegradable reinforcing fibers comprise poly(hydroxyalkanoate) fibers, wherein the thermoplastic biodegradable reinforcing fibers comprise poly(lactic acid) fibers, wherein the thermoplastic biodegradable reinforcing fibers are un-bonded, wherein the thermoplastic biodegradable reinforcing fibers are wettable, and wherein the composite is free of wetting agents.

[0012] These embodiments may further include absorbent composites wherein the biodegradable superabsorbent material comprises carboxymethyl cellulose, wherein the biodegradable superabsorbent is present in a loading from about 10 wt % to about 70 wt %, wherein the absorbent composite further comprises pulp fibers, wherein the pulp fibers are present in a loading from about 25 wt % to about 85 wt %, and wherein the composite is free of wetting agents.

wherein the thermoplastic biodegradable reinforcing fibers are present in a loading from about 5 wt % to about 30 wt %, and wherein the gel strength of the superabsorbent is from about 500 dynes/cm² to about 80,000 dynes/cm².

[0013] In another embodiment of the invention, there is provided an absorbent composite, comprising from about 10 wt % to about 70 wt % of a biodegradable superabsorbent material, from about 25 wt % to about 85 wt % of pulp fibers, and from about 5 wt % to about 30 wt % of poly(lactic acid) reinforcing fibers.

[0014] These embodiments may further include absorbent composites wherein the poly(lactic acid) reinforcing fibers are un-bonded, wherein the poly(lactic acid) reinforcing fibers have a length from about 2 mm to about 60 mm, wherein the poly(lactic acid) reinforcing fibers have a diameter from about 1.5 denier to about 6 denier, wherein the poly(lactic acid) reinforcing fibers have from about 0 crimps per inch to about 12 crimps per inch, wherein the composite has a permeability of at least 10 darcies, wherein the composite has a density from about 0.09 grams per cubic centimeter to about 0.3 grams per centimeter, wherein the composite is free of wetting agents, wherein the weight ratio of pulp fibers to poly(lactic acid) reinforcing fibers is from about 1:1 to about 5:1, and wherein the weight ratio of biodegradable superabsorbent material to poly(lactic acid) reinforcing fibers is from about 1:1 to about 4:1.

[0015] In another embodiment of the invention, there is provided a method of forming an absorbent composite, comprising combining a superabsorbent material and a plurality of biodegradable reinforcing fibers into a mixture, and compressing the mixture in a dry state into a composite having a density from about 0.09 grams per cubic centimeter to about 0.3 grams per centimeter, wherein the biodegradable reinforcing fibers remain un-bonded.

[0016] These embodiments may further include a method wherein the biodegradable reinforcing fibers comprise poly(hydroxyalkanoate) fibers, wherein the biodegradable reinforcing fibers comprise poly(lactic acid) fibers, wherein the composite is free of wetting agents, wherein the combining comprises air-forming the superabsorbent material with the biodegradable reinforcing fibers, wherein the combining further comprises combining pulp fibers with the superabsorbent material and the biodegradable reinforcing fibers, and wherein the combining comprises air-forming the superabsorbent material with the biodegradable reinforcing fibers and the pulp fibers.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] FIG. 1 is a graph of permeability of absorbent composites containing a variety of superabsorbent materials, both with and without biodegradable reinforcing fibers;

[0018] FIG. 2 is a graph of the mass of liquid absorbed over time by absorbent composites containing a biodegradable superabsorbent material;

[0019] FIG. 3 is a graph of the mass of liquid absorbed over time by absorbent composites containing a high gel stiffness superabsorbent material;

[0020] FIG. 4 is a graph of liquid distribution within an absorbent composite containing a high gel stiffness superabsorbent material with and without biodegradable reinforcing fibers; and

[0021] FIG. 5 is a graph of liquid distribution within an absorbent composite containing a biodegradable superabsorbent material with and without biodegradable reinforcing fibers.

DETAILED DESCRIPTION

[0022] An absorbent structure includes a superabsorbent material and a plurality of biodegradable reinforcing fibers together as an absorbent composite. The presence of reinforcing fibers can increase the stiffness and improve the resiliency of the composite structure. Biodegradable reinforcing fibers may be used in conjunction with biodegradable superabsorbent materials to produce a composite that is biodegradable. Reinforcing fibers that are inherently wettable may allow for a reduction or elimination in the amount of surfactant used in the composite. In one example, fibers made of aliphatic polyesters can be incorporated readily into an absorbent structure, can provide desirable absorbent properties, and also can be biodegradable. Aliphatic polyesters that can be used as reinforcing fibers include biodegradable poly(hydroxyalkanoates) such as poly(lactic acid).

[0023] Absorbent composites include a superabsorbent material and a plurality of reinforcing fibers. In addition, absorbent composites can include pulp fibers. An absorbent composite can be a simple mixture of these components, or the reinforcing fibers can be bonded to the other components of the composite, for example by heating the mixture at an elevated temperature or by treating the mixture with a bonding agent.

[0024] As used herein, the term "superabsorbent material" refers to a water-swallowable, water-insoluble organic or inorganic material having an absorbent capacity for a 0.9 percent by weight (0.9 wt %) aqueous sodium chloride solution of at least 10 grams of solution per gram of polymer. That is, a superabsorbent material is capable of absorbing at least about 10 times its own weight in a 0.9 wt % aqueous sodium chloride solution. Preferably, a superabsorbent material is capable of absorbing at least about 20 times its weight, more preferably at least about 30 times its weight, even more preferably at least about 40 times its weight, even more preferably at least about 50 times its weight, even more preferably at least about 60 times its weight in a 0.9 wt % aqueous sodium chloride solution. The term "hydrogel" refers specifically to superabsorbent material in the water-swollen state.

[0025] Examples of organic superabsorbent materials include natural materials such as agar, pectin, guar gum and the like, as well as synthetic materials such as synthetic superabsorbent polymers. Superabsorbent polymers include, for example, polyacrylamides, polyvinyl alcohol, ethylene maleic anhydride copolymers, polyvinyl ethers, hydroxypropyl cellulose, polyvinylmorpholinone, alkali metal salts of polyacrylic acids, and polymers and copolymers of vinyl sulfonic acid, polyacrylates, polyacrylamides, polyvinyl pyridines, and the like. Other exemplary superabsorbent polymers include hydrolyzed acrylonitrile grafted starch, acrylic acid grafted starch, and isobutylene maleic anhydride copolymers and mixtures thereof.

[0026] Specific examples of polyacrylate superabsorbent materials include SANWET ASAP 2300 polymer (Chemdal, Portsmouth, Va.), DOW DRYTECH 2035LD polymer (Dow Chemical Co., Midland, Miss.), FAVOR SAB 870M and

FAVOR SAB 880 polymers (Stockhausen, Inc., Greensboro, N.C.), and the high gel stiffness polymer SXM 9543 (Stockhausen).

[0027] Specific examples of biodegradable superabsorbent materials include carboxymethyl cellulose materials, such as biodegradable superabsorbents available from Stockhausen. Carboxymethyl cellulose based biodegradable superabsorbent materials are described, for example, in U.S. Patent Application Publication No. 2004/0157734 A1, which is incorporated by reference herein. As noted in this patent document, a partially neutralized, uncrosslinked, carboxyl-containing polysaccharide can be preswelled and subsequently dried, and the dried polycarboxypolysaccharide can be surface-post crosslinked by means of a surface crosslinker. Polycarboxypolysaccharides may inherently contain carboxyl groups, or they may be derived from polysaccharides without carboxyl groups but that are provided with carboxyl groups by subsequent modification. Polycarboxypolysaccharides may be modified to contain other groups, particularly groups that improve the solubility in water, such as hydroxyalkyl and especially hydroxyethyl groups and also phosphate groups. Specific examples of polycarboxypolysaccharides include carboxymethylguar, carboxylated hydroxyethyl or hydroxypropylcellulose, carboxymethylcellulose and carboxymethylstarch, oxidized starch, carboxylated phosphatetarch, xanthan and mixtures thereof. Polycarboxy-polysaccharide superabsorbent polymers may be modified by addition of carboxyl-free polysaccharides, such as polygalactomannans or hydroxyalkylcelluloses, and/or by addition of other additives. The polycarboxypolysaccharide may be preswollen in an aqueous phase to form a hydrogel, and the aqueous phase may also include additive substances. Following thermal drying, comminution and classification of the hydrogel, the surface of the polycarboxypolysaccharide powder can be crosslinked with covalent and/or ionic crosslinkers which react with surface moieties, preferably carboxyl, carboxylate or hydroxyl groups, preferably by heating. The resulting particulate superabsorbent polymers can exhibit very good retention and absorption ability, significantly improved absorbency for water and aqueous fluids against an external pressure, and excellent aging stability.

[0028] The superabsorbent materials may be in any form suitable for use in absorbent composites including particles, fibers, flakes, films, foams, or spheres. Preferably, the superabsorbent material includes particles of hydrocolloids, preferably an ionic hydrocolloid. The superabsorbent polymers preferably are lightly crosslinked to render the material substantially water insoluble. Crosslinking may be accomplished, for example, by irradiation and/or by covalent, ionic, van der Waals, or hydrogen bonding. Superabsorbent materials may be shell crosslinked so that the outer surface or shell of the superabsorbent particle, fiber, flake, film, foam, or sphere possesses a higher crosslink density than the inner portion of the superabsorbent.

[0029] As used herein, the term "fiber" or "fibrous" refers to a particulate material wherein the ratio of the length of the particulate material to the diameter of the particulate material is greater than about 10. Conversely, a nonfiber or nonfibrous material refers to a particulate material wherein the length to diameter ratio is about 10 or less. Both the reinforcing fibers and the pulp fibers are fibrous materials.

[0030] A wide variety of fibers can be used as, or in the preparation of, the fibrous pulp. Examples of pulp fibers include, but are not limited to, cellulosic fibers such as wood and wood products, e.g., wood pulp fibers. Examples of pulp fibers include non-woody paper-making fibers from cotton; from straws and grasses, such as rice and esparto; from canes and reeds, such as bagasse; from bamboos; from stalks with bast fibers, such as jute, flax, kenaf, cannabis, linen and ramie; and from leaf fibers, such as abaca and sisal. Examples of pulp fibers include man-made fibers obtained from regenerated cellulose or cellulose derivatives, such as cellulose acetate. The fibrous pulp also can use mixtures of such materials, e.g., mixtures of one or more cellulosic fibers. Other materials from which the fibrous pulp may be made include non-cellulosic fibers such as wool and glass, and synthetic fibers, such as polyethylene, polypropylene and polyester. Pulp fibers generally may have lengths from about 0.5 mm to about 20 mm. For example, pulp fibers may have lengths from about 1 mm to about 10 mm, and may have lengths from about 2 mm to about 5 mm.

[0031] Biodegradable reinforcing fibers can be any thermoplastic fiber made of a biodegradable material. As used herein, the term "thermoplastic" refers to a polymeric material that can be processed by melting, forming, and shaping. This is in contrast to a thermoset polymeric material, which cannot be melted and shaped again after its original shaping is complete. As used herein, the term "biodegradable" refers to a polymeric material that, when composted under standard conditions for 180 days, at least 60% of the organic carbon in the material is converted to carbon dioxide, relative to a positive reference material (cellulose=100%). The American Society for Testing and Materials (ASTM) Standard Test Method for Determining Aerobic Biodegradation of Plastic Materials Under Controlled Composting Conditions, designation D 5338, is used for this determination. Consistent with this test procedure, samples are initially incubated for 45 days; and, if significant biodegradation of the test substance is still being observed, the incubation time may be extended to 90 days or 180 days.

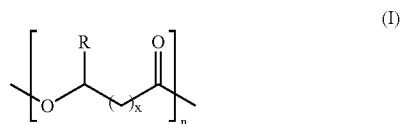
[0032] Biodegradable reinforcing fibers may be continuous in length, that is, individual fibers may extend the length or width of the absorbent composite. Spunbond fibers are an example of continuous fibers. Biodegradable reinforcing fibers may also be non-continuous. Non-continuous fibers include staple fibers, linters, and melt blown fibers, and may range from 2 mm to 60 mm in length. In certain embodiments of the invention, the non-continuous reinforcing fibers may range from 5 mm to 40 mm in length. Other embodiments include biodegradable reinforcing fibers which are between 7 mm and 25 mm long. Biodegradable reinforcing fibers may have diameters from about 1.5 denier to about 6 denier and may have from zero to 12 crimps per inch.

[0033] It is desirable that the biodegradable reinforcing fibers are wettable. As used herein, the term "wetable" refers to a material such as a fiber that, without any separate substance on its surface, exhibits a water-in-air contact angle of less than 90° (i.e., 0° to 90°). Preferably, the biodegradable reinforcing fibers exhibit a water-in-air contact angle from about 0° to about 85°, and more preferably from about 0° to about 80°. Preferably, wettable biodegradable fibers exhibit a water-in-air contact angle of less than 90°, at a temperature from about 0° C. to about 100° C., and preferably at typical use conditions, such as from about 20° C. to

about 40° C. In some conventional absorbent composite systems, the addition of wetting agents to the absorbent composite reduces the absorbent properties of the composites. Preferably, the biodegradable reinforcing fibers do not contain any separate substance on the fiber surface other than the fiber material.

[0034] Examples of biodegradable reinforcing fibers include biodegradable aliphatic polyesters. The term “polyester” means a polymer having ester ($-\text{C}(=\text{O})-\text{O}-$) linkages periodically in the backbone. Aliphatic polyesters are polyesters that contain alkyl groups, including alkanes, alkenes and alkynes, but do not contain aromatic groups. The alkyl groups may be linear, branched and/or cyclic.

[0035] A preferred class of aliphatic polyesters is the poly(hydroxyalkanoate) family (PHAs). PHAs have the general structural formula (I):



where R is hydrogen or an alkyl group, x is an integer from 0 to 10, and n is the number of repeating units. Typically, R is hydrogen or an alkyl group containing from 1 to 15 carbon atoms. The physical properties of PHAs can be controlled by altering the R group and/or by altering the number (x) of $-\text{CH}_2-$ groups between the ester groups. Different repeating units may also be combined into a single polymer, and the nature and distribution of the repeating units can also affect the final properties. Typical examples of PHAs include poly(3-hydroxybutyrate), poly(4-hydroxybutyrate), poly[(3-hydroxybutyrate)-co-(3-hydroxyvalerate)], poly(glycolic acid), poly(lactic acid), and poly(caprolactone). A general description of PHAs, and of the relationships of chemical structure with mechanical properties and biodegradation behavior, is given in U.S. Pat. No. 6,548,569.

[0036] One specific example of biodegradable reinforcing fibers that are wettable are fibers made of poly(lactic acid) (PLA). PLA is a biodegradable PHA having the general formula (I) where R is methyl ($-\text{CH}_3$) and x is zero. Fibers of PLA can be made to have a tensile modulus of at least 2 gigaPascals (GPa), providing for good resiliency of the fibers and of absorbent composites containing the fibers. Since PLA is thermoplastic, exposure of a composite containing PLA to elevated temperatures can provide for softening or melting of the outer surface of the fibers and subsequent bonding of the fibers to the other components of the composite. It has been found surprisingly that PLA fibers can be used as reinforcing fibers in absorbent composites to yield composites having increased absorbent capacity, improved liquid wicking, better liquid intake, higher resiliency of the absorbent structure, and improved permeability of the structure. Examples of biodegradable PLA fibers that may be used as reinforcing fibers include the PLA fibers disclosed in U.S. Pat. Nos. 6,506,873 and 6,177,193, and the PLA/PLA bicomponent fibers disclosed in U.S. Pat. No. 5,698,322.

[0037] The high modulus of PLA fibers can impart increased resiliency to stabilized composites. There have

been efforts to increase the resiliency of absorbent composites by increasing the gel stiffness, also referred to as the gel strength, of the superabsorbent material. However, an increase in gel stiffness in a superabsorbent material can result in a decrease in the absorbent capacity of the superabsorbent in conventional systems. Absorbent capacity is the amount of liquid absorbed per unit mass of superabsorbent material.

[0038] Gel stiffness may be defined as the ratio of the absorbency under a load of 0.9 pounds per square inch (psi) to the centrifuge retention capacity. The measurement of gel stiffness is described in U.S. Pat. No. 5,415,643, which is incorporated herein by reference. Alternatively, direct measurements of the response of a swollen gel to shear forces may be used to determine gel strength; Onwumere et al. (U.S. Pat. No. 5,047,456, granted 10 Sep. 1991, assigned to Kimberly-Clark Corporation), incorporated herein by reference, provides such a test method. In particular, gel strength may be represented by the shear or storage modulus G' of a swollen gel at a strain of 1% and frequency of 1 rad/sec measured using a RDS-II Rheometer (Rheometrics, Inc. Buffalo Grove, Ill.) and expressed in units of dynes/cm².

[0039] It has been observed surprisingly that PLA fibers can be used in a composite with high gel stiffness superabsorbent materials to improve the absorbent capacity of the composite. PLA fibers can also be used in a composite with superabsorbent materials having lower gel stiffness to increase the resiliency of the composite. Absorbent composites comprising superabsorbents with a gel strength in the range of 500-80,000 dynes/cm² can advantageously benefit from the inclusion of PLA fibers. Furthermore, absorbent composites comprising superabsorbents with a gel strength in the range of 1000-40,000 dynes/cm² or in the range of 2000-20,000 dynes/cm² can benefit from the inclusion of PLA fibers.

[0040] Resiliency in absorbent composites is useful in keeping the absorbent structure open and in preventing collapse of the capillary structure in the composite upon absorption of liquid. This open structure is believed to allow better penetration of liquid into the composite, thereby improving permeability. Improving the permeability of a composite is beneficial in improving the overall performance of an absorbent product and can result in better liquid intake, more efficient utilization of the absorbent capacity, and increased skin dryness for the user.

[0041] The resilient nature of PLA helps to reinforce the composite structure and provides for greater void volume under an applied external load. This can lead to a higher absorbent capacity of the composite compared to composites containing only superabsorbent material and pulp fibers. The ability of PLA fibers to reinforce the absorbent composite enables superabsorbents with low gel stiffness to function effectively in structures stabilized with PLA. This is particularly beneficial for obtaining satisfactory performance using biodegradable superabsorbents, which typically have lower gel stiffness compared to conventional polyacrylate superabsorbents.

[0042] The wettability of PLA can reduce or eliminate the need for surfactant treatments. To stabilize absorbent composites containing superabsorbent material and pulp fibers, the contact angle of the reinforcing fibers ideally is low enough to be wetted by the liquid insult, so that the liquid

can be taken up efficiently into the composite. The advancing contact angle of PLA is about 82 degrees, and the receding contact angle is about 68 degrees. Thus, PLA fibers are sufficiently wettable in the absence of wetting agents, surfactants, spin finish agents, or other surface treatments. The wettability of PLA also enables larger quantities of PLA reinforcing fibers to be incorporated into an absorbent composite without impairing the wicking behavior of the composite. For example, conventional polyethylene/PET bi-component binder fibers typically cannot be incorporated into an absorbent composite at levels greater than 5 wt %, as higher loadings reduce the rate of liquid absorption of the composite. In contrast, it has been found surprisingly that PLA reinforcing fibers can be added at levels as high as 25 wt % of the absorbent composite without reducing the wicking of liquids.

[0043] The biodegradability of PLA fibers can allow for the development of biodegradable absorbent composites. The absorbent properties of biodegradable superabsorbent materials typically are not as good as those of non-biodegradable superabsorbents, such as the conventional polyacrylate systems. Biodegradable superabsorbents tend to have lower gel stiffness than the non-biodegradable materials, which can limit the rate of absorption as well as the overall absorbent capacity. PLA fibers can be used successfully as reinforcing fibers in biodegradable superabsorbent materials, and the entire absorbent composite can thus be disposed of as biodegradable waste. Moreover, the use of PLA fibers as reinforcing fibers in biodegradable absorbent composites surprisingly can improve the absorbent properties of biodegradable systems to levels comparable to those of polyacrylate superabsorbents.

[0044] Biodegradable reinforcing fibers also include fibers containing PLA together with other polymers, which may or may not be biodegradable. It is noted that a fiber may contain a significant amount of non-biodegradable material, yet still fall within the definition of "biodegradable" as set forth above when the entire fiber is considered. Examples of biodegradable reinforcing fiber materials containing PLA together with other polymers include blends of PLA with non-biodegradable polymers such as polyethylene, polypropylene, polystyrene, and poly(ethylene terephthalate). Examples also include composite fibers of PLA and other polymers. Preferably the biodegradable reinforcing fibers contain less than 10 wt % of non-biodegradable material. More preferably the biodegradable reinforcing fibers contain less than 7 wt % of non-biodegradable material, still more preferably contain less than 5 wt % of non-biodegradable material, and still more preferably contain less than 1 wt % of non-biodegradable material.

[0045] The individual components of the absorbent composite can be present in varying amounts. However, it has been found that the following percentages work well in forming an absorbent composite for use in an absorbent structure. The pulp fibers can range from about 25 wt % to about 85 wt % of the absorbent composite. The reinforcing fibers can range from about 5 wt % to about 30 wt % of the absorbent composite. The superabsorbent can range from about 10 wt % to about 70 wt % of the absorbent composite. In one example, an absorbent composite for absorbing and retaining urine contains about 58 wt % pulp fibers, about 10 wt % of reinforcing fibers, and about 32 wt % of superabsorbent. In another example, an absorbent composite for

absorbing and retaining a variety of aqueous body wastes, including urine, contains from about 35 wt % to about 60 wt % of pulp fibers, from 5 wt % to about 25 wt % of reinforcing fibers, and from about 15 wt % to about 40 wt % of superabsorbent.

[0046] The pulp fibers preferably are present in the absorbent composite in a greater weight percentage than the reinforcing fibers. Desirably the weight ratio of pulp fibers to reinforcing fibers is in the range of 1:1 to 5:1. Alternatively the weight ratio of pulp fibers to reinforcing fibers is in the range of 1.5:1 to 3:1. This can help to reduce the overall cost of the absorbent composite, as cellulosic pulp fibers are generally much less expensive than reinforcing fibers, and to ensure that an absorbent article has sufficient liquid absorbing capacity. Preferably, the reinforcing fibers are present in a loading of at least 5 wt % of the absorbent composite to ensure that the absorbent composite has sufficient mechanical properties.

[0047] It is desirable that the weight ratio of superabsorbent to reinforcing fibers be in the range of 1:1 to 1:4. Alternatively, absorbent composites with the weight ratio of reinforcing fibers to superabsorbent be in the range of 0.33:1 to 0.75:1 may be used. In these ranges there are sufficient reinforcing fibers to enhance absorbent performance without adding excessive cost.

[0048] The absorbent composite can be formed by mixing the superabsorbent, biodegradable reinforcing fibers, and optional fibrous pulp. This mixture, in a substantially dry condition, can then be compressed to a density ranging from about 0.09 grams per cubic centimeter (g/cm^3) to about 0.3 g/cm^3 . Preferably, the absorbent composite is compressed to a density ranging from about 0.15 g/cm^3 to about 0.22 g/cm^3 . More preferably, the absorbent composite is compressed to a density of about 0.2 g/cm^3 . This compression of the absorbent composite will assist in forming the absorbent article.

[0049] Absorbent composites can be made by a variety of methods, including airlaid, carding, wetlaid and coform processes. Exemplary embodiments of airlaid processes are described in U.S. Pat. Nos. 4,666,647; 5,028,224; 6,207,099; 6,479,061. The carding process uses a "card" which is a machine consisting of a series of rolls, the surfaces of which are covered with many projecting wires or metal teeth. See, for example, the "Dictionary of Fiber & Textile Technology", Hoechst Celanese Corp., Charlotte, N.C., 1990. Carding separates, aligns, and delivers fibers as a nonwoven web. The wetlaid process consists of dispersing fibers in an aqueous suspension and then filtering the fibers onto a screen belt or perforated drum. Wetlaid nonwovens generally utilize shorter fibers than carding. The wetlaid process results in a more random orientation of the fibers and more isotropic properties than carding. Exemplary embodiments of coform processes are described in U.S. Pat. Nos. 4,100,324 and 5,952,251.

[0050] If thermal bonding is desired, the mixture can be heat cured prior to compression, during the compression, or after the composite has been compressed. For example, heat curing can be carried out by heating the mixture to a temperature of about 165° C. for a time from about 8 seconds to about 10 seconds. Alternatively, microwave radiation may be used to heat the absorbent composite, using methods such as those disclosed in U.S. Pat. No. 5,916,203.

The thermoplastic nature of PLA allows PLA reinforcing fibers to be thermally bonded to one or more other components of the absorbent composite. PLA fibers can be fabricated to have a wide range of melting points, allowing for optimization of the time and temperature of the bonding process.

[0051] In some absorbent composite systems, PLA reinforcing fibers provide better absorbent properties when they are not thermally bonded. For example, it has been found surprisingly that absorbent composites containing un-bonded PLA fibers may provide more rapid vertical wicking than composites containing no reinforcing fibers or containing PLA fibers that have been thermally bonded into the composite. This is in contrast to conventional binder fibers, which provide their optimum performance only when the binder fibers have been thermally bonded. The elimination of thermal bonding from the manufacturing process may reduce production time and cost and may reduce the variability of properties of absorbent composites within a particular system.

[0052] In one embodiment, stabilized absorbent composites containing biodegradable reinforcing fibers have minimal tensile strength. Composites of this type can be incorporated into a disposable absorbent product by, for example, depositing a portion of the composite onto a substrate and depositing a layer over the composite to secure the composite within the product. In another embodiment, stabilized absorbent composites containing biodegradable reinforcing fibers can have sufficient tensile strength in the machine direction to allow the composite to be wound into rolls. Rolls of this type can be unwound later, and the unwound composite can be processed on conventional converting equipment.

[0053] The tensile strength of the composite can be adjusted by changing parameters including the concentration of the reinforcing fibers, the conditions used for the optional thermal bonding, the specific density to which the composite is compacted, and other parameters known to those skilled in the art. Tensile strengths of absorbent composites can be tested using a model MTS/Sintech 1/S which is commercially sold by MTS Systems Corporation (Research Triangle Park, N.C.). The tensile strength at peak load is measured by securing a 50 mm strip of stabilized material between two movable jaws of a tensile tester. A distance of about 10 cm initially separates the two jaws, and the two jaws are then moved outward away from one another at a rate of 25 cm/minute until the strip of material breaks. The tensile strength is recorded as peak load. Absorbent composites that have been thermally bonded may have a tensile strength of at least 12 Newtons per 50 mm (N/50 mm). Absorbent composites that have not been thermally bonded typically will have a tensile strength of less than 12 N/50 mm.

[0054] The following specific examples are given by way of further illustration, and are not meant to limit the above disclosure or the claims that follow.

EXAMPLES

Examples 1-12

Formation of Absorbent Composites

[0055] Individual mixtures were prepared containing 40 wt % superabsorbent and 60 wt % fibrous component, which

included fibrous pulp and biodegradable reinforcing fibers. The superabsorbent was one of three superabsorbent materials—biodegradable superabsorbent, high gel stiffness SXM 9543, or FAVOR SAB 880—all obtained from Stockhausen, Inc. (Greensboro, N.C.). The fibrous pulp was CR 1654, a southern softwood kraft pulp made by Alliance Corporation (a unit of The Aaron Group of Companies, Plymouth Meeting, Pa.).

[0056] The PLA fibers were mono-component staple PLA fibers produced by Fiber Innovations Technology (FIT, Johnson City, Tenn.). These fibers had a melting point of about 162° C., a fiber length of 1.5 inch (3.8 cm), 3 denier fiber diameter, and about 9 crimps/inch. Two types of PLA fibers were used. Referring to Table 1, the fibers indicated as “neat” were fibers of pure PLA without any separate substance on the fiber surface. The fibers indicated as having a spin finish contained residual surfactant on the fiber surface, since these fibers were treated with a spin finish containing 0.03% surfactant.

[0057] Absorbent composites were then air-formed using a hand sheet former to produce air-formed absorbent composites, each composite having a basis weight of 400 grams per square meter (gsm). Each air-formed composite was then transferred to a Carver Press and densified to 0.2 grams per cubic centimeter (g/cc) density. As indicated in Table 1, for some of the composites the PLA fiber was thermally bonded by heating the air-formed composite in a forced air oven (also referred to as a through-air bonder).

TABLE 1

Absorbent Composites			
Example No.	Superabsorbent	PLA (wt %)	Treatment
1	Biodegradable	15	neat
2	Biodegradable	15	spin finish
3	Biodegradable	25	spin finish
4	Biodegradable	25	bonding
5	Biodegradable	—	—
6	SXM 9543	7.5	neat
7	SXM 9543	15	neat
8	SXM 9543	15	spin finish
9	SXM 9543	15	bonding
10	SXM 9543	—	—
11	FAVOR SAB 880	15	neat
12	FAVOR SAB 880	—	—

[0058] Permeability Measurements

[0059] Permeability is a measure of the ease with which liquid can pass through a material. Absorbent composites through which liquid can pass more easily should have a higher value of permeability, and are said to be more “open.”

[0060] The permeability test uses Darcy's Law to calculate the permeability by measuring the flow of liquid through a fully swollen composite. This test was carried out as described in U.S. Pat. No. 6,437,214, which is substantially equivalent to Federal Test Method Standard FTMS 191 Method 5514, dated Dec. 31, 1968. In measuring permeability, absorbent samples were cut into 2 $\frac{3}{8}$ inch (6.0 cm) diameter circles and placed in a cup with a mesh screen at the bottom. The cup with the sample was placed in 0.9 wt % aqueous sodium chloride solution (saline) for 60 minutes. The cup was then removed from the saline bath and filled to 7.8 cm with saline. A fluid delivery pump was adjusted to

maintain this liquid height for 60 seconds while liquid flowed through the sample into a container placed on a balance. The flow rate was measured and was then used to calculate permeability (K) using Darcy's law:

$$K = \frac{H \cdot Q \cdot \mu}{A \cdot p \cdot \Delta P}$$

where H is the height of the composite after swelling in cm; Q is the mass flow rate in g/s, μ is the liquid viscosity in poise; A is the cross-sectional area in cm^2 , p is the liquid density in g/cm^3 ; and ΔP is the hydrostatic head in dyne/cm^2 . Through conversion factors, the composite permeability is reported in units of darcies ($1 \text{ darcy} = 10^{-8} \text{ cm}^2$).

[0061] The effect of biodegradable reinforcing fibers on the permeability of the absorbent composite is shown in **FIG. 1**. For each of the three superabsorbents, the permeability was measured for absorbent composites with no reinforcing fibers and with 15 wt % PLA reinforcing fibers. Each of the systems showed an increase in permeability with the inclusion of PLA reinforcing fibers. These results indicate that adding PLA reinforcing fibers should enhance the permeability of any absorbent composite containing a superabsorbent material.

[0062] Vertical Wicking Measurements

[0063] Vertical wicking is a measure of the ease with which a liquid is absorbed into a material. The ability of a composite to wick liquid vertically and to distribute the absorbed liquid is related to its capillary tension, which in turn is a function of the surface tension between the composite and the liquid and of the pore size within the composite. In measuring vertical wicking, 12.5x3 inch (31.8x7.6 cm) absorbent composite samples were placed vertically into a pool of saline for 30 minutes. The mass of liquid absorbed by the sample in a given amount of time was recorded.

[0064] The effect of PLA staple fibers on vertical wicking is illustrated in the graphs of **FIGS. 2 and 3**, each of which plot the mass of liquid absorbed as a function of time. **FIG. 2** shows the results for Example Nos. 1-5, containing biodegradable superabsorbent. The composite containing 15 wt % PLA without surfactant treatment ("neat PLA") had more rapid liquid absorption compared to the composite containing 15 wt % PLA with surfactant treatment. Also, liquid absorption was higher at 15 wt % PLA fiber content than at 25 wt % PLA fiber content. **FIG. 3** shows the results for Example Nos. 6-10, containing the high gel stiffness superabsorbent. Here also PLA without surfactant treatment provided for more rapid liquid absorption. In both the biodegradable superabsorbent system and the high gel stiffness system, thermal bonding of the PLA reinforcing fibers resulted in the lowest measurements of vertical wicking.

[0065] X-Ray Densitometry Measurements

[0066] After a sample has been analyzed in the vertical wicking test, liquid distribution within the sample can be determined using x-ray densitometry. The sample containing the absorbed liquid is placed flat in an x-ray unit and exposed. The x-ray image is captured and analyzed for liquid distribution using software from OPTIMUS. The

amount of liquid absorbed in the composite for a range of heights above the saline pool is measured and plotted to obtain the liquid profile of the product.

[0067] Liquid distribution profiles for the absorbent composites of Example Nos. 7 and 10 (high gel stiffness superabsorbent) and of Example Nos. 1 and 5 (biodegradable superabsorbent) are shown in **FIGS. 4 and 5**, respectively. **FIG. 4** illustrates that the liquid distribution profile for composites containing a high gel stiffness superabsorbent with 15 wt % PLA fibers is a more even distribution than for the same composite without PLA reinforcing fibers. This is observed in that more liquid is present at greater heights above the saline pool for the PLA-containing composite than for the control. A similar improvement in the liquid distribution with incorporation of 15 wt % PLA fibers is also illustrated in **FIG. 5** for the lower gel stiffness biodegradable superabsorbent system.

[0068] The liquid wicking and distribution results illustrated in **FIGS. 2-5** all indicate a surprising and unexpected benefit in using PLA fibers to improve liquid distribution. This is in addition to the surprising and unexpected benefit in using PLA fibers to increase the overall permeability of absorbent composites.

[0069] It is therefore intended that the foregoing detailed description be regarded as illustrative rather than limiting, and that it be understood that it is the following claims, including all equivalents, that are intended to define the spirit and scope of this invention.

1. An absorbent composite, comprising:

a biodegradable superabsorbent material; and

a plurality of thermoplastic biodegradable reinforcing fibers.

2. The absorbent composite of claim 1, wherein the thermoplastic biodegradable reinforcing fibers comprise poly(hydroxyalkanoate) fibers.

3. The absorbent composite of claim 2, wherein the thermoplastic biodegradable reinforcing fibers comprise poly(lactic acid) fibers.

4. The absorbent composite of claim 1, wherein the thermoplastic biodegradable reinforcing fibers are un-bonded.

5. The absorbent composite of claim 1, wherein the thermoplastic biodegradable reinforcing fibers are wettable.

6. The absorbent composite of claim 5, wherein the composite is free of wetting agents.

7. The absorbent composite of claim 1, further comprising pulp fibers.

8. The absorbent composite of claim 1, wherein the biodegradable superabsorbent material comprises carboxymethyl cellulose.

9. The absorbent composite of claim 1, wherein the biodegradable superabsorbent is present in a loading from about 10 wt % to about 70 wt %.

10. The absorbent composite of claim 7, wherein the pulp fibers are present in a loading from about 25 wt % to about 85 wt %.

11. The absorbent composite of claim 1, wherein the thermoplastic biodegradable reinforcing fibers are present in a loading from about 5 wt % to about 30 wt %.

12. The absorbent composite of claim 1, wherein the gel strength of the superabsorbent is from about 500 dynes/cm² to about 80,000 dynes/cm².

13. An absorbent composite, comprising:

a superabsorbent material having a gel strength from about 500 dynes/cm² to about 80,000 dynes/cm²; and

a plurality of thermoplastic biodegradable reinforcing fibers.

14. The absorbent composite of claim 13, wherein the thermoplastic biodegradable reinforcing fibers comprise poly(hydroxyalkanoate) fibers.

15. The absorbent composite of claim 14, wherein the thermoplastic biodegradable reinforcing fibers comprise poly(lactic acid) fibers.

16. The absorbent composite of claim 13, wherein the thermoplastic biodegradable reinforcing fibers are un-bonded.

17. The absorbent composite of claim 13, wherein the thermoplastic biodegradable reinforcing fibers are wettable.

18. The absorbent composite of claim 17, wherein the composite is free of wetting agents.

19. The absorbent composite of claim 13, wherein the superabsorbent material comprises carboxymethyl cellulose.

20. The absorbent composite of claim 13, wherein the superabsorbent is present in a loading from about 10 wt % to about 70 wt %.

21. The absorbent composite of claim 13, further comprising pulp fibers.

22. The absorbent composite of claim 21, wherein the pulp fibers are present in a loading from about 25 wt % to about 85 wt %.

23. The absorbent composite of claim 13, wherein the thermoplastic biodegradable reinforcing fibers are present in a loading from about 5 wt % to about 30 wt %.

24. An absorbent composite, comprising:

from about 10 wt % to about 70 wt % of a biodegradable superabsorbent material;

from about 25 wt % to about 85 wt % of pulp fibers; and

from about 5 wt % to about 30 wt % of poly(lactic acid) reinforcing fibers.

25. The absorbent composite of claim 24, wherein the poly(lactic acid) reinforcing fibers are un-bonded.

26. The absorbent composite of claim 24, wherein the poly(lactic acid) reinforcing fibers have a length from about 2 mm to about 60 mm.

27. The absorbent composite of claim 24, wherein the poly(lactic acid) reinforcing fibers have a diameter from about 1.5 denier to about 6 denier.

28. The absorbent composite of claim 24, wherein the poly(lactic acid) reinforcing fibers have from about 0 crimps per inch to about 12 crimps per inch.

29. The absorbent composite of claim 24, wherein the composite has a permeability of at least 10 darcies.

30. The absorbent composite of claim 24, wherein the composite has a density from about 0.09 grams per cubic centimeter to about 0.3 grams per centimeter.

31. The absorbent composite of claim 24, wherein the composite is free of wetting agents.

32. The absorbent composite of claim 24, wherein the weight ratio of pulp fibers to poly(lactic acid) reinforcing fibers is from about 1:1 to about 5:1; and the weight ratio of biodegradable superabsorbent material to poly(lactic acid) reinforcing fibers is from about 1:1 to about 4:1.

33. A method of forming an absorbent composite, comprising:

combining a superabsorbent material and a plurality of biodegradable reinforcing fibers into a mixture; and

compressing the mixture in a dry state into a composite having a density from about 0.09 grams per cubic centimeter to about 0.3 grams per centimeter;

wherein the biodegradable reinforcing fibers remain un-bonded.

34. The method of claim 33, wherein the biodegradable reinforcing fibers comprise poly(hydroxyalkanoate) fibers.

35. The method of claim 34, wherein the biodegradable reinforcing fibers comprise poly(lactic acid) fibers.

36. The method of claim 33, wherein the composite is free of wetting agents.

37. The method of claim 33, wherein the combining comprises air-forming the superabsorbent material with the biodegradable reinforcing fibers.

38. The method of claim 33, wherein the combining further comprises combining pulp fibers with the superabsorbent material and the biodegradable reinforcing fibers.

39. The method of claim 38, wherein the combining comprises air-forming the superabsorbent material with the biodegradable reinforcing fibers and the pulp fibers.

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