The invention includes needle punched composite fabrics that provide separate finish systems. A first finish is applied to the fiber batt prior to preparation of the composite. A second "overlay fiber finish" is provided subsequent to a needling process.
NEEDLE PUNCHED NONWOVEN FABRIC AND
PROCESS FOR THE MANUFACTURE THEREOF

BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates to the production of needle punched non-wovens with improved productivity and quality. More specifically, it relates to Papermachine Clothing (PMC) Press Felts with improved productivity and quality.

Summary of Related Technology

A paper machine has three distinct sections - forming, pressing and drying. Different types of fabrics, with different performance requirements, are used in each section. In the press section of the paper machine there will be one, two, or more press felts installed. A press felt is an endless belt which receives, transports, and most importantly removes water from the pulp material. The requirements for PMC press felts are extremely severe. Typically the wear rate of the press felts will be much faster than the fabrics used in the forming and drying section. When the press section can no longer remove water at the required, economical rate the felts are replaced. This requires the paper machine to be shutdown resulting is lost productivity.

Needle punched non-woven fabric structures including press felts derive their strength and cohesiveness from inter-fiber entanglement and inter-fiber frictional forces. In the case of typical press felt batt-on-base constructions the entanglement of the staple batt fibers with the base structure is also important. This is true whether the base is a woven fabric or some other construction. There have been many methods suggested or used to improve the entanglement or bonding of the batt fibers. This includes modifying the base fabric for improved bonding. As far back as 1929 US patent US1737607A was issued for an improved base fabric for needle punched felt. In the realm of press felts improvements in bonding were achieved by replacing single yarns in the fill direction with cabled monofilaments yarns US2165772A (1939). US Patent US2423828A (1947, Albany Felt Co.) is the first reference found that is based on replacing wool or cotton yarns in press felts with some amount fibers filaments made
from "synthetic resins" such as "nylon". Numerous other modifications to the base fabric construction have been utilized including using yarns spun from synthetic staple fibers, using twisted multifilament yarns and "spira:ly wound essentially untwisted" fibers in the fill direction US3039496A (1962).

Great improvements have been made in the speed and efficiency of the needling machines. An early example of an improvement is needling felts from both sides US2896302A (1959, Albany Felt Co.). Improvements in needling efficiency have been achieved by changes in the design of the needles. US3090100A (1963, Chatham Manufacturing Co.) describes the use and advantages of having the needles penetrate at an angle to the surface of the felt as opposed to the normal perpendicular penetration.

In the area of improving the batt fiber the use of fibers with "built-in potential energy of a curl and twist" US2774129A (1956), and "retractable" US2910763A (1959, Dupont) fibers has been suggested. The use of different bonding agents has been suggested in multiple patents. The first reference found was related to using a blend of "fusible staple synthetic linear polymer binding filaments, and staple filaments which are substantially unaffected at the softening temperature of said polymer" US2336797A (1943, Dupont). US2943379A (1960, Lockport Felt Co.) discusses the use of fusible fibers and chemical agents such as resins and latexes to bond fibers in press felts. US4151323A (1979, Huyck) discloses the application of a resin to the roll side of the felt during production. The resin is said to improve bonding of the staple fiber to the base.

US3206351A (1965, The Fiberwoven Corp.) indicates improved bonding via specified alignment of the batt fibers prior to needling. US3230599A (1966, Huyck) indicates improved bonding via specifying both the alignment of the batt fibers prior to needling, and the alignment of the needles in relation to the felt.

It is current practice to add fibers made of low-melt polymer materials, such low melt nylon fibers, to bond the batt fibers. These fibers may be either 100% low-melt or bicomponent fibers where only the sheath will melt during processing. For press felts the bonding occurs during heatsetting of the fabrics post needling. This heatsetting is done at temperatures which exceed the melt point of low-melt polymer.
SUMMARY OF THE INVENTION
The bonding efficiency in the needle punching process is improved by addition of specific overlay finishes to the web after carding and prior to needling. The type of finish has been shown to have a large impact on this bonding efficiency as well.

BRIEF DESCRIPTION OF THE DRAWINGS
FIG. 1 is a diagram for an apparatus useful for testing fiber-to-fiber friction coefficients.
FIG. 2 is a diagram for an apparatus useful testing fiber-to-metal friction coefficients
FIG. 3 is a flow chart of a simplified process for the production of batt material for press felts.
FIG. 4 schematically depicts a general protocol for evaluation of various finishes.

DETAILED DESCRIPTION OF THE INVENTION
For the purposes of this invention, the term "overlay fiber finish" is meant to include the "second fiber finish" which is applied to a fabric after carding and before needling of the fabric. The composition may be a single composition or a blend of different finish compositions.

Press felts of the batt on base construction made using the needle punching process have been manufactured for more than 60 years. These felts are manufactured by where batt fibers are bonded to a base fabric and to each other using needle punch machines. A needle punch machine uses barbed needles to entangle the fibers with the base and within each other. In a typical construction there will be multiple layers of batt fiber needle punched in series. Batt fiber is applied to both the top and the bottom of the base fabric. Base fabrics are typically woven monofilament constructions, but other types of base fabrics have been used.

The requirements for a press felt include:
• Dimensional strength
• Specified Caliper
• Specified air and/or water permeability
• Excellent fiber bonding to minimize fiber loss on the paper machine
• Surface characteristics to achieve the desired paper sheet properties and to meet the requirements of the paper machine referred to as sheet handling.

The fiber bonding efficiency can be described as the number of needle strokes per unit area of the felt required to achieve the specified finished product requirements.

The variability in the machine direction and cross direction of these properties is as important as the nominal values. Too much variation can result in paper quality issues and production issues such as lower speeds or increased paper machine shutdowns.

The fiber properties required for efficient opening and carding the staple batt fibers are different from those required for efficient needling of the fiber. These frictional properties are significantly affected by the finish applied to the fiber. Finishes are typically aqueous solutions or emulsions containing one or more lubricants, anti-static agents, emulsifiers, surfactants, antimicrobials, neutralizing agents and other functional improving components. Finishes should be stable and maintain consistent properties over extended periods of time.

The lubricant(s) or combination of lubricants and emulsifiers and surfactants primarily provide the frictional and cohesive properties that affect the processes. Typical lubricants include, but are not limited to, fatty esters isolated from naturally-occurring materials, such as coconut oil US3428560 (1969, E.I. du Pont de Nemours and Company), peanut oil, palm oil; petroleum based oils, such as mineral oil, polyakylene glycol oils and silicon-based oils; synthetic esters, such as those obtained from reacting fatty acids with aliphatic alcohols; co-polymers; natural waxes and synthetic waxes. Anti-static agents, emulsifiers and other additives to the finish must be carefully chosen as these too can affect the frictional properties either directly or through interactions with the other components.

For carding, a fiber must have the proper cohesiveness to allow the fibers to be aligned uniformly and form a uniform, cohesive web. Too much cohesiveness and the batt fiber alignment will not be uniform. Too little cohesiveness will also cause non-uniformity due to stretching of the web during processing and storage. This means an intermediate level of fiber-to-fiber friction is needed to achieve the required cohesion.
The carding process also requires a fiber with relatively low fiber-to-metal friction to minimize physical damage to the fibers. If the fiber-to-metal friction is too high, then the carding elements can overload and consequently jam, causing downtime on the equipment. On the other hand, if the fiber-to-metal friction is too low, the fibers will be too slippery causing inadequate and non-uniform carding. The right blend of fiber-to-fiber and fiber-to-metal friction must be achieved with the finish formulation. This is also heavily dependent on the denier and crimp of the fiber, as well as, the carding elements. Those skilled in the art have developed or identified commercial finish formulations that provide adequate carding performance.

(1) Low fiber-to-fiber friction can be achieved through the addition of fiber lubricants or fiber softening agents, including but not limited to ethoxylated castor oil and sorbitan esters, such as POE (20) sorbitan monooleate. There are many other chemicals that could potentially be used.

(2) Sufficiently high fiber-to-metal friction can be achieved through the addition of sorbitan esters, sorbitol esters and/or ethoxylated castor oil. Again, this not an exhaustive list and is only meant to provide a few examples.

To achieve optimum needling a different level of fiber cohesiveness and therefore different frictional properties are needed. The mechanical bond created by the needle punching process is held by the friction between fibers. Therefore, increasing cohesion between fibers improves the locking of the fibers into the felt. The primary fiber-to-metal friction requirements for needling staple fibers are very good lubrication between the fast moving needles and the fiber, good pick-up by the needles, and then easy release when the needle retracts. A finish that provides relatively high fiber-to-fiber friction and low fiber to metal (hydrodynamic) friction will provide the best needling performance.

(1) High fiber-to-fiber friction can be achieved through the addition of cohesive agents such as ethoxylated alcohols, including POE decyl alcohol, POE (3) lauryl alcohol, POE (4) lauryl alcohol, POE (10) oleyl alcohol, POE (20) oleyl alcohol, derivatives of the aforementioned alcohol ether ethoxylates with capping groups of typical alkyl or propylene oxide; polyethylene glycol or esters of fatty acids. This is not an exhaustive list and someone skilled in the art could identify
alternative materials that would provide similar benefits. US5525243 (1996, Henkel) describes a finish comprising of a lubricant, anti-static agent and polyethylene glycol that increases the coefficient of friction between fibers in synthetic textile fibers.

(2) Low fiber-to-metal friction can be also achieved through careful selection of finish lubricants. Esters of long-chain fatty acids are one such material known to provide low fiber-to-metal friction. This includes polyethylene oxides esters of (8) stearate, (20) stearyl alcohol, (9) laurate, (4) lauryl alcohol, (23) lauryl alcohol, (10) cetyl alcohol to name a few. It is knowledge in the art that lubricant viscosity and hydrodynamic friction are directly proportional and thus the viscosity of the lubricant over an appropriate range of temperatures should be considered when selecting finish components.

Frictional testing by INVISTA supports these statements. Friction testing was completed for two finish formulations, DY-4 and NS-28. Both tests used 70 denier nylon 6,6 monofilament.

For measurements of air permeability, if air permeability of said needle punched nonwoven fabric with second fiber finish is at least 5% less than air permeability of the needle punched nonwoven fabric without the application of the second fiber finish then this would indicate a useful improvement in efficiency of needle punching process. For measurements of tensile strength in the longitudinal and transverse directions, if tensile strength in either the longitudinal or the transverse direction of said needle punched nonwoven fabric with second fiber finish is at least 5% greater than the tensile strength in either the longitudinal or transverse of the needle punched nonwoven fabric without the application of the second fiber finish then this would indicate a useful improvement in the efficiency of the needle punching process. For measurements of fabric density, if the fabric density of said needle punched nonwoven fabric with second fiber finish is at least 5% greater than the fabric density of the needle punched nonwoven fabric without the application of the second fiber finish then this would indicate a useful improvement in efficiency of the needle punching process. Fabric density is defined as the ratio of fabric weight, measured in mass per unit area, to the fabric thickness.
TEST PROCEDURE:

Fiber-to-fiber friction coefficients were measured using a standard capstan method. A suitable device for which is depicted in FIG. 1. The test consists of a test yarn 2 attached to a weight at one end 4, wrapped 180° around a mandrel 8 and attached at the other end to a strain gauge 6. Before adding the test yarn 2, the mandrel 8 is wrapped in a crisscross pattern with yarn (not shown) in order to test fiber-to-fiber friction. The mandrel is connected to a motor (not shown) and rotated at a very slow speed.

From the reading of the strain gauge 6, the coefficient of friction can be measured using the Belt equation:

\[ \frac{T_2}{T_1} = e^{\mu \cdot \theta} \]

where, \( T_1 \) is the pre-loaded weight 4, \( T_2 \) is the measurement from the strain gauge 6, \( \theta \) is the wrap angle and \( \mu \) is the coefficient of friction. For this test, a 30 gram weight was used.

Fiber-to-metal friction was measured using a Rothschild-type instrument in order to run higher speeds and achieve hydrodynamic friction. A diagram of one such set-up shown in FIG. 2

The take-off roll 10 pulls the yarn 16 from a yarn package 14 to a hysteresis break 20 and through the system 18 and tension is measured at 11 and 12. As with the capstan arrangement, the Belt equation can be used again to calculate the coefficient of kinetic friction. For this testing, the pre-tension was set at 30 grams, the wrap angle around the friction pin 22 was 170° and the speed of the yarn 16 was 100 yards/minute.

<table>
<thead>
<tr>
<th>Finish</th>
<th>Fiber-to-Fiber Friction</th>
<th>Fiber-to-Metal Friction</th>
</tr>
</thead>
<tbody>
<tr>
<td>DY-4</td>
<td>0.35</td>
<td>0.89</td>
</tr>
<tr>
<td>NS-28</td>
<td>0.27</td>
<td>1.24</td>
</tr>
</tbody>
</table>

Testing was conducted with 1.0% finish on the fiber on a weight percent basis. DY-4 contains 65% isobutyl stearate, which would provide low fiber-to-metal friction and
adequate fiber-to-fiber friction. Low fiber-to-metal friction is due to the very low viscosity of isobutyl stearate (approximately 10 centistokes at 25°C). There is a very good correlation between fiber-to-metal (high speed, hydrodynamic) friction and the viscosity of the lubricant. NS-28 on the other hand contains 20 - 25% ethoxylated castor oil, which would be expected to give high fiber-to-metal friction and lower fiber-to-fiber friction.

It has been previously typical in the industry to apply these finishes to the fiber during fiber spinning and/or drawing to enable processing of the fiber without excessive filament breakage, fuzzing, static and other non-uniformities and to provide good carding performance. This has proven insufficient in optimizing both needling and carding performance as the frictional needs for these processes are notably different and cannot be accomplished with a single finish. It is then the subject of this invention to provide a non-woven, needle-punched article containing two finishes applied at separate points within the manufacturing process; the first on the fiber itself and optimized for fiber production and carding, and the second applied after carding and prior to needle-punching, which is optimized for the needle punching process. The second finish can be applied by any number of methods, such as by spray or by foaming.

TEST PROTOCOL FOR EVALUATION OF FINISH PERFORMANCE

The aforementioned trials to evaluate the performance of the various finishes would not have been economically or practically feasible if conducted on standard commercial equipment. As an alternative, pilot scale equipment was used that is representative of the commercial equipment, but is economical and easily accessible. Simulating commercial conditions is critical to the evaluation of finishes and is a necessary step in the development of finish formulations to use in this application as finish properties, characteristics, components, etc. alone are insufficient in predicting performance during needle-punching.
For these reasons, a protocol was developed for evaluation of the various finishes. The general protocol is as follows and is schematically depicted in FIG. 4:

1. Produce batt material.

   The simplified process for the production of batt material for press felts is shown in FIG. 3.

   This forms a web of staple fibers that can now be combined with other batt layers and a base fabric during needling-punching to form a felt. The pre-needling step is very helpful in that it imparts some strength to the batt to withstand later handling. Since the batt is a continuous web, it was taken-up on cardboard cores following the pre-needling step to form rolls of batt material.

2. Create layer of batt 30

   The batt could then be unrolled and cut to the desired length to provide a layer of material. For this testing, sections were about two meters long by one meter wide and were cut from the roll.

3. Apply finish 32 to layer.

   This can be done using a hand-operated spray bottle or a garden-type sprayer. Other methods could be used as well, but the hand-operated spray bottle produced a uniform, atomized mist and seemed to work best. Finish was applied over the entire surface area of the batt with care given to applying the finish uniformly. The weight of the spray bottle was measured before and after application to record the amount of finish applied.

4. Lay batt on substrate 34.

   For the first pass, the batt layer with finish applied will go directly on woven or nonwoven base fabric, which has dimensions matching the batt layer. Later layers will be on the previously needled article. This step must be done carefully to have the two align at the edges and to prevent wrinkles from forming.

5. Feed composite through needle punching process 36.

   The layers should be carefully fed together through the needle punch machine. The resultant needled article is then brought back to front of needle punching process in preparation for next layer of batt. Needle design is a key component to the needling
In this regard, needles identical to those used in commercial processes can be used to more accurately represent actual manufacturing.

6. Repeat steps 2 through 5.

Steps 2 through 5 are then repeated for each additional layer of batt material to provide a multiple composite 40 per the requirements of the test.

This protocol provides a convenient and useful method for fabricating a wide variety of felt constructions in a manner that simulates commercial press felt production equipment.

TEST METHODS

ASTM D3776 for basis weight
ASTM D5729 for caliper
ASTM D737 for air permeability
ASTM D5035 for breaking strength (MD and CD)

EXAMPLE #1

Test felts were produced using the carding and needling facilities at North Carolina State University Nonwovens laboratory.

- Each Felt has 5 layers of batt fiber needle punched into a woven base fabric.
- Each layer of batt fiber was approximately 100 grams square meter.
- Needle Punch Density = 90 punches per square centimeter for each pass.
- Needle = Foster F 20 6-1 8-2/3B/Conical 15x17x40x3.5 RBA
- Depth of Needle Penetration = 11 mm
The same 15 denier Type 881 staple fiber was used to produce the batts for the control and the test items. This fiber had a spin finish applied during production. This is NS-28 at 0.9% finish-on-yarn. NS-28 in a 20% concentration emulsion is comprised of 12% refined coconut oil, 4% ethoxylated castor oil capped with oleic acid (SynLube 728 manufactured by Milliken Chemical Co.), 2.5% tallow amine ethoxylated with 16 units ethylene oxide and reacted with dimethyl sulphate (Afilan V-4667 manufactured by Clariant), 2.5% phosphate ester of oleyl alcohol (Tryfac 1046K manufactured by Pulcra Chemicals), < 1% sulfonated peanut oil sodium salt (Standapol 1610 manufactured by Pulcra Chemicals), < 0.5% sodium dioctyl sulfosuccinate (Aerosol OT-75% manufactured by Cytek Industries) and the rest water. The batt fiber was carded using the roll top card. Following carding, the fiber was cross-lapped and pre-needled. Multiple batt rolls were made for the needling trials. Needling was then done using the needle loom. On the test items an overlay finish was applied to each layer of batt fiber. The finishes were emulsions in water, and they were applied by spraying the finish on to the top of the batt fiber. DY-4 was comprised of 65% isobutyl stearate (Emerest 2324 manufactured by Pulcra Chemicals), 21% sulfonated peanut oil sodium salt (Standapol 1610 manufactured by Pulcra Chemicals), 8% oleic acid (Emersol 233 manufactured by Pulcra Chemicals), 3% triethanol amine (TEA-85% containing 15% DEA manufactured by The Dow Chemical Company) and 1.5% diethylene glycol (DEG manufactured by The Dow Chemical Company). Water, antimicrobial and potassium hydroxide as a neutralizing agent were also added in small quantities (< 3%). The compositions of the

<table>
<thead>
<tr>
<th>Step</th>
<th>Layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Batt Layer</td>
</tr>
<tr>
<td>2</td>
<td>Batt Layer</td>
</tr>
<tr>
<td>3</td>
<td>Batt Layer</td>
</tr>
<tr>
<td>4</td>
<td>Batt Layer</td>
</tr>
<tr>
<td>5</td>
<td>Batt Layer</td>
</tr>
</tbody>
</table>
finishes from Goulston are proprietary; and therefore, are not known and cannot be disclosed.

Samples of the completed felts were tested by an analytical lab. The results for the control and the three test items are shown in Table 1.

**TABLE 1**

<table>
<thead>
<tr>
<th>Sample</th>
<th>Base</th>
<th>C</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>1 vs C</th>
<th>2 vs C</th>
<th>3 vs C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basis Wt, g/m²²</td>
<td>903</td>
<td>1027</td>
<td>1020</td>
<td>992</td>
<td>13.7%</td>
<td>12.9%</td>
<td>9.8%</td>
<td></td>
</tr>
<tr>
<td>Corrected Wt g/m²²</td>
<td>903</td>
<td>925</td>
<td>928</td>
<td>903</td>
<td>2.4%</td>
<td>2.8%</td>
<td>0.0%</td>
<td></td>
</tr>
<tr>
<td>Air Perm, cfm</td>
<td>190</td>
<td>158</td>
<td>151</td>
<td>174</td>
<td>-16.7%</td>
<td>-20.6%</td>
<td>-8.3%</td>
<td></td>
</tr>
<tr>
<td>Normalized Air Perm</td>
<td>186</td>
<td>159</td>
<td>152</td>
<td>171</td>
<td>-14.7%</td>
<td>-18.4%</td>
<td>-8.3%</td>
<td></td>
</tr>
<tr>
<td>Thickness, mm</td>
<td>5.85</td>
<td>5.55</td>
<td>5.58</td>
<td>5.33</td>
<td>-5.2%</td>
<td>-4.7%</td>
<td>-9.0%</td>
<td></td>
</tr>
<tr>
<td>Normalized Thickness</td>
<td>5.97</td>
<td>5.53</td>
<td>5.54</td>
<td>5.44</td>
<td>-7.4%</td>
<td>-7.2%</td>
<td>-8.9%</td>
<td></td>
</tr>
<tr>
<td>MD Breaking Strength, lbf</td>
<td>158</td>
<td>113</td>
<td>117</td>
<td>115</td>
<td>101</td>
<td>3.7%</td>
<td>1.9%</td>
<td>-10.7%</td>
</tr>
<tr>
<td>CD Breaking Strength, lbf</td>
<td>166</td>
<td>125</td>
<td>122</td>
<td>147</td>
<td>133</td>
<td>-3.0%</td>
<td>17.4%</td>
<td>5.7%</td>
</tr>
</tbody>
</table>

Sample C is Control
Sample 1 is Overlay Finish INVISTA NS-2:
Sample 2 is Overlay Finish - Goulston PS-8717 (25%)
Sample 3 is Made with Overlay Finish - Goulston PS-12520 (20%)
Nominal Basis Wt = 921
Overlay Finish Application =
Sample 1 - 10% by Weight
Samples 2, 3 9% by Weight

The test results are shown as recorded, and also normalized to a basis weight of 921 grams per square meter, the average of samples tested. Normalizing takes into account the effect of the different sample densities. Indications of improved needling efficiency would be lower air permeability and lower thickness at the same nominal
density. It can be seen from the results that versus the control test items #1 and #2 have lower thickness, and lower air permeability. Test item #3 had essentially the same air permeability but significantly lower thickness.

The test results indicate that the needling efficiency was improved by the use of the overspray finish - at least for the first two test items. In other words the properties of control felt (C) can be achieved with fewer needle strokes with the use of an overlay finish of the type specified above for items #1 and #2. The type of finish used for the overlay is important as evidenced by the results for item #3. These do not show the same level of improvement as for items #1 and #2.

The damage the needling does on the base fabric can be seen by comparing the breaking strength data for the base fabric prior to needling to that of the felts after needling. It can be seen that despite the addition of more fiber the breaking strength goes down. This is because the damage done to the base fabric by the needles exceeds the strength provided by the addition of staple fibers to the structure. This illustrates another advantage of improving needling efficiency, less damage to the base fabric. This higher strength improves the dimensional stability of the felt. This is particularly important to seamed felts. Damage caused by needling can result in premature failure of the seam on a paper machine. Item #2 has a higher breaking strength in the cross direction than the other samples. This is another indication of improved bonding efficiency.

**EXAMPLE #2**

A second trial was conducted at the North Carolina State University Nonwovens laboratory to determine whether a proprietary INVISTA finish, DY-4, was superior to the commercially-available Goulston Lurol PS-8717-25% finish, which was the best performing finish from Example #1.

The test set-up was essentially identical to the first trial with the following exceptions.

1) Due to material availability, 15 denier, 3-inch cut length, Type 852 fiber was used instead of T-881. As before, INVISTA NS-28 finish had been applied during fiber production as a spin finish.
2) In addition, since the previous test, the nonwovens laboratory replaced the previous roll-top card with a high-speed, double side carding line by Trutzschler.

3) Foster 40 gage conical needle was used.

As before, the batt was produced through the opening, carding, cross-lapping and pre-needling processes. Five layers of batt were then needle punched, one at a time, into the base fabric to create the felt. Prior to each pass through the needle loom, the finish was applied in the form of a spray to the surface of the batt.

In total, five conditions were tested. All finishes were applied in a 25% finish/75% water emulsion.

1. Control with no overspray.
2. Non-atomized spray of Goulston Lurol PS-8717-25% at an application rate of approximately 30% by wt.
3. Atomized spray of INVISTA DY-4-25% at an application rate of approximately 4.5%.
4. Atomized spray of Goulston Lurol PS-8717-25% at an application rate of approximately 5% by wt.
5. Atomized spray of INVISTA DY-4-25% at an application rate of approximately 12.5% by wt.

For the purposes of this document, the key conditions to be compared are numbers 3 and 4, as this will determine whether the INVISTA DY-4 finish is superior to the Goulston Lurol PS-8717 finish and 3 and 1, which will show the improvement provided by the DY-4 overspray. Samples of each of these conditions were supplied to the analytical laboratory for basis weight, thickness, air permeability and MD/CD strip tensile strength. Density was calculated from the thickness and basis weight results. The summary of the results is tabulated below:
<table>
<thead>
<tr>
<th>Condition</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air Permeability (cfm)</td>
<td>Nominal</td>
<td>240.60</td>
<td>156.1</td>
<td>216.8</td>
<td>218.5</td>
</tr>
<tr>
<td></td>
<td>Normalize d</td>
<td>193.7</td>
<td>222.0</td>
<td>226.1</td>
<td>226.7</td>
</tr>
<tr>
<td>Breaking Strength - MD</td>
<td>Nominal</td>
<td>116.2</td>
<td>102.6</td>
<td>116.3</td>
<td>85.9</td>
</tr>
<tr>
<td>Peak Load (lbf)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Breaking Strength - CD</td>
<td>Nominal</td>
<td>118.4</td>
<td>103.5</td>
<td>129.9</td>
<td>95.4</td>
</tr>
<tr>
<td>Peak Load (lbf)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thickness (m)</td>
<td>Nominal</td>
<td>0.0058</td>
<td>0.0054</td>
<td>0.0052</td>
<td>0.0055</td>
</tr>
<tr>
<td>Basis Wt. (g/m²)</td>
<td>Nominal</td>
<td>789.4</td>
<td>979.6</td>
<td>808.2</td>
<td>817.0</td>
</tr>
<tr>
<td></td>
<td>Normalize d w/ Finish Removed</td>
<td>792.7</td>
<td>786.1</td>
<td>792.7</td>
<td>755.7</td>
</tr>
<tr>
<td>Density (g/cc)</td>
<td>Normalize d</td>
<td>0.137</td>
<td>0.146</td>
<td>0.152</td>
<td>0.143</td>
</tr>
</tbody>
</table>

By specifically comparing conditions 3 and 4, it is apparent that the INVISTA DY-4 finish performed superior to the Goulston Lurol PS-8717 finish.
The conclusion that can be drawn from this data is that for the same number of needle strokes, the felt made with the DY-4 overspray was less permeable stronger and denser than an equivalent felt produced with a similar amount of PS-8717 overspray. The improvement in both MD and CD strip tensile strength can be attributed to better fiber-to-fiber cohesion and bonding during the needling process as a result of the higher fiber-to-fiber friction provided by the DY-4 finish. The increase in density is also related to the frictional characteristics of the DY-4 finish, most likely a combination of better fiber-to-fiber bonding when the fibers are initially pushed through by the needle and better fiber release from the needle during retraction. It can also be clearly seen that the DY-4 finish substantially improved the needling efficiency over the control felt which did not have any overspray, just the original NS-28 spin finish. The table below shows the comparison of results between conditions #3 and #1.

<table>
<thead>
<tr>
<th>Comparison of DY-4 to PS-8717 @ ~ 5% Finish-on-Felt Cond. #3 vs. #4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Permeability</td>
</tr>
<tr>
<td>Breaking Strength - Machine-Direction</td>
</tr>
<tr>
<td>Breaking Strength - Cross-machine-Direction</td>
</tr>
<tr>
<td>Density</td>
</tr>
</tbody>
</table>
Comparison of DY-4 Overspray @ 5% Finish-on-Felt to Control Cond. #3 vs. #1

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Permeability</td>
<td>-7.7%</td>
</tr>
<tr>
<td>Breaking Strength -</td>
<td>0.2%</td>
</tr>
<tr>
<td>Machine-Direction</td>
<td></td>
</tr>
<tr>
<td>Breaking Strength -</td>
<td>9.7%</td>
</tr>
<tr>
<td>Cross-machine-Direction</td>
<td></td>
</tr>
<tr>
<td>Density</td>
<td>11.0%</td>
</tr>
</tbody>
</table>

In this case, the DY-4 overspray provided a significant reduction in air permeability due to the fact that a denser, more compact felt was produced compared to the control without any overspray. It can also be concluded that breaking strength in the cross-machine direction was increased. These observations were a result of the improved frictional characteristics that the DY-4 provided by reducing the fiber-to-metal friction, thus reducing damage to the felt from the needles and enabling easier release of the fiber from the needle; and increasing the fiber cohesion, which improved inter-fiber entanglement during needle penetration.

**EXAMPLE #3**

A third trial was conducted to explore the effect of specific finish components and formulations on felt properties. The isobutyl stearate-based DY-4 has proven to be the most effective needling finish thus far in testing. Test set-up was controlled to be as similar as possible to the second trial.

As before, the batt was produced through the opening, carding, cross-lapping and pre-needling processes. Five layers of batt were then needle punched, one at a time, into the base fabric to create the felt. Prior to each pass through the needle loom, the finish was applied in the form of a spray to the surface of the batt.

Several finishes were evaluated. As before, the finishes were applied as an atomized spray of 25% finish/75% water emulsion. The % finish on felt (wt. of finish/wt. of felt) was between 4 and 5%. Three versions of the DY-4 finish were evaluated along
with other isobutyl stearate-based finish and two other non-isobutyl stearate-based finishes:

2. DY-4B: Same as standard DY-4, except 21% Standapol 1610 was replaced with an equal amount of 50% aqueous solution of ethoxylated triglyceride (POE (200) castor oil 50% active, Standapol 5918 manufactured by Pulcra Chemicals). Standapol 5918 was selected as one would expect it to provide good fiber-to-fiber lubrication and poor fiber-to-metal lubrication, both of which are not considered to be desirable for needle punching.
3. DY-4C: Same as standard DY-4, except 21% Standapol 1610 was replaced with an equal amount of polyoxyethylene (4) lauryl alcohol (Ethal® LA-4 manufactured by Ethox Chemicals). This component was selected to compare to Standapol 5918 as it is a cohesive agent with good fiber-to-metal lubrication. These characteristics should be beneficial for needle punching.
4. NY-18
5. NY-74: 75% refined coconut oil (from Cargill) and 25% oleic acid diester of castor oil (25EO).
6. NS-2: 99.8% random copolymer of 50% EO/50% PO (UCON-50-HB-170 from Dow Chemical) and 0.2% oleic acid (Emersol 233 manufactured by Pulcra Chemicals).

As before, samples of the needle punched felts were submitted to the analytical laboratory for basis weight, thickness, air permeability and MD/CD strip tensile strength. Density was calculated from the thickness and basis weight results. The tables below summarize the results:
The effect of finish components can be seen by directly comparing the felt made with DY-4C finish to the felt made with DY-4B.

This data shows that the felt made with the DY-4C overspray had significantly higher breaking strength in the cross-machine direction and was denser than the felt made with the DY-4B overspray. This data indicates that the POE (4) lauryl alcohol

<table>
<thead>
<tr>
<th>Property</th>
<th>% Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breaking Strength – Machine-Direction</td>
<td>0.4%</td>
</tr>
<tr>
<td>Breaking Strength – Cross-machine-Direction</td>
<td>22.1%</td>
</tr>
<tr>
<td>Density</td>
<td>8.4%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Overspray Finish (applied 4 - 5% by wt.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DY-4</td>
</tr>
</tbody>
</table>

| Breaking Strength - MD Peak Load (lbf) | Nominal | 134.8 | 116.3 | 116.8 | 114.2 | 127.6 | 113.7 |
| Breaking Strength - CD Peak Load (lbf) | Nominal | 134.8 | 110.8 | 142.2 | 150.7 | 95.6  | 129.4 |
| Thickness (m) | Nominal | 0.0062 | 0.0067 | 0.0062 | 0.0067 | 0.0063 | 0.0068 |
| Basis Wt. (g/m²) | Nominal | 872.6 | 858.2 | 869.2 | 911.2 | 878.6 | 938.6 |
| Density (g/cc) | Normalized w/ Finish Removed | 846.6 | 834.2 | 845.6 | 888.6 | 847.8 | 913.7 |
| Density (g/cc) | Normalized | 0.137 | 0.125 | 0.136 | 0.133 | 0.134 | 0.134 |
component within the DY-4C finish provided better performance than the 50% active POE (200) castor oil component in DY-4B. It can be concluded that the increase in felt strength and density is the result of better fiber entanglement and stronger mechanical bonding, which supports the assertion that increasing fiber-to-fiber friction and reducing fiber-to-metal friction will improve needle punching efficiency.

It is also clear that isobutyl stearate-based finishes are very well suited for improving needling bonding to increase felt strength, particularly in the cross-machine direction.

<table>
<thead>
<tr>
<th>Finish</th>
<th>Isobutyl Stearate-based</th>
<th>NY-18</th>
<th>Non-Isobutyl Stearate-based</th>
</tr>
</thead>
<tbody>
<tr>
<td>DY-4</td>
<td>134.8</td>
<td>150.7</td>
<td>NY-74</td>
</tr>
<tr>
<td>DY-4C</td>
<td>142.2</td>
<td></td>
<td>95.6</td>
</tr>
<tr>
<td>NS-2</td>
<td>129.4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

This is likely due to the low viscosity of isobutyl stearate, as it is known that low viscosity finishes provide good hydrodynamic lubrication, which is synonymous with low fiber-to-metal friction. In this testing, as well as previous testing, the DY-4 finish consistently out-performed the other finishes to provide better fiber bonding during needle-punching.

**EXAMPLE #4**

A fourth trial was conducted to run additional materials that would be expected to have favorable effects on needling performance based on known viscosity and/or frictional properties. Test set-up was controlled to be as similar as possible to the second and third trials and the batt material produced during the third trial was used during this one.

As before, five layers of batt were needle punched, one at a time, into the base fabric to create the felt. Prior to each pass through the needle loom, the finish was applied in the form of a spray to the surface of the batt.
Several finishes were evaluated. As before, the finishes were applied as a spray of 25% finish/75% water emulsion. The % finish on felt (wt. of finish/wt. of batt) was between 5 and 7%. The DY-4 and NS-2 finishes were evaluated again along with other finishes that were predicted to provide favorable needling performance:


2. Standard NS-2: 99.8% random copolymer of 50% EO/50% PO (UCON-50-HB-170 from Dow Chemical) and 0.2% oleic acid (Emersol 233 manufactured by Pulcra Chemicals).

3. NS-2B: Same as standard NS-2, except UCON-50-HB-170 from Dow Chemical was replaced with a block copolymer of 10% EO/90% PO (Pluronic® L-31 from BASF). This material was selected as one would expect it to provide good fiber-to-metal lubrication.

4. NS-2C: 35% active polydimethylsiloxane emulsion. This material was selected since its fiber-to-metal frictional properties are well-suited for needle punching as the recommended applications include sewing thread and needle lubrication.

As before, samples of the needle punched felts were submitted to the analytical laboratory for basis weight, thickness, air permeability and MD/CD strip tensile strength. Density was calculated from the thickness and basis weight results. The table below summarizes the results:
Overspray Finish (applied 5 - 7% by wt.)

<table>
<thead>
<tr>
<th>Air Perm (cfm)</th>
<th>Control</th>
<th>DY-4</th>
<th>NS-2</th>
<th>NS-2B</th>
<th>NS-2C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal</td>
<td>252.2</td>
<td>191.0</td>
<td>223.5</td>
<td>222.7</td>
<td>216.6</td>
</tr>
<tr>
<td>Normalized</td>
<td>221.5</td>
<td>244.6</td>
<td>241.2</td>
<td>237.2</td>
<td></td>
</tr>
<tr>
<td>% Change vs. Control</td>
<td>-12.2%</td>
<td>-3.0%</td>
<td>-4.4%</td>
<td>-6.0%</td>
<td></td>
</tr>
</tbody>
</table>

| MD Strip Tensile | Nominal | 115.8 | 123.1 | 111.5 | 113.2 | 124.5 |
| % Change vs. Control | 6.3% | -3.7%| -2.2%| 7.5% |

| CD Strip Tensile | Nominal | 101.3 | 116.1 | 105.7 | 107.5 | 114.8 |
| % Change vs. Control | 14.6% | 4.3%| 6.1%| 13.3% |

| Thickness (m) | Nominal | 0.0062 | 0.0058 | 0.0058 | 0.0057 | 0.0057 |
| % Change vs. Control | -5.4% | -6.3%| -7.1%| -7.6% |

| Basis Wt. (g/m²) | Nominal | 821.6 | 952.8 | 899.2 | 889.8 | 899.6 |
| Normalized w/ Finish Subtracted | 916.5 | 872.8 | 859.0 | 869.6 |

| Density (g/cc) | Normalized | 0.133 | 0.157 | 0.151 | 0.150 | 0.152 |
| % Change vs. Control | 17.9% | 13.4%| 12.6%| 14.5% |

It can be seen that all four finishes provide some benefits during the needling process. DY-4 and NS-2, which have both been tested previously, performed consistently with previous trials. Properties of the felts made with NS-2B and NS-2C both showed evidence that needling efficiency was increased.
The following effects were noted for all four of these finishes: decreased air permeability, increased strip tensile strength in the cross-web direction and increased density. All of these changes indicate that the resultant felts, which were made with the same batt material, base fabric and needling process as the control, were stronger and had a tighter structure, both signals that needling was more efficient. DY-4 continued to stand out as the best performer. NS-2C, a silicone polymer emulsion, performed very well as well. This was expected as the material is used for thread and needle lubrication in sewing operations, which is a similar application to needle punching.

Low fiber-to-metal friction can be also achieved through careful selection of finish lubricants. Esters of long-chain fatty acids are one such material known to provide low fiber-to-metal friction. This includes polyethylene oxides esters of (8) stearate, (20) stearyl alcohol, (9) laurate, (4) lauryl alcohol, (23) lauryl alcohol, (10) cetyl alcohol to name a few. It is knowledge in the art that lubricant viscosity and hydrodynamic friction

<table>
<thead>
<tr>
<th>% Change Vs. Control</th>
<th>DY-4</th>
<th>NS-2</th>
<th>NS-2B</th>
<th>NS-2C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Perm</td>
<td>-12.2%</td>
<td>-3.0%</td>
<td>-4.4%</td>
<td>-6.0%</td>
</tr>
<tr>
<td>MD Strip Tensile</td>
<td>6.3%</td>
<td>-3.7%</td>
<td>-2.2%</td>
<td>7.5%</td>
</tr>
<tr>
<td>CD Strip Tensile</td>
<td>14.6%</td>
<td>4.3%</td>
<td>6.1%</td>
<td>13.3%</td>
</tr>
<tr>
<td>Density</td>
<td>17.9%</td>
<td>13.4%</td>
<td>12.6%</td>
<td>14.5%</td>
</tr>
</tbody>
</table>

Low fiber-to-metal friction can be also achieved through careful selection of finish lubricants. Esters of long-chain fatty acids are one such material known to provide low fiber-to-metal friction. This includes polyethylene oxides esters of (8) stearate, (20) stearyl alcohol, (9) laurate, (4) lauryl alcohol, (23) lauryl alcohol, (10) cetyl alcohol to name a few. It is knowledge in the art that lubricant viscosity and hydrodynamic friction
are directly proportional and thus the viscosity of the lubricant over an appropriate range
of temperatures should be considered when selecting finish components.

Compositions of overlay fiber finish (or the second fiber finish) may include:

1. 10 - 90% primary lubricant, 0 - 50% secondary lubricant, 0 - 33% tertiary
lubricant, 0 - 15% surfactant, 0 - 10% emulsifier, 0 - 5% water, 0 - 5%
potassium hydroxide;
   a. Where primary lubricant is isobutyl stearate
   b. Where secondary lubricant is sulfated peanut oil
   c. Where tertiary lubricant is oleic acid
   d. Where surfactant is triethanol amine
   e. Where emulsifier is diethylene glycol

2. 10 - 90% primary lubricant, 0 - 50% secondary lubricant, 0 - 33% tertiary
lubricant, 0 - 15% surfactant, 0 - 10% emulsifier, 0 - 5% water, 0 - 5%
potassium hydroxide;
   a. Where primary lubricant is isobutyl stearate
   b. Where secondary lubricant is POE (4) lauryl alcohol
   c. Where tertiary lubricant is oleic acