A method is provided for forming a wet-laid nonwoven glass fiber mat comprised of a plurality of bundles of fibers. The method includes the steps of adding chopped fibers to an aqueous slurry containing a sufficient amount of a suitable hydrophobic agent to cause the fibers to form a plurality of bundles. The fibers are then formed into a mat which may be used in a number of reinforcement applications. A method is also provided for modifying the components in the water slurry to produce mats comprising either bundles of fibers or dispersed fibers.
METHOD FOR PRODUCING A WET-LAID FIBER MAT

TECHNICAL FIELD AND INDUSTRIAL APPLICABILITY

[0001] The present invention relates to a process for producing a non-woven fiber mat, and more particularly, to a wet-laid process for forming a glass fiber mat comprised of small bundles of glass fibers.

BACKGROUND OF THE INVENTION

[0002] Two main techniques utilized for producing glass fiber mats are wet-laid processing and dry-laid processing. Typically, in a wet-laid process, an aqueous slurry containing dispersed fibers and a variety of other components such as surfactants, viscosity modifiers, defoaming agents, or other chemical agents is prepared and sufficiently agitated to disperse the fibers throughout the slurry composition. The aqueous slurry is then deposited onto a moving screen, chain or fabric that retains the majority of the fibers while allowing a substantial portion of the water to be removed and thereby form a fiber web supported by the upper surfaces of the screen.

[0003] A binder composition may then be applied to the fiber web and the resulting mat is then typically dried at a temperature sufficient to remove the remaining water and to cure the binder. The resulting non-woven mat consists of an assembly of dispersed, individual glass filaments. Wet-laid processes are preferred in applications where a very uniform distribution of fibers in the non-woven mat is desired.

[0004] Conversely, a typical dry-laid process tends to produce mats in which the fibers are grouped into bundles (i.e., multiple fibers generally adjacent one another and arranged in a substantially parallel relationship). In a conventional dry-laid process, the fibers are chopped and blown onto a conveyor to form a dry web to which a binder is then applied to form the mat. Dry-laid processes tend to be favored in instances in which a more open structure is desired in the resulting mat that will allow, for example, more rapid penetration of viscous liquids or resins, and in instances in which it may be desirable to reduce the volume of the glass fibers.

[0005] However, conventional dry-laid processes tend to produce mats that are of less uniform weight when compared with mats produced by a wet-laid process, i.e., different areas of the mats have different weights and/or fiber densities. This variation in mat weight can be exacerbated during the production of lightweight mats, e.g., mats having a basis weight of 300 g/m² or less. At lower basis weights below about 300 g/m², the relatively poor small-scale weight uniformity of the air-laid process mat becomes increasingly apparent in terms of uneven distribution of the fibers. As a result, machine productivity is also sacrificed because the conveyor speed cannot be increased in proportion to the reduction in bias weight of the mat without further degrading the uniformity.

[0006] In addition, processes utilizing dry-chopped input fibers tend to be more expensive than those utilizing wet-chopped input fibers because the fibers in a dry-laid process are dried and packaged in separate steps before being chopped offline, while size can be applied directly to the manufactured fibers shortly before they are chopped to form the chopped fibers that will be added to the aqueous slurry.

[0007] For certain reinforcement applications useful during the formation of molded parts using polymer resins, it would be desirable to form fiber mats in which the mat comprises bundles of fibers (similar to the bundling achieved during a dry-laid process) and yet has a generally uniform weight (similar to that achieved during a wet-laid process).

[0008] Various wet-laid processes have been proposed for producing fiber mats that exhibited increased levels of bundling of the fibers. One such process is described in U.S. Pat. No. 4,242,404 to Bondoc in which bundles or “strings” of fibers are formed along with individual fibers. Another such process is described in U.S. Pat. No. 4,112,174 to Hanne in which a mat comprising individual glass fibers and glass fiber bundles is formed with the bundles being held together with a water insoluble binder.

[0009] However, because such mats still include a number of dispersed fibers in addition to the fiber bundles, they have proven generally unsuitable for applications in which higher porosities are desired or necessary. Further, it has been noted that the process disclosed by Bondoc tends to produce bundles of relatively long fibers. This result is particularly undesirable in reinforcement applications because the longer fibers tend to be visible in the final molded product and detract from the product’s appearance.

[0010] Another solution was disclosed in U.S. Pat. No. 6,054,022 to Helwig et al. in which a chopped strand mat was manufactured using a wet-laid process with wet use chopped strands (WUCS) as the fiber input. Although a conventional WUCS fiber was used, but a hydrophobic agent, such as an ethylene oxide/propylene oxide block copolymer was added to the aqueous slurry composition, i.e., the “white” water system to cause the dispersed WUCS fibers to self-assemble into small bundles. These small bundles were then maintained throughout the forming process and were present in the final product. Although this method improved the uniformity and porosity of the resulting fiber mat, it was difficult to control on a commercial scale and the addition of the hydrophobic agent was associated with certain negative effects on subsequent products.

[0011] Accordingly, a need remains for an economically competitive process capable of producing lightweight glass fiber mats which are both relatively uniform in weight and are comprised of primarily of bundles of relatively short fibers and which exhibits an open, porous structure suitable for and compatible with use in the production of reinforced molded parts with highly viscous resin compositions.

SUMMARY OF THE INVENTION

[0012] The present invention provides an economically competitive process capable of producing lightweight glass fiber mats which are both relatively uniform in weight and are comprised of primarily of bundles of relatively short fibers and which exhibits an open, porous structure suitable for and compatible with use in the production of reinforced molded parts with highly viscous resin compositions. The present process provides a wet-laid glass fiber mat utilizing a conventional aqueous slurry composition, thereby avoiding the difficulties associated with the inclusion of the
hydrophobic agent, while still promoting the organization of the fibers into discrete bundles of closely associated multiple fibers arranged in a substantially parallel relationship. The resulting mat may comprise small or large bundles of fibers, is of a substantially uniform weight, and has a generally porous structure.

[0013] In particular, the process according to the present invention uses WUCS that have been treated with a modified size composition that promotes the formation of the fiber bundles within the slurry without the difficulties associated with adding a hydrophobic agent directly to the slurry composition. Then, as in the conventional processes, the slurry will be applied to a supporting and porous conveyor through which the majority of the water will be removed to form a fiber web. The fiber web will then typically be transferred to another downstream conveyor for application of a binder composition, after which it will be dried and the binder cured to form the finished fiber mat product.

[0014] The resulting non-woven glass fiber mat comprises bundles of chopped fibers. The disclosed process may be used with a range of chopped fiber products, but it is expected that wet-chopped fibers having a length of from about 3 mm to about 50 mm, or, more typically, from about 25 mm to about 50 mm will be suitable for most applications. The fiber bundles formed in the resulting mat may include between about 50 and about 500 fibers, depending on both the size composition, the slurry composition and the slurry processing prior to deposition on the conveyor. For purposes of the present invention, bundles comprising between about 50 and 100 individual fibers will be referred to as small bundles while bundles comprising between about 300 and about 500 individual fibers will be referred to as large bundles, with intermediate bundles having between about 100 and about 300 individual fibers.

[0015] The non-woven glass fiber mat preferably has a basis weight of from about 40 to about 500 g/m², and more preferably, from about 60 to about 300 g/m². The thickness of the fiber mat is typically thinner than wet-laid mats comprised of a corresponding weight of dispersed fibers, but will tend to vary somewhat depending on the average bundle size and bundle size distribution. For example, smaller bundles tend to produce thicker mats while larger bundles tend to produce thinner mats.

[0016] The method of the present invention provides an advantage over prior processes in that the size composition used to treat the chopped fibers prior to their distribution in the aqueous slurry which tends to cause or promote bundle formation within the slurry may be easily modified to form mats comprising primarily dispersed fibers (i.e., having substantially no fiber bundles). This can be done without having to drain the aqueous slurry from the machine or mixing tank in which the fibers are processed, which results in a substantial savings in time and cost.

[0017] For example, a method according to another exemplary embodiment of the invention, incorporates a step of modifying the components of the aqueous size composition used to prepare the chopped fibers. A wet-laid fiber mat is then prepared as described above by preparing and dispensing a slurry incorporating the chopped fibers treated with the modified size composition to form a fiber web, applying a binder composition to the web and curing a binder to form a fiber mat product in which the majority of the fibers are present as associated bundles rather than individual fibers.

[0018] When the formation of mats with bundled fibers is no longer desired, the method may include the step of increasing the amount of a surfactant or introducing a different surfactant package to the existing slurry sufficient to counteract, at least partially, the bundling of the fibers induced by the size composition. A mat comprising primarily dispersed fibers may then be produced by removing water from the fibers to form a web and applying a binder.

[0019] When the formation of mats with bundled fibers is no longer desired, the method may include the step of modifying the size composition that is being applied to the fibers before chopping to reduce or suppress the tendency of the fibers to form bundles in the slurry. A mat comprising primarily dispersed fibers may then be produced by removing water from the fibers to form a web and applying a binder.

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

[0020] The process of the present invention provides many advantages over prior art mats which are formed by a dry-laid process. The wet-laid process of the present invention provides a highly porous, thin, non-woven glass fiber mat which has greater uniformity of fiber distribution than mats produced in dry-laid processes. Further, the mat of the present invention can be produced at lower cost because it uses low-cost wet chopped fibers which are formed into bundles by altering the components of the slurry used in a normal wet-laid process. In addition, the slurry components may be modified so as to produce mats comprising either bundles of fibers or dispersed fibers without having to replace the entire slurry.

[0021] The wet-laid mat of the present invention may be processed with the use of papermaking-type machines such as Fourdriner, wire cylinder, Stevens Former, Roto Former, Inver Former and Venti Former machines. The general procedure for preparing the glass fiber mat of the present invention is to form an aqueous slurry which may further contain a surfactant, a viscosity modifier and a complexing agent. The amount of water in the slurry may vary depending on the size of the equipment used. Typical volumes of water may range from 40,000 to 80,000 liters. Wet-chopped fibers treated with a size composition according to the invention are added to the slurry, typically at a concentration between about 0.2 wt% and about 1 wt% of the slurry, agitated to form a thick stock. During this agitation, the fibers begin to form bundles.

[0022] The aqueous slurry will typically include at least one surfactant, usually a cationic surfactant, that may be maintained within the slurry at a concentration of between about 30 to about 200 ppm. The surfactant functions to lubricate the fibers and aid in dispersion of the fibers as they are initially placed in the slurry. The aqueous slurry will also typically include at least one viscosity modifier, such as hydroxyethyl cellulose, that may be maintained within the slurry at a concentration of about 2000 ppm. The viscosity modifier is utilized to increase the viscosity of the aqueous slurry to a level that facilitates agitation and improve control of water drainage as water is removed through the conveyor from the fiber web. The aqueous slurry may also include a complexing agent, such as a polycarboxylate salt at a concentration of between about 20 to about 100 ppm, that will function to tie up the surfactant, thus aiding in fiber bundle formation.
[0023] In the present method, however, no separate hydrophobic agent is added to the aqueous slurry composition. Many of the size compositions utilized in the production of WUCS contain a cationic surfactant that acts as the primary dispersant and causes the bundles of chopped fibers to filamentize as they are introduced into the white water. One such cationic surfactant is K-12, an acetate salt of a 2:1 condensate of stearic acid and tetraethylenepentamine. An exemplary size composition A includes the ingredients listed below in TABLE 1.

<table>
<thead>
<tr>
<th>Material</th>
<th>% Active Solids</th>
<th>% by wt. Solids</th>
<th>Weight (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nalco 7530</td>
<td>25.5%</td>
<td>0.0488%</td>
<td>3.60</td>
</tr>
<tr>
<td>K-12 premix</td>
<td>8.8%</td>
<td>0.1014%</td>
<td>76.05</td>
</tr>
<tr>
<td>Y-9669 silane</td>
<td>100.0%</td>
<td>0.023%</td>
<td>1.69</td>
</tr>
<tr>
<td>A-1100 silane</td>
<td>58.0%</td>
<td>0.079%</td>
<td>5.94</td>
</tr>
<tr>
<td>PVAI premix</td>
<td>24.6%</td>
<td>0.4801%</td>
<td>146.42</td>
</tr>
<tr>
<td>Acetic Acid</td>
<td>0.079%</td>
<td></td>
<td>5.70</td>
</tr>
<tr>
<td>Water</td>
<td>96.808%</td>
<td></td>
<td>7250.60</td>
</tr>
<tr>
<td>Total</td>
<td>100.00%</td>
<td>0.6500%</td>
<td>7500.00</td>
</tr>
</tbody>
</table>

[0024] With regard to the size components listed in TABLE 1 above, and TABLES 2 and 3 below, the Nalco 7530 is a high molecular weight acrylamide copolymer prepared in water and hydrocarbon that is often used as a flocculant that is being used primarily as a viscosity (or rheology) modifier to increase size viscosity and thereby enhance the degree of size coating on the glass during the fiberizing operation. The PVAI premix is polyvinyl alcohol dissolved in water and prepared to have a 25% solids content that is included primarily as a film former for bundling the fibers and enhancing the strand chopping operation. The specific polyvinyl alcohol used in formulating the PVAI premix was CELVOL 205, a low molecular weight, partially hydrolyzed (87.0-89.0% hydrolysis), polyvinyl alcohol.

[0025] When a conventional size composition such as size composition A is used to prepare WUCS, as the WUCS are added to a conventional agitated white water system, the bundles of fibers undergo substantially complete filamentization, i.e., are dispersed throughout the slurry as individual fibers. The size compositions according to the present invention, however, replace at least a portion of the cationic surfactant of the conventional size composition with a bundling agent, such as a 2:1 condensate of EMERSOL 213 oleic acid and tetraethylenepentamine. An emulsion of the acetate salt of this condensate was prepared and then utilized in the preparation of an exemplary size formulation B having the overall composition reflected below in TABLE 2:

**TABLE 2**

<table>
<thead>
<tr>
<th>Material</th>
<th>% Active Solids</th>
<th>% by wt. Solids</th>
<th>Weight (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nalco 7530</td>
<td>25.5%</td>
<td>0.0488%</td>
<td>3.60</td>
</tr>
<tr>
<td>Linoleic/TEPA/HOAc</td>
<td>7.5%</td>
<td>0.1750%</td>
<td>134.28</td>
</tr>
<tr>
<td>RC-1 silane</td>
<td>98.0%</td>
<td>0.0225%</td>
<td>2.59</td>
</tr>
<tr>
<td>A-1100 silane</td>
<td>58.0%</td>
<td>0.0795%</td>
<td>5.94</td>
</tr>
<tr>
<td>PVAI premix</td>
<td>24.6%</td>
<td>0.4801%</td>
<td>146.42</td>
</tr>
<tr>
<td>Acetic Acid</td>
<td>0.079%</td>
<td></td>
<td>5.70</td>
</tr>
<tr>
<td>Water</td>
<td>96.020%</td>
<td></td>
<td>7201.47</td>
</tr>
<tr>
<td>Total</td>
<td>100.00%</td>
<td>0.7063%</td>
<td>7500.00</td>
</tr>
</tbody>
</table>

[0026] Another exemplary size composition according to the present invention, replaces at least a portion of the cationic surfactant of the conventional size composition with a bundling agent, such as a 2:1 condensate of EMERSOL 213 oleic acid and tetraethylenepentamine. An emulsion of the acetate salt of this condensate was prepared and then utilized in the preparation of an exemplary size formulation C having the overall composition reflected below in TABLE 3:

**TABLE 3**

<table>
<thead>
<tr>
<th>Material</th>
<th>% Active Solids</th>
<th>% by wt. Solids</th>
<th>Weight (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nalco 7530</td>
<td>25.5%</td>
<td>0.0488%</td>
<td>3.60</td>
</tr>
<tr>
<td>Oleic/TEPA/HOAc</td>
<td>7.5%</td>
<td>1.7500%</td>
<td>134.28</td>
</tr>
<tr>
<td>RC-1 silane</td>
<td>98.0%</td>
<td>0.0225%</td>
<td>2.59</td>
</tr>
<tr>
<td>A-1100 silane</td>
<td>58.0%</td>
<td>0.0795%</td>
<td>5.94</td>
</tr>
<tr>
<td>PVAI premix</td>
<td>24.6%</td>
<td>0.4801%</td>
<td>146.42</td>
</tr>
<tr>
<td>Acetic Acid</td>
<td>0.079%</td>
<td></td>
<td>5.70</td>
</tr>
<tr>
<td>Water</td>
<td>96.020%</td>
<td></td>
<td>7201.47</td>
</tr>
<tr>
<td>Total</td>
<td>100.00%</td>
<td>0.7063%</td>
<td>7500.00</td>
</tr>
</tbody>
</table>

Synthesis of Conventional Surfactant (LUBESIZE K-12)

[0027] LUBESIZE K-12 is a cationic surfactant that is an adduct of tetraethylenepentamine (TEPA) and stearic acid that is used in preparing the comparative size composition reflected above in TABLE 1. It has no degree of unsaturation. The ingredients used to synthesize LUBESIZE K-12 are set forth below in TABLE 4:

**TABLE 4**

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Weight (g)</th>
<th>% of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stearic Acid</td>
<td>125.00</td>
<td>63.98</td>
</tr>
<tr>
<td>Tetraethylenepentamine (TEPA)</td>
<td>46.75</td>
<td>23.93</td>
</tr>
<tr>
<td>Acetic Acid</td>
<td>23.62</td>
<td>12.09</td>
</tr>
<tr>
<td>Total</td>
<td>195.37</td>
<td>100.00</td>
</tr>
</tbody>
</table>
200° F. (93.3° C.) under a light nitrogen blanket. Once all of the stearic acid was melted, the melt was agitated while maintaining the nitrogen blanket with the temperature of the melt being maintained at about 200° F. while the tetraethylenepentamine (TEPA) was slowly added to the stearic acid melt to form the reaction mixture. Because the reaction is exothermic, the temperature of the reaction mixture will typically exceed 200° F. even without supplemental heating applied during the addition of the TEPA. However, after an exotherm peak is reached and the temperature of the reaction mixture begins to decrease, supplemental heating may be resumed to maintain the reaction mixture at or above 200° F.

[0029] Once all of the TEPA was added, the temperature of the reaction mixture was increased quickly, but at a rate that did not produce excessive foaming. When the reaction mixture temperature reached about 380° F. (193.30° C.), it was determined that approximately 50% of the distillate had been removed. The nitrogen blanket was then removed, a low nitrogen sparge was applied and the heating continued until the distillate flow stopped as the reaction mixture temperature approached 480° F. (249° C.).

[0030] Once the evolution of distillate was substantially complete, the reaction mixture was cooled to a temperature of approximately 160-170° F. (71.1-76.7° C.). The total distillate removed from the combined stearic acid and TEPA reaction mixture was determined to be approximately 12% by weight of the initial reaction mixture. The acetic acid was then slowly added (over a period of approximately 15 minutes) to the reaction mixture, which resulted in a slight exotherm of approximately 10° F. (about 4.5° C.) was noted as the acetic acid was added. After all of the acetic acid was added, the mixture was agitated for approximately 10 minutes and then poured onto release paper where it was permitted to cool and solidify.

[0031] The synthesized product, at 1% by weight in water, and was slightly acidic, having a pH in the range of about 4.5-5.0, and, prior to acid neutralization, exhibited a residual acid value of about 0.4% and an essentially non-detectable iodine value. The iodine value, also referred to as the iodine number, is a relative measure of the degree of unsaturation of an oil, fat, or wax. Fully saturated oils, fats, and waxes take up no iodine, resulting in an iodine value of zero, but partially saturated and unsaturated oils, fats, and waxes will take up varying quantities of iodine. The solidified product was determined to be the compound also identified as Lubesize K-12.

Synthesis of an Exemplary Bundling Agent A

[0032] The synthesis procedure as set forth above with respect to the LUBESIZE K-12 was repeated, but with the substitution of an equivalent molar basis of linoleic acid, a polyunsaturated fatty acid also referred to as 9,12-octadecadienoic acid, for the stearic acid. The linoleic acid used was EMERSOL 315 linoleic acid commercially available from Cognis Corp.

[0033] Prior to acid neutralization, the synthesized product exhibited a residual acid value of 0.29% and an iodine value of 24.8. Given that the iodine value of the EMERSOL 315 linoleic acid used in this synthesis was 27.4, it was determined that over 90% of the original unsaturation in the fatty acid was maintained in the synthesized product. The synthesized product also includes a conjugated diene structure. As reflected above, this bundling agent was then utilized in preparing size composition B.

Synthesis of Bundling Agent B

[0034] The synthesis procedure as set forth above with respect to the LUBESIZE K-12 was repeated, but with the substitution of an equivalent molar basis of oleic acid for the stearic acid. The oleic acid, a monounsaturated fatty acid also referred to as 9-octadecenoic acid, used was Emersol 213 oleic acid from Cognis Corp.

[0035] Prior to acid neutralization, the synthesized product exhibited a residual acid value of about 0.18% and an iodine value of 21.8. Given that the iodine value of Emerson 213 oleic acid was 24.3, it was determined that again approximately 90% of the unsaturation in the fatty acid was maintained in the synthesized product. As reflected above, this bundling agent was then utilized in preparing size composition C.

Composition Ranges for Size Compositions A, B and C

[0036] Ranges for the various components in the size compositions A, B and C are listed in TABLE 5.
### TABLE 5

<table>
<thead>
<tr>
<th>Material</th>
<th>Range 1 (*), %</th>
<th>Range 2 (*), %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nalco 7530</td>
<td>about 0.005 to about 0.100</td>
<td>about 0.01 to about 0.04</td>
</tr>
<tr>
<td>Cationic surfactant (+)</td>
<td>about 0.020 to about 0.500</td>
<td>about 0.05 to about 0.20</td>
</tr>
<tr>
<td>Y-9660 silane</td>
<td>about 0.005 to about 0.100</td>
<td>about 0.01 to about 0.06</td>
</tr>
<tr>
<td>A-100 silane</td>
<td>about 0.010 to about 0.300</td>
<td>about 0.02 to about 0.15</td>
</tr>
<tr>
<td>PVAI</td>
<td>about 0.400 to about 0.900</td>
<td>about 0.60 to about 0.80</td>
</tr>
</tbody>
</table>

(*) Based on total solids content of the size
(+ ) Including K-12, linoleic/TEPA/HOAe, and oleic/TEPA/HOAe shown in size compositions A, B, and C respectively

### Evaluation of Comparative and Exemplary Examples

[0037] Conventional size composition A, the exemplary size composition B, and a second comparative size composition C as detailed above, were separately applied to 16 μm glass fiber in the forming room, after which the sized fibers were chopped, inline, to an average length of about 25 mm, to prepare chopped fiber. When this chopped fiber was run on a wet-laid process pilot line using substantially identical slurry composition and formation conditions, the chopped fiber treated with exemplary size composition B yielded a fiber mat composed almost entirely of small bundles of fibers. Compared to the corresponding fiber mat prepared with the conventional size composition A and comparative size composition C, fiber mats prepared with exemplary size composition B having similar basis weights exhibit both reduced thickness and increased porosity when manufactured under substantially identical process conditions.

[0038] Representative fiber mats were prepared using size compositions A-C as detailed above. The resulting fiber mats were then tested to determine Basis Weight (lbs/1000 ft²), Loss-On-Ignition (LOI) as a percent of the weight of the initial fiber mat, air permeability (Btu/min ft²); and thickness (inches). The results of this evaluation for mats having similar basis weight are reflected below in TABLE 6.

### TABLE 6

<table>
<thead>
<tr>
<th>Fiber Mat</th>
<th>Basis Weight (lbs/1000 ft²)</th>
<th>LOI (%)</th>
<th>Air Permeability1 (Btu/min ft²)</th>
<th>Caliper2 (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.79</td>
<td>17.7</td>
<td>887.2</td>
<td>0.024</td>
</tr>
<tr>
<td>2</td>
<td>1.80</td>
<td>6.9</td>
<td>1078.5</td>
<td>0.016</td>
</tr>
<tr>
<td>3</td>
<td>1.79</td>
<td>17.9</td>
<td>866.1</td>
<td>0.024</td>
</tr>
</tbody>
</table>

1 The ASTM D737 procedure was adopted for measuring the air permeability.
2 The ASTM D1777 procedure was adopted for measuring the caliper.

[0039] As reflected above, the data shows that the fiber mat manufactured with exemplary size composition 2, which was formed from the chopped fibers treated with size composition B, exhibited both lower LOI (% binder weight in mat) and caliper (mat thickness) numbers. Comparing the control mats 1 and 3 with the exemplary mat 2, reveals that conventional wisdom regarding the formation of fiber mat products allows room for improvement, particularly with regard to porosity (as reflected in the air permeability values) and thickness. Similarly, comparing control mats 1 and 3, the similarity in their properties, with the air permeability for the mat C sample (oleic acid synthesis) was about the same as the control mat (LUBESIZE K-12), while the exemplary mat, mat 2, indicates an improvement in both the porosity and thickness.

[0040] The data also illustrates that a bundling agent in a size formulation that includes a diene structure, size B, to produce bundled fibers yields a mat having increased porosity and reduced thickness.

[0041] As will be appreciated by those skilled in the art, the intended use for the resulting fiber mat will tend to guide the selection of an appropriate binder composition, fiber mat properties and/or manufacturing techniques. For example, if the fiber mat is intended for use in a roofing mat, a urea-formaldehyde resin binder may be utilized to improve compatibility of the mat with the asphalt composition. As will be appreciated by those of ordinary skill in the art, any suitable binder and/or binder application process may be utilized to convert the fiber web to a desired fiber mat product.

[0042] In addition to binder compositions applied to the fiber mat as a solution, slurry or emulsion, the aqueous slurry, and consequently the fiber mat, may incorporate one or more varieties of thermoplastic binder fibers. Depending on the binder fiber(s) selected, the addition of the binder fibers may tend to increase the strength of the wet fiber web, facilitating the transfer of the web between the forming section and the saturator section of the production line or during other subsequent handling and/or transfer operations.

[0043] The binder fibers could include bicomponent binder fibers, in which the fiber structure of the binder would generally be preserved in the final product, and/or homofil binder fiber(s) having a composition that allows essentially the entire fiber, when exposed to the "curing" conditions, to melt and form "weld points" at the points in the fiber web where two or more glass bundles are in direct contact or are only slightly separated. The bicomponent binder fibers will typically provide a softer hand and better conformability while the homofil binder fibers will tend to increase the relative porosity of the fiber mat, a property that may be especially desirable when the resulting fiber mat is intended for a process involving impregnation of the mat with one or more high-viscosity resins.

[0044] Conventional fiber mat production techniques may be utilized for forming a fiber mat from the slurry prepared in accord with the present invention. After preparing the slurry, the fiber-containing slurry will typically be passed to a head box from which the slurry is deposited onto a moving wire screen or other suitable conveyor.

[0045] Suction or vacuum is typically provided on the backside of the conveyor to aid in the dewatering of the deposited slurry and form a fiber web comprising bundles of fibers. The fiber web is then coated with a binder composition, in the absence of or in addition to the inclusion of binder fibers in the fiber web, using any suitable means and then passed through a drying oven which dries the fiber mat and cures the binder and/or activates the binder fiber(s).

[0046] One suitable binder is an emulsion of a copolymer of ethylene and vinyl acetate. However, as noted above, it will be appreciated by those of ordinary skill in the art that the choice of binder will depend on the intended end use for the fiber mat product. Any binder which is suitable for use in a wet-formed mat operation may be used in the present invention.
In embodiments in which the slurry contains a surfactant, a preferred cationic surfactant is AEROSOL C-61, available from Cytec Industries. In such embodiments, the surfactant may be used in combination with a complexing agent, such as a polycarboxylate salt, for example DISPEX N40V available from Allied Colloids, that will tend to form a complex with at least a portion of the surfactant to temper the action of the surfactant and promote the formation of the fiber bundles.

In embodiments where the slurry contains a viscosity modifier for the purpose of regulating the slurry viscosity, suitable viscosity modifiers include hydroxethyl cellulose, anionic polyacrylamide, and polyethylene oxide. A preferred viscosity modifier is NATROSOL 250 HHR (hydroxethyl cellulose) available from Aqualon Co.

As noted above, the chopped glass fibers suitable for use in the present invention are typically wet-chopped fibers having a length of from about 3 mm to about 50 mm, and more preferably, from about 25 mm to about 50 mm. Longer fibers tend to form longer and irregular length strings that may interfere with the appearance of a reinforced product, while shorter fibers will tend to form bundles that have limited contact and will tend to produce a weaker fiber mat. If molded into parts, the irregular shape of the bundles formed from longer fibers may tend to “print-through” the surface of the molded part, resulting in less uniform surface that may include visible fibers.

The fibers should preferably have a diameter of about 16 to about 25 μm. The diameter of the fiber will tend to determine the acceptable chop length range, e.g., with larger the fiber diameters tending to support longer acceptable chop lengths.

A wide range of size compositions may be used on the fibers. However, sufficient time must be allowed for the sizing to wash off the fibers when they are placed in the slurry. This time may vary depending on the temperature of the slurry and the degree of agitation of the slurry after fiber addition, as well as the composition of the size used on the fibers. For example, the temperature of the slurry is typically in the range of from about 20° C. to about 40° C., and it usually takes from about 5 to 15 minutes for the size to wash off and for the bundles to form. When the temperature of the slurry is lower, the dissolution of the size is usually slower. The surfactant components incorporated in the slurry will also tend to affect the removal of the size composition from the fibers.

The resulting fiber mat comprising bundles of fibers may be used in a number of different applications. For example, the mat may be used in the reinforcement of polyurethane foam headliners. The wet-laid mats may also be used in reinforced plastic applications such as in the production of boat hulls or food service trays.

While certain representative embodiments and details have been shown for purposes of illustrating the invention, it will be apparent to those skilled in the art that various changes in the methods and apparatus disclosed herein may be made without departing from the scope of the invention, which is defined in the appended claims.

What is claimed is:

1. A method for forming a wet-laid glass fiber mat comprising:
   - preparing glass fibers, the glass fibers being coated with a size composition having a bundling agent;
   - mixing the glass fibers into an aqueous slurry composition to form a fiber slurry in which the fibers tend to form bundles of at least about 50 fibers;
   - applying the fiber slurry to a porous conveyor;
   - dewatering the fiber slurry to form a fiber web composed primarily of fiber bundles;
   - applying a binder composition to the fiber web to form a treated fiber web; and
   - curing the treated fiber web to form a fiber mat.

2. The method for forming a wet-laid glass fiber mat according to claim 1, wherein:
   - the slurry composition includes a cationic surfactant and a viscosity modifier.

3. The method for forming a wet-laid glass fiber mat according to claim 1, wherein:
   - the bundling agent is prepared from a condensate of a polyunsaturated fatty acid and an amine.

4. The method for forming a wet-laid glass fiber mat according to claim 1, wherein:
   - the bundling agent is an acetate prepared from a condensate of a polyunsaturated fatty acid and an amine.

5. The method for forming a wet-laid glass fiber mat according to claim 4, wherein:
   - the amine is present in a ratio of between about 1:1 and about 3:1 relative to the polyunsaturated fatty acid.

6. The method for forming a wet-laid glass fiber mat according to claim 5, wherein:
   - the bundling agent is an acetate salt of a condensate of linoleic acid and tetraethylene pentamine.

7. The method for forming a wet-laid glass fiber mat according to claim 6, wherein:
   - the linoleic acid and the tetraethylene pentamine are present in the condensate at a ratio of about 2:1.

8. An aqueous size composition for treating mineral fibers comprising:
   - a silane cross-linking agent; and
   - a bundling agent comprising condensate of a polyunsaturated fatty acid and an amine.

9. The aqueous size composition according to claim 8, wherein:
   - the composition includes a cationic surfactant and a viscosity modifier.

10. The aqueous size composition according to claim 8, wherein:
    - the bundling agent is an acetate prepared from a condensate of a polyunsaturated fatty acid and an amine.

11. The aqueous size composition according to claim 8, wherein:
    - the amine is present in a ratio of between about 1:1 and about 3:1 relative to the polyunsaturated fatty acid.

12. The aqueous size composition according to claim 11, wherein:
    - the bundling agent is an acetate salt of a condensate of linoleic acid and tetraethylene pentamine.
13. The aqueous size composition according to claim 12, wherein:

the linoleic acid and the tetraethylenepentamine are present in the condensate at a ratio of about 2:1.

14. A method of synthesizing a bundling agent comprising:

charging a vessel with an unsaturated fatty acid;

heating the unsaturated fatty acid to form a melt, the unsaturated fatty acid exhibiting an initial degree of unsaturation;

adding an amine with the melt to form a reaction mixture;

heating the reaction mixture to distill lighter components and produce a distillate, wherein the reaction mixture;

cooling the reaction mixture;

treating the reaction mixture to form a treated reaction mixture; and

solidifying the treated reaction mixture to obtain the bundling agent, wherein the bundling agent maintains at least about 90% of the original unsaturation.

15. The method of synthesizing a bundling agent according to claim 14, wherein:

agitating the melt while the melt is being maintained under a nitrogen blanket; and

removing the nitrogen blanket and applying a low nitrogen sparge until production of the distillate is substantially complete and the reaction mixture temperature approaches 480°F (249°C); and

and cooling the reaction mixture temperature.

16. The method of synthesizing a bundling agent according to claim 14, wherein:

the unsaturated fatty acid includes a major portion of linoleic acid; and

the amine is a multifunctional amine.

17. The method of synthesizing a bundling agent according to claim 14, wherein:

the amine is chosen from alkylenepolyamines, amines represented by the formula \( R_1 N((CH_2)_y NH)_{2-x} - H \) in which \( x \) is one or more and \( y \) is an integer having a value of 4 to 10. Typical amines of this class are the alkylenediamines such as 1,6-diamino-3-methyl-n-hexane; 1,3-propylenediamine 1,4-diamino-n-butane; 1,6-diamine-n-hexane, 1,10-diamino-n-decane and polyalkylenepolyamines such as diethylenetramine, triethylenetetramine, tetraethylenepentamine, polypropyleneamines and polybutylenepolyamines.

18. The method of synthesizing a bundling agent according to claim 14, wherein:

the amine is chosen from tetraethylenepentamine, polypropyleneamines and polybutylenepolyamines.

19. The method of synthesizing a bundling agent according to claim 14, wherein:

the amine is tetraethylenepentamine.

20. A wet-laid glass fiber mat comprising:

mineral fibers comprising a silane cross-linking agent and a bundling agent comprising condensate of a polyunsaturated fatty acid and an amine.

21. The wet-laid glass fiber mat of claim 20, wherein said mineral fibers further comprise a cationic surfactant and a viscosity modifier.

22. The wet-laid glass fiber mat of claim 20, wherein said bundling agent is an acetate prepared from a condensate of a polyunsaturated fatty acid and an amine.

23. The wet-laid glass fiber mat of claim 20, wherein said amine is present in a ratio of between about 1:1 and about 3:1 relative to the polyunsaturated fatty acid.

24. The wet-laid glass fiber mat of claim 23, wherein said bundling agent is an acetate salt of a condensate of linoleic acid and tetraethylenepentamine.