Methods for reducing the surface pilling tendency and improving abrasion resistance of a pillable fabric are disclosed. The methods include providing a pillable fabric including fibrils extending from the surfaces thereof, supporting the fabric, and exposing the fabric to a hydroentanglement process that imparts an energy in the range of at least about 4000 to 5000 KJoules/Kg of fabric using pressures of 200 bars or greater. The presence of fibrils on the fabric surface are reduced to an amount wherein the pilling production on the fabric is less than about 20% after 5,000 cycles of abrasion on a Martindale device according to ASTM D4970 testing standard and the fabric remaining mass is at least about 80% to 90% after 50,000 cycles of abrasion on a Martindale device according to ASTM D4966 testing standard.
Figure 2: Typical hydroentangling nozzle cross section (left) and its top and bottom views (right).
Figure 3: Typical hydroentangling configurations. Examples shown have 5 manifolds.
FIGURE 4: THE EFFECT OF HYDROENTANGLING AND WASHING ON SAMPLE THICKNESS
Figure 5. SEM Images of 16.00 NH and 16.00 1P
Figure 6. SEM Images of 16.67 NH and 16.67 1P
Figure 7. SEM Images of 17.56 NH and 17.56 1P
FIGURE 8A: WEIGHT LOSS OF 16.00 FABRICS BY ABRASION
FIGURE 8B: WEIGHT LOSS OF 16.67 FABRICS BY ABRASION
FIGURE 8C: WEIGHT LOSS OF 17.56 FABRICS BY ABRASION
Figure 9. The SEM Images of 16.00 NH: The effect of Abrasion cycle
Figure 10. The SEM Images of 16.00 1P: The effect of Abrasion cycle
Figure 11. The SEM Images of 17.56 NH: The effect of Abrasion cycle
Figure 12. The SEM Images of 17, 56 1P: The effect of Abrasion cycle
Fig. 13 B

Graph showing the relationship between Pilling and the number of cycles. The graph includes lines for Tig 17.56 NH, Tig 17.56 1P, and Tig 17.56 2P.
Figure 14A Picture of a cotton knitted fabric non-hydroentangled after 5000 cycles of pilling test.
Fig. 14B Picture of a cotton knitted fabric hydroentangled after 5000 cycles of pilling test
Fig. 15

A

100% Cotton Jersey, Non-washed, Non-hydroentangled. 35X(left), 100X (Right)

B

C

100% Cotton Jersey, Washed, Non-hydroentangled. 35X(left), 100X (Right)

D

E

F

100% Cotton Jersey, Non-washed, Hydroentangled (1a). 35X(left), 100X (Right)

G

H

100% Cotton Jersey, Non-washed, Hydroentangled (1b, 2Pass). 35X(left), 100X (Right)
A. 50/50 Cotton/Polyester Jersey, Washed, Non-Hydroentangled. 35X(left), 100X (Right)
- Loose fibers on the surfaces

B. 50/50 Cotton/Polyester Jersey, Washed, Hydroentangled (2a). 35X(left), 100X (Right)

C. Non-washed, Hydroentangled (2a).

D. Washed, Hydroentangled (2a).
Fig. 17

100% Polyester Jersey, Washed, Non-Hydroentangled (3a W). 35X(left), 100X (Right)

100% Polyester Jersey, Washed, Hydroentangled (3a W). 35X(left), 100X (Right)
PHYSICAL AND MECHANICAL PROPERTIES OF FABRICS BY HYDROENTANGLING

RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Patent Application Ser. No. 60/529,490, filed Dec. 15, 2003; the disclosure of which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

[0002] The subject matter disclosed herein relates generally to fabrics having antipilling properties. More particularly, the present subject matter relates to methods for reducing the pilling tendency and improving abrasion resistance of a pillable fabric through the use of a hydroentanglement process.

BACKGROUND ART

[0003] Cotton and cotton blend woven and knitted fabrics have a great tendency to be subjected to pilling or generate so-called “pills”. Many other staple fibers and blends thereof when formed into woven and knitted fabrics also have a tendency to pill. Pills are small bunches or balls of interlaced fluff caused by small bundles of entangled fibers clinging to the cloth surface by one or more surface fibrils. Pilling is typically preceded by fuzz formation and when the material is subject to physical stimulus such as friction, the fuzz or fluff clumps together and is gathered by the fibrils. This undesirable pilling effect occurs with the lapse of time and wear and the tendency to pill generally lowers the commercial value of the fabrics.

[0004] Given the undesirable nature of a fabric that is subject to pilling, several industrial means have previously been employed in order to prevent such generation of pills. For example, U.S. Pat. No. 3,975,486 to Sekiguchi et al. is directed to a process for producing an antipilling acrylic fiber wherein the steps of coagulation, stretching and relaxing heat treatment are conducted under particular conditions. Likewise, U.S. Pat. No. 4,205,037 to Fujimatsu is directed to acrylic synthetic fibers highly resistant to pilling and having good dyeability produced by specifying the composition of the acrylic polymer, the condition of the primary stretching step, the internal water content of the water-swollen gel fibers, and the conditions of the steps of the drying-compacting, secondary stretching and relaxing heat treatment. Additionally, U.S. Pat. No. 6,051,034 to Caldwell is directed to a method for reducing pilling ofcellulosic towels wherein a composition comprising an acidic agent, and optionally a fabric softener, is applied to a pillable cellulosic towel, preferably to the face of the towel. The towel is then heated for a time and under conditions sufficient to effect a controlled degradation of the cellulosic fibers, thereby reducing pilling.

[0005] While these prior art antipilling techniques have included various methods of reducing the pilling tendency of a fabric using chemical or other process modifications, the need exists for a simpler and more effective finishing method for producing fabrics that have a lower tendency to pill as well as having improved abrasion resistance.

[0006] As is well known to those skilled in the art, hydroentanglement or “spun lacing” is a process used for mechanically bonding a web of loose fibers to form fabrics directly from fibers. This class of fabric typically belongs to the nonwovens family of engineered fabrics. In conventional hydroentangling processes, webs of nonwoven fibers are treated with high pressure fluid jets while supported on apertured patterning screens. Typically, the patterning screen is provided on a drum or continuous planar conveyor. The underlying mechanism in hydroentanglement is the subjecting of the fibers to a non-uniform pressure field created by successive banks of fine, closely spaced, high-velocity water jets. The impact of the water jets with the fibers, while they are in contact with their neighboring fibers, displaces and rotates the fibers with respect to their neighbors and entangles these fibers with the neighboring fibers. During these relative displacements, some of the fibers twist around others and/or interlock with the neighboring fibers to form a strong structure due to fiber-to-fiber frictional forces. The final outcome is a highly compressed and uniform fabric composed of entangled fibers that is characterized by relatively high strength, flexibility, and conformability.

[0007] In the past, various efforts have been directed to improving the dimensional stability and physical properties of woven and knitted fabrics through the finishing step of hydroentanglement. In such applications, warp and filling fibers in fabrics are hydroentangled at crossover points to effect enhancement in fabric cover.

[0008] For example, U.S. Pat. No. 4,695,500 to Dyer et al. is directed to a loosely constructed knit or woven fabric that is dimensionally stabilized by causing staple length textile fibers to be entangled about the intersections of the yarns comprising the fabric. The stabilized fabric is formed by covering one or both sides of the loosely constructed base fabric with a light web of the staple length fibers, and subjecting the composite material to hydraulic entanglement while supported on a porous forming belt configured to direct and concentrate the staple length fibers at the intersections of the yarns comprising the base fabric.

[0009] U.S. Pat. No. 5,136,761 to Sternlieb et al. is directed to an apparatus and method for enhancement of woven and knit fabrics through the use of dynamic fluids which entangle and bloom fabric yarns. The process includes a two stage enhancement process wherein top and bottom sides of the fabric are respectively supported and impacted with a fluid curtain included high pressure jet streams. The controlled process energies and use of the support members having open areas which are aligned in offset relation to the process line produces fabrics having a uniformed finish and improved characteristics including edge fray, drape, stability, abrasion resistance, fabric weight and thickness.

[0010] U.S. Pat. No. 5,761,778 to Fleissner is directed to a method for hydrodynamic entanglement or needling, preferably for binder-free compaction, of fibers of a fiber web, especially a nonwoven fiber web, composed of natural or synthetic fibers of any type, wherein the fibers of the fiber web are entangled and compacted with one another by a plurality of water streams or jets applied at high pressure, with a large number of the water streams or jets striking the fiber web not only in succession but also several times on alternate sides of the web for optimum twisting of the fibers on the top and bottom on the fiber web.

[0011] Finally, U.S. Pat. No. 6,557,223 to Greenway et al. is directed to improvements in hydroenhancement efficiency
obtained by operating a manifold in relative movement to fabric transported under the manifold so as to deliver a low energy to the fabric per pass in multiple passes on the fabric. This process results in greater enhancement efficiency and reduction in wasted energy, and also improves fabric coverage and reduces fabric shrinkage.

[0012] While these prior art hydroentanglement finishing processes have been directed to improving dimensional stability and physical properties such as edge fray and drape and abrasion resistance, there remains a need to better reduce the pilling tendency and better improve abrasion resistance of a pillable fabric utilizing a physical finishing method that can be employed based upon specific process parameters for generation of an antipilling fabric.

SUMMARY

[0013] In accordance with one embodiment of the present subject matter, a method for reducing the surface pilling tendency and also improving abrasion resistance of a pillable fabric is disclosed.

[0014] The method includes the step of providing a pillable fabric, the fabric having a top surface, and side edges and comprising yarns which intersect at crossover points to define interstitial open areas in the fabric and further comprising fibrils extending from at least one of the top and bottom surfaces thereof. The fabric may comprise a woven fabric or a knitted fabric and the fabric yarns may include cotton, polyester, nylon, or blends thereof. The fabric is supported on a support member wherein the support member may comprise a belt, a drum, or a belt/drum combination and may include a pattern of closely spaced fluid pervious open areas to affect fluid passage therebetween. At least one of the surfaces is exposed to a hydroentanglement process to cause entanglement of the fibrils into the interstitial open areas of the fabric. The hydroentanglement process preferably includes imparting an energy in the range of at least about 4000 to 5000 KJoules/Kg of fabric using pressures of 200 bars or greater and includes the use of banks of one or more high pressure water jet manifolds that apply high pressure water jets to the fabric top and/or bottom surfaces.

[0015] The method further includes reducing the presence of the fibrils on the at least one fabric surface to an amount wherein the pilling production on the fabric is less than about 20% after 5,000 cycles of abrasion on a Martindale device according to ASTM D4970 testing standard. The fibrils are also reduced to an amount wherein the remaining mass of the fabric is at least about 80% to 90% after 50,000 cycles of abrasion on a Martindale device according to ASTM D4966 testing standard.

[0016] It is therefore an object of the present subject matter to provide a method for reducing the pilling tendency and improving abrasion resistance of a pillable fabric utilizing a finishing hydroentanglement process that results in the removal or entanglement of pilling-causing fibrils such that the tendency of the fabric to pill is greatly reduced, as gauged by pilling production calculated or remaining mass calculated after a set number of abrasion test cycles.

[0017] An object of the present subject matter having been stated hereinabove, and which is addressed in whole or in part by the present subject matter, other objects will become evident as the description proceeds when taken in connection with the accompanying drawings as best described hereinbelow.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] FIGS. 1A and 1B are plan and side views, respectively, of a typical woven product treated in accordance with the process of the present subject matter;

[0019] FIGS. 2A-2C are cross-sectional, top plan, and bottom plan views, respectively, of a typical hydroentangling nozzle provided in accordance with the present subject matter;

[0020] FIGS. 3A and 3B are schematic drawings of typical hydroentangling configurations in accordance with the present subject matter;

[0021] FIG. 4 is a line graph depicting the effect of hydroentangling and washing on fabric sample thickness;

[0022] FIGS. 5A-5F; 6A-6F; and 7A-7F are enlarged photographic surface views of control fabric samples and samples treated in accordance with the present subject matter;

[0023] FIGS. 8A-8C are line graphs depicting weight loss of fabric samples in relation to the number of abrasion cycles conducted; FIGS. 9A-9H; 10A-10H; 11A-11H; and 12A-12H are enlarged photographic surface views of control fabric samples and samples treated in accordance with the present subject matter after undergoing abrasion testing;

[0024] FIGS. 13A and 13B are line graphs depicting pilling production of fabric samples in relation to the number of abrasion cycles conducted;

[0025] FIGS. 14A and 14B are enlarged photographic surface views showing pilling production of a control fabric sample and a sample treated in accordance with the present subject matter, respectively, after undergoing abrasion testing; and

[0026] FIGS. 15A-15H; 16A-16F; and 17A-17D are enlarged photographic surface views of control fabric samples and varying fabric composition samples treated in accordance with the present subject matter.

DETAILED DESCRIPTION

[0027] The subject matter disclosed herein relates to methods for reducing the pilling tendency and improving abrasion resistance of a pillable fabric through the use of a hydroentanglement process. Hydroentanglement finishing at specified process parameters results in the complete removal or entanglement of surface yarn fibrils into the body of the fabric thereby improving the fabric strength while making the surface more smooth. Since the fibrils are no longer available on the fabric surface, they cannot entangle other fibers to form fluff balls or pills. The present subject matter is directed to the use of a high energy hydroentanglement process that has lead to significantly improved physical and mechanical properties of fabrics.

[0028] Referring to FIGS. 1A and 1B, a typical pillable fabric 10 treated by the process of the present subject matter is shown by example as a woven fabric, although it is also envisioned that additional fabrics such as knitted fabrics may be treated in accordance with the present subject matter.
Fabric 10 has a top surface TS, a bottom surface BS, and side edges E and comprises an open structure comprising warp yarns 12 extending in the machine direction and fill yarns 14 crossing at right angles to the warp yarns. The yarns are not secured at the intersections and consequently are easily displaced by external forces. Fibrils 16 are hook-like projections extending from yarns 12, 14 which extend away from top and bottom surfaces TS, BS of fabric 10 and contribute to the pilling properties of the fabric.

Yarns 12, 14 of fabric 10 may be selected from cotton, polyester, nylon, and other yarn compositions known to those of skill in the art. Additionally, blends of various fiber types may be used to form the fabric yarns.

Referring now to FIGS. 2A-2C, a typical hydroentangling nozzle assembly 20 provided in accordance with one aspect of the present subject matter is shown in cross-section, top plan view, and bottom plan view, respectively. Hydroentangling nozzles are traditionally made up of two sections: a cylindrical section 22 (capillary part) with a typical diameter of about 120 microns, connected to a slim cone 24 with a side angle extending approximately 18 degrees outwardly from the side of cylindrical section 22. Hydroentangling water jets are issued from thin-plate strips 26 having 1600-2000 orifices per meter and produce operating pressures ranging from 10 bars to over 1000 bars. FIG. 2B depicts a top view of strip 26 wherein cylindrical section 22 of the orifice is shown, and FIG. 2C depicts a bottom view of strip 26 wherein cone 24 of the orifice is shown.

The amount of energy imparted to the fabric during hydroentangling can be very significant. Energy calculation is based on Bernoulli equation that ignores viscous losses throughout the system. Having the hydroentangling manifold’s pressure as $P_1$, the water jet velocity can be calculated as:

$$V_j = \sqrt{2\rho (P_1 - P_0)}$$

Where $\rho = 998.2$ kg/m$^3$ (the density of water at room temperature), $P_1$ is the pressure in Pa, and $V_j$ is in m/s. (Note that 1 bar is equal to 10$^5$ Pa.)

Rate of energy transferred by the water jet is calculated as follows:

$$E = \frac{\pi}{8} \rho d^2 C_d V_j^3$$

Where $d$ is the diameter of the orifice capillary section in millimeters (assumed in a Hydrocalculator to be 0.127 mm), $C_d$ is the discharge coefficient, and $E$ is energy rate in J/s.

Specific energy is calculated based on the following formula:

$$SE = \frac{J}{kg_{piece}} = \frac{E}{M}$$

Where $M$ is the mass flow rate of the fabric in Kg/s and is calculated as follows

$$M = \text{Sample width} [\text{m}] \times \text{Basis weight} [\text{kg/m}^2] \times \text{Belt speed} [\text{m/s}]$$

Therefore, SE will be obtained in Joules per kg of fabric.

With reference to FIGS. 3A and 3B, pilling tendency reduction and abrasion resistance enhancement of fabric 10 is accomplished by entanglement and intertwining of fibrils on the surfaces of fabric 10 by hydroentangling finishing systems 30 and 40 wherein fabric 10 is supported by support members such as a drum 32 or an endless belt 34 or a combination thereof and impacted with a curtain of water jets under controlled process energies. Support members 32, 34 may include a pattern of closely spaced fluid pervious open areas to affect fluid passage therethrough and are designed to process fabric 10 through the system at a controlled rate.

Since knitted fabric has a tendency to shrink during exposure to water processes, it is further envisioned by the present subject matter that the side edges of the knitted fabric may be restrained during the hydroentanglement process in order to reduce the potential for shrinkage during processing (not shown). The restraining of the fabric edges may be accomplished by clamps along the conveyor system or by other mechanisms known to those of skill in the art.

Hydroentanglement system 30 further includes preferably two banks 36A, 36B of one or more high pressure water jet manifolds 38 oriented in a perpendicular direction relative to movement of fabric 10. Manifolds 38 may typically be spaced several inches apart and include a plurality of closely aligned and spaced nozzles 20. Hydroentanglement system 40 also preferably includes two banks 46A, 46B of one or more high pressure water jet manifolds 38. It is envisioned that banks 36A, 36B (FIG. 3A) with manifolds 38 may be arranged along support members 32 of system 30 in order to impart pilling reduction enhancement to both surfaces TS, BS of fabric 10 with one pass direction. Banks 46A, 46B with manifolds 38 may be arranged along support members 32, 34 of system 40 (FIG. 3B) to impart the same effects. For example, as shown in FIGS. 3A and 3B, hydroentanglement systems 30 and 40 may comprise one bank 36B, 46B of three manifolds 38 that impart pilling reduction enhancement to fabric top surface TS and another bank 36A, 46A of two manifolds 38 that impart pilling reduction enhancement to fabric bottom surface BS.

Each manifold 38 may comprise approximately 1600 to 2000 fluid nozzle orifices 20 per meter, wherein each nozzle 20 has an orifice diameter of approximately 80-300 microns, preferably 120 microns. Water pressure in each manifold 36 may be between 10 bars and 1000 bars depending on the amount of nozzle orifices 20 present and the size of the particular orifices. For optimum results in pilling reduction and abrasion resistance, it has been discovered that hydroentanglement systems 30 and 40 should each impart an energy in the range of at least about 4000 to 5000 KJoules/Kg of fabric using pressures of 200 bars or greater during processing of fabric 10.

EXAMPLES

Test Methods and Standards Reporting

Experiments were conducted on sample fabrics using hydroentanglement system 40 (see FIG. 3B) in order
to determine the effect on mechanical properties (pilling, abrasion, etc.) and hand improvement of a finished textile utilizing the finishing concept of the present subject matter. Different settings of the hydroentanglement process were tested for physical properties with the results presented below.

[0044] The samples exposed to hydroentangling were subjected to the hydroentangling process as described hereinabove. The hydroentangling process system comprised one bank of three (3) water jet manifolds that enhanced the top surface (lace) of the fabric and one bank of two (2) water jet manifolds that enhanced the bottom surface (back) of the fabric. The manifold pressures of the systems were as shown in Table 1.

<table>
<thead>
<tr>
<th>Manifold Position</th>
<th>Water Jet Pressure (bar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manifold 1 - Face pre-wet</td>
<td>60</td>
</tr>
<tr>
<td>Manifold 2 - Face entangling</td>
<td>150</td>
</tr>
<tr>
<td>Manifold 3 - Face entangling</td>
<td>200</td>
</tr>
<tr>
<td>Manifold 4 - Back entangling</td>
<td>150</td>
</tr>
<tr>
<td>Manifold 5 - Back entangling</td>
<td>200</td>
</tr>
</tbody>
</table>

[0045] The determination of the resistance to the formation of pills, abrasion resistance, and other related surface changes on textile fabrics is governed by test standards ASTM D4966 for abrasion resistance and ASTM D4970 for pilling. The testing procedures utilize the Martindale tester and is generally applicable to all types of fabrics.

[0046] In general, under the ASTM D4966 test, abrasion resistance is measured by subjecting the specimen to rubbing motion in the form of a geometric figure under known conditions of pressure and abrasive action. Resistance to abrasion is evaluated by the determination of mass loss as the difference between the masses before and after abrasion (expressed as a percentage of the before abrasion mass) and an end point when a hole appears in the fabric sample.

[0047] In general, under the ASTM D4970 test, resistance to pill formation testing involves mounting the fabric on the Martindale tester wherein the face of the test specimen is rubbed against the face of the same mounted fabric in a geometric pattern. The test specimen is compared with visual standards of actual fabrics or photographs of fabrics showing a range of pilling resistance in order to gauge the degree of fabric pilling or surface appearance change. The observed resistance to pilling is reported using an arbitrary scale from 5 (no pilling) to 1 (very severe pilling) as described in more detail hereinbelow.

Example I

The Effect of the Tightness Factor

[0048] Referring to FIGS. 5-14, experiments were first run on a single type of fiber composition at various fiber tightness factors. Due to its vast usage in the garment industry, the sample textile fabric chosen consisted of a single jersey structure knitted on a circular knitting machine (gauge 18) incorporating yarns of 100% cotton (Ne 18/1 cp ringspun; 35 Tex). Three tightness factor fabrics 15 were used and various samples were either washed or not washed and were broken down into groups including no hydroentangling passes, one hydroentangling pass, and two hydroentangling passes. The samples were identified as shown in Table 2.

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>Tightness Factor</th>
<th>Surface Mass (g/m²)</th>
<th>Thickness (mm)</th>
<th>Hydroentangling Passes</th>
<th>Wash/Dry</th>
</tr>
</thead>
<tbody>
<tr>
<td>C16.00</td>
<td>16.00</td>
<td>183</td>
<td>0.597</td>
<td>0</td>
<td>No</td>
</tr>
<tr>
<td>NH</td>
<td>16.00</td>
<td>183</td>
<td>0.597</td>
<td>1</td>
<td>No</td>
</tr>
<tr>
<td>IP</td>
<td>16.00</td>
<td>183</td>
<td>0.597</td>
<td>1</td>
<td>Yes</td>
</tr>
<tr>
<td>C16.67</td>
<td>16.67</td>
<td>188</td>
<td>0.610</td>
<td>0</td>
<td>No</td>
</tr>
<tr>
<td>NH</td>
<td>16.67</td>
<td>188</td>
<td>0.610</td>
<td>1</td>
<td>No</td>
</tr>
<tr>
<td>IP</td>
<td>16.67</td>
<td>188</td>
<td>0.610</td>
<td>1</td>
<td>Yes</td>
</tr>
<tr>
<td>C17.56</td>
<td>17.56</td>
<td>199</td>
<td>0.648</td>
<td>0</td>
<td>No</td>
</tr>
<tr>
<td>NH</td>
<td>17.56</td>
<td>199</td>
<td>0.648</td>
<td>1</td>
<td>No</td>
</tr>
<tr>
<td>IP</td>
<td>17.56</td>
<td>199</td>
<td>0.648</td>
<td>2</td>
<td>No</td>
</tr>
<tr>
<td>C17.56</td>
<td>17.56</td>
<td>199</td>
<td>0.648</td>
<td>1</td>
<td>Yes</td>
</tr>
<tr>
<td>IP W</td>
<td>17.56</td>
<td>199</td>
<td>0.648</td>
<td>1</td>
<td>Yes</td>
</tr>
</tbody>
</table>

[0049] Effect on Thickness

[0050] FIG. 4 graphically depicts the effect of hydroentangling and washing on the thickness of the various samples. The non-hydroentangled/non-washed samples had the greatest sample thicknesses ranging from approximately 0.6 mm to 0.65 mm, while the hydroentangled/non-washed samples had the lowest sample thicknesses ranging from approximately 0.56 mm to 0.58 mm. Washing of the hydroentangled samples generally increased sample thickness slightly.

[0051] Effect on Surface Properties

[0052] As shown pictorially in FIGS. 5-7, in all three sets of fabrics, more loose surface fibers (fibrils) are found in the non-hydroentangled fabrics, as the structure is more loose in general. Surface fibrils in the hydroentangled fabrics are more compact and are entangled into the interstices between the yarns or 15 cut from the fabric surface altogether, thus allowing the fabric structures to be more apparent in the hydroentangled fabrics due to the absence of multiple loose surface fibers.

[0053] FIGS. 5A, 5C, and 5E show the 16 tightness factor non-hydroentangled fabric at magnifications of 35x, 100x, and 300x, respectively. FIGS. 5B, 5D, and 5F show the 16 tightness factor one-pass hydroentangled fabric at magnifications of 35x, 100x, and 300x, respectively.

[0054] FIGS. 6A, 6C, and 6E show the 16.67 tightness factor non-hydroentangled fabric at magnifications of 35x, 100x, and 300x, respectively. FIGS. 6B, 6D, and 6F show the 16.67 tightness factor one-pass hydroentangled fabric at magnifications of 35x, 100x, and 300x, respectively.

[0055] FIGS. 7A, 7C, and 7E show the 17.56 tightness factor non-hydroentangled fabric at magnifications of 35x,
100x, and 300x, respectively. FIGS. 7B, 7D, and 7F show the 17.56 tightness factor one-pass hydroentangled fabric at magnifications of 35x, 100x, and 300x, respectively.

**[0056]** Effect on Abrasion Resistance (Mass Loss)

**[0057]** With reference to FIGS. 8A-8C, three fabric samples of three (3) different tightness factors showed increases in abrasion resistance when subjected to hydroentanglement, indicated by the significantly lower weight reduction (i.e., more remaining mass) after exposure to up to 70,000 cycles on the Martindale tester. Higher abrasion resistance in hydroentangled samples vs. non-hydroentangled samples was shown by reduced mass loss and longer cycles needed to make the first hole in the fabrics.

**[0058]** Specifically, FIG. 8A depicts abrasion testing on fabric samples with a 16 tightness factor. The non-hydroentangled sample (NH) showed a steep decline in remaining mass reaching around 75% remaining mass when a hole developed in the fabric after approximately 35,000 cycles. The one-pass non-washed hydroentangled sample (1P) showed a remaining mass of approximately 87% when a hole developed in the fabric after approximately 50,000 cycles. The one-pass washed hydroentangled sample (1PW) showed a gradual decline in remaining mass reaching around 82% when a hole developed in the fabric after approximately 70,000 cycles.

**[0059]** FIG. 8B depicts abrasion testing on fabric samples with a 16.67 tightness factor. The non-hydroentangled sample (NH) showed a steep decline in remaining mass reaching around 73% remaining mass when a hole developed in the fabric after approximately 36,000 cycles. The one-pass non-washed hydroentangled sample (1P) showed a remaining mass of approximately 91% when a hole developed in the fabric after approximately 50,000 cycles. The one-pass washed hydroentangled sample (1PW) showed a gradual decline in remaining mass reaching around 83% when a hole developed in the fabric after approximately 52,000 cycles.

**[0060]** FIG. 8C depicts abrasion testing on fabric samples with a 17.56 tightness factor. The non-hydroentangled sample (NH) showed a steep decline in remaining mass reaching around 78% remaining mass when a hole developed in the fabric after approximately 36,000 cycles. The one-pass non-washed hydroentangled sample (1P) showed a remaining mass of approximately 83% when a hole developed in the fabric after approximately 52,000 cycles. The two-pass non-washed hydroentangled sample (2P) showed a remaining mass of approximately 83% when a hole developed in the fabric after approximately 48,000 cycles. As shown pictorially in FIGS. 9-12, representing two (2) types of tightness factor fabrics being hydroentangled and non-hydroentangled, as the abrasion cycles increased, fibers in both series of fabrics were cut and fibrillated. However, while the cut ends of the fibers in the non-hydroentangled fabrics are protruded from the surface and can lead to generation of pilling, the cut ends of the fibers in the hydroentangled fabrics remained entangled into the fabric interstices so as to not contribute to pilling tendency.

**[0061]** Specifically, FIGS. 9A-9H show the fabric surface of the 16 tightness factor non-hydroentangled fabric at magnifications of 35x and 100x at abrasion cycles of 0, 2000, 20000, and 35000.

**[0062]** FIGS. 10A-10H show the fabric surface of the 16 tightness factor one-pass hydroentangled fabric at magnifications of 35x and 100x at abrasion cycles of 0, 2000, 20000, and 35000.

**[0063]** FIGS. 11A-11F show the fabric surface of the 17.56 tightness factor non-hydroentangled fabric at magnifications of 35x and 100x at abrasion cycles of 0, 2000, and 35000.

**[0064]** FIGS. 12A-12H show the fabric surface of the 17.56 tightness factor one-pass hydroentangled fabric at magnifications of 35x and 100x at abrasion cycles of 0, 2000, 30000, and 60000.

**[0065]** The markedly improved abrasion resistance of fabric samples exposed to the hydroentangling process of the present invention can be attributed to the entanglement or removal of the surface fibrils. This effect leads to a smoother fabric surface and a reduction in mass loss of the fabric during abrasion testing.

**[0066]** Effect on Pilling

**[0067]** Tests were conducted to determine the resistance of the fabric samples to form pills on the fabric surface. The Martindale tester was used to run through approximately 60,000 cycles, wherein the samples were intermittently inspected and a standard pilling rating was assigned to the samples according to the rating scale shown in Table 3.

<table>
<thead>
<tr>
<th>Pilling Rating Scale</th>
<th>Surface Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>No pilling</td>
</tr>
<tr>
<td>4</td>
<td>Slight pilling</td>
</tr>
<tr>
<td>3</td>
<td>Moderate pilling</td>
</tr>
<tr>
<td>2</td>
<td>Severe pilling</td>
</tr>
<tr>
<td>1</td>
<td>Very severe pilling</td>
</tr>
</tbody>
</table>

**[0068]** With reference to FIGS. 13A and 13B, the pilling tendency of the fabrics (16 tightness factor in FIG. 13A and 17.56 tightness factor in FIG. 13B) were greatly reduced after hydroentanglement, and even more so after washing and or multiple passes through the hydroentangling process. The non-hydroentangled fabrics samples (NH) showed very severe pilling after only approximately 150 cycles, while the hydroentangled fabrics (1P) displayed only slight pilling even after 5000 cycles. The two-pass (2P) hydroentangling fabric sample (see FIG. 13B) showed no pilling until approximately 2000 cycles, when it began showing slight pilling.

**[0069]** FIGS. 14A and 14B pictorially display the pilling effect after 5000 cycles on the Martindale device. FIG. 14A shows a cotton knit non-hydroentangled fabric sample after 5000 cycles. The sample displayed very significant pilling (see also FIGS. 13A and 13B), due to the presence of surface fibrils. FIG. 14B shows a cotton knit hydroentangled fabric sample after 5000 cycles. The sample displayed only slight pilling, hardly noticeable to the viewer (see also FIGS. 13A and 13B).

**[0070]** As shown in FIGS. 13A, 13B and 14A, 14B, the pilling behavior is strongly improved in fabric samples exposed to the hydroentangling process of the present sub-
ject matter. Similar to the markedly improved abrasion resistance, the pilling resistance of the hydroentangled fabrics can be attributed to the specific energy ranges of the present subject matter which cause a lack of fibrils at the surface of the fabric either through entanglement of the fibrils into the fabric interstices or perhaps removal of the fibrils altogether. The smooth, fibril-less fabric surface results in a fabric which has great abrasion resistance and a tendency not to produce pils.

Example II

The Effect of Fiber Composition and Hydroentangling Parameters

Referring now to FIGS. 15-17, experiments were additionally run on fabrics of various compositions and at varying hydroentangling processing parameters. The textile fabric structure comprised a single jersey construction with a 17.5 tightness factor. The fabric compositions were formed as shown in Table 4 and the samples and hydroentangling parameters (for those samples that were hydroentangled) were identified as shown in Table 5.

<table>
<thead>
<tr>
<th>Fiber Composition</th>
<th>Tightness factor</th>
<th>Surface Mass (g/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100% cotton</td>
<td>17.5</td>
<td>229</td>
</tr>
<tr>
<td>50/50 Cotton/polyester</td>
<td>17.5</td>
<td>216</td>
</tr>
<tr>
<td>100% Polyester</td>
<td>17.5</td>
<td>199</td>
</tr>
</tbody>
</table>

![Table 4](image)

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>Pressure #1(bar)</th>
<th>Pressure #2(bar)</th>
<th>Pressure #3(bar)</th>
<th>Pressure #4(bar)</th>
<th>Pressure #5(bar)</th>
<th>Belt type</th>
<th>Belt speed (m/min)</th>
<th>Number of Passes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a</td>
<td>60</td>
<td>150</td>
<td>200</td>
<td>150</td>
<td>200</td>
<td>100</td>
<td>10</td>
<td>1 Cotton</td>
</tr>
<tr>
<td>2b</td>
<td>60</td>
<td>150</td>
<td>200</td>
<td>150</td>
<td>200</td>
<td>100</td>
<td>10</td>
<td>2 Cotton</td>
</tr>
<tr>
<td>3c</td>
<td>60</td>
<td>150</td>
<td>200</td>
<td>150</td>
<td>200</td>
<td>100</td>
<td>10</td>
<td>3 Cotton</td>
</tr>
<tr>
<td>2a</td>
<td>60</td>
<td>150</td>
<td>200</td>
<td>150</td>
<td>200</td>
<td>100</td>
<td>10</td>
<td>1 Co/Poly</td>
</tr>
<tr>
<td>3b</td>
<td>60</td>
<td>150</td>
<td>200</td>
<td>150</td>
<td>200</td>
<td>100</td>
<td>10</td>
<td>1 Polyester</td>
</tr>
<tr>
<td>4a</td>
<td>60</td>
<td>150</td>
<td>200</td>
<td>150</td>
<td>200</td>
<td>100</td>
<td>50</td>
<td>1 Cotton</td>
</tr>
</tbody>
</table>

![Table 5](image)

[0076] FIGS. 15E and 15F show the surface image of a non-washed, one-pass hydroentangled 100% cotton jersey fabric (sample 1a) at 35x and 100x magnification, respectively, and FIGS. 15G and 15H show the surface image of a non-washed, two-pass hydroentangled 100% cotton jersey fabric (sample 1b) at 35x and 100x magnification, respectively. Each of these samples showed extensive fibrillation of the cotton fibers and entanglement of the surface fibers into the fabric interstice structure or removal of the surface fibers altogether. The two-pass hydroentangled fabric sample showed even more fibrillation of the fibers over the one-pass hydroentangled sample, along with additional flattening of the structure.

[0077] Effect on 50/50 Cotton/Polyester Fabrics

[0078] FIGS. 16A-16F pictorially display the surface structure of a variety of the 50/50 cotton/polyester jersey fabric samples.

[0079] Specifically, FIGS. 16A and 16B show the surface image of a washed, non-hydroentangled 50/50 cotton/polyester jersey fabric at 35x and 100x magnification, respectively. While some fibers were fibrillated, the fabric sample showed no substantial changes in the loose surface fibers.

[0080] FIGS. 16C and 16D show the surface image of a non-washed, one-pass hydroentangled 50/50 cotton/polyester jersey fabric (sample 2a, non-washed) at 35x and 100x magnification, respectively, and FIGS. 16E and 16F show the surface image of a washed, one-pass hydroentangled 50/50 cotton/polyester jersey fabric (sample 2a, washed) at 35x and 100x magnification, respectively. Each of these samples showed extensive fibrillation of the cotton fibers and entanglement of the surface fibers into the fabric interstice structure or removal of the surface fibers altogether.

[0073] Effect on 100% Cotton Fabrics

[0074] FIGS. 15A-15H pictorially display the surface structure of a variety of the 100% cotton jersey fabric samples.

[0075] Specifically, FIGS. 15A and 15B show the surface image of a non-washed, non-hydroentangled 100% cotton jersey fabric at 35x and 100x magnification, respectively, and FIGS. 15C and 15D show the surface image of a washed, non-hydroentangled 100% cotton jersey fabric at 35x and 100x magnification, respectively. While the washed sample showed some fibrillation of the fibers, neither of these non-hydroentangled fabric samples showed substantial changes in the loose surface fibers as the structure in general remained in a loose state.

[0081] Effect on 100% Polyester Fabrics

[0082] FIGS. 17A-17D pictorially display the surface structure of a variety of the 100% polyester jersey fabric samples.

[0083] Specifically, FIGS. 17A and 17B show the surface image of a washed, non-hydroentangled 100% polyester jersey fabric at 35x and 100x magnification, respectively. The fabric sample showed no substantial changes in the loose surface fibers.

[0084] FIGS. 17C and 17D show the surface image of a washed, one-pass hydroentangled 100% polyester jersey fabric (sample 3a, washed) at 35x and 100x magnification, respectively. The sample showed extensive entanglement of the surface fibers into the fabric interstice structure or removal of the surface fibers altogether.
[0085] The present subject matter reflects a use of specific ranges of hydroentanglement energies to produce a fabric containing unexpectedly and surprisingly advantageous properties of reduced surface pilling and improved abrasion resistance.

[0086] It will be understood that various details of the invention may be changed without departing from the scope of the invention. Furthermore, the foregoing description is for the purpose of illustration only, and not for the purpose of limitation, as the invention is defined by the claims as set forth hereinafter.

What is claimed is:

1. A method for reducing the surface pilling tendency and improving abrasion resistance of a pillable fabric, the method comprising the steps of:
   (a) providing a pillable fabric having a top surface, a bottom surface, and side edges and comprising yarns which intersect at crossover points to define interstitial open areas in the fabric, and the fabric further comprising fibrils extending from at least one of the top and bottom surfaces thereof;
   (b) supporting the fabric on a support member;
   (c) exposing at least one of the surfaces to a hydroentanglement process to cause entanglement of the fibrils into the interstitial open areas of the fabric, wherein the hydroentanglement process includes imparting an energy in the range of at least about 4000 to 5000 KJoules/Kg of fabric using pressures of 200 bars or greater; and
   (d) reducing the presence of the fibrils on the at least one fabric surface to an amount wherein the pilling production on the fabric is less than about 20% after 5,000 cycles of abrasion on a Martindale device according to ASTM D 4970 testing standard and the fabric remaining mass is at least about 80% to 90% after 50,000 cycles of abrasion on a Martindale device according to ASTM D 4966 testing standard.

2. The method of claim 1 wherein the fabric is a woven fabric.

3. The method of claim 1 wherein the fabric is a knit fabric.

4. The method of claim 3 further comprising the step of restraining the side edges of the knit fabric to prevent shrinkage during the hydroentanglement process.

5. The method of claim 1 wherein the fabric yarns are selected from the group consisting of cotton, polyester, nylon, and blends thereof.

6. The method of claim 1 wherein the support member is selected from the group consisting of a belt, a drum, and a belt/drum combination.

7. The method of claim 6 wherein the support member includes a pattern of closely spaced fluid pervious open areas to affect fluid passage through the support member.

8. The method of claim 1 wherein both surfaces of the fabric are exposed to the hydroentanglement process.

9. The method of claim 1 wherein the hydroentanglement process is accomplished by the use of a hydroentanglement system comprising at least one bank of one or more high pressure water jet manifolds.

10. The method of claim 9 wherein the hydroentanglement system comprises two banks of high pressure water jet manifolds that apply high pressure water jets to the fabric top and bottom surfaces.

11. The method of claim 10 wherein the hydroentanglement system comprises one bank of three manifolds that apply high pressure water jets to the fabric top surface and one bank of two manifolds that apply high pressure water jets to the fabric bottom surface.

12. The method of claim 9 wherein the water pressure of the one or more manifolds is between 10 bars and 1000 bars.

13. The method of claim 12 wherein each of the one or more manifolds further comprises approximately 1600 to 2000 fluid jet orifices per meter, wherein each orifice has a diameter of approximately 80 to 300 microns.


15. A method for reducing the surface pilling tendency and improving abrasion resistance of a pillable cotton knit fabric, the method comprising the steps of:
   (a) providing a pillable cotton knit fabric having a top surface, a bottom surface, and side edges and comprising yarns which intersect at crossover points to define interstitial open areas in the fabric, and the fabric further comprising fibrils extending from at least one of the top and bottom surface thereof;
   (b) supporting the fabric on a support member;
   (c) restraining the side edges of the knit fabric;
   (d) exposing at least one of the surfaces to a hydroentanglement process comprising at least one bank of one or more high pressure water jet manifolds to cause entanglement of the fibrils into the interstitial open areas of the fabric, wherein the hydroentanglement process system imparts an energy in the range of at least about 4000 to 5000 KJoules/Kg of fabric using pressures of 200 bars or greater; and
   (e) reducing the presence of the fibrils on the at least one fabric surface to an amount wherein the pilling production on the fabric is less than about 20% after 5,000 cycles of abrasion on a Martindale device according to ASTM D 4970 testing standard and the fabric remaining mass is at least about 80% to 90% after 50,000 cycles of abrasion on a Martindale device according to ASTM D 4966 testing standard.

16. The method of claim 15 wherein the support member is selected from the group consisting of a belt, a drum, and a belt/drum combination.

17. The method of claim 16 wherein the support member includes a pattern of closely spaced fluid pervious open areas to affect fluid passage through the support member.

18. The method of claim 15 wherein both surfaces of the fabric are exposed to the hydroentanglement process system.

19. The method of claim 15 wherein the hydroentanglement system comprises two banks of high pressure water jet manifolds that apply high pressure water jets to the fabric top and bottom surfaces.

20. The method of claim 19 wherein the hydroentanglement system comprises one bank of three manifolds that apply high pressure water jets to the fabric top surface and one bank of two manifolds that apply high pressure water jets to the fabric bottom surface.

21. The method of claim 15 wherein the water pressure of the one or more manifolds is between 10 bars and 1000 bars.
22. The method of claim 22 wherein each of the one or more manifolds further comprises approximately 1600 to 2000 fluid jet orifices per meter, wherein each orifice has a diameter of approximately 80 to 300 microns.

23. A fabric produced according to the method of claim 15.

24. A pill and abrasion resistant fabric comprising:
   (a) a top surface, a bottom surface, and side edges;
   (b) multiple yarns intersecting at crossover points to define interstitial open areas in the fabric;
   (c) fibrils extending from at least one of the top and bottom surfaces which have been entangled into the interstitial open areas of the fabric by exposure of at least one of the top and bottom surfaces to a hydroentanglement process including imparting an energy in the range of at least about 4000 to 5000 KJoules/Kg of fabric using pressures of 200 bars or greater; and
   (d) wherein the pill and abrasion resistant fabric possesses a reduced pill production potential of less than about 20% after 5,000 cycles of abrasion on a Martindale device according to ASTM D4970 testing standard and possesses an increased abrasion resistance potential wherein the fabric remaining mass is at least about 80% to 90% after 50,000 cycles of abrasion on a Martindale device according to ASTM D4966 testing standard.


27. The fabric of claim 24 wherein the fabric yarns are selected from the group consisting of cotton, polyester, nylon, and blends thereof.

28. The fabric of claim 24 wherein both surfaces of the fabric have been exposed to the hydroentanglement process.

29. A pill and abrasion resistant cotton knitted fabric comprising:
   (a) a top surface, a bottom surface, and side edges;
   (b) multiple yarns intersecting at crossover points to define interstitial open areas in the fabric;
   (c) fibrils extending from at least one of the top and bottom surfaces which have been entangled into the interstitial open areas of the fabric by exposure of at least one of the top and bottom surfaces to a hydroentanglement process including imparting an energy in the range of at least about 4000 to 5000 KJoules/Kg of fabric using pressures of 200 bars or greater; and
   (d) wherein the pill and abrasion resistant fabric possesses a reduced pill production potential of less than about 20% after 5,000 cycles of abrasion on a Martindale device according to ASTM D4970 testing standard and possesses an increased abrasion resistance potential wherein the fabric remaining mass is at least about 80% to 90% after 50,000 cycles of abrasion on a Martindale device according to ASTM D4966 testing standard.

30. The fabric of claim 29 wherein both surfaces of the cotton knitted fabric have been exposed to the hydroentanglement process.

* * * * *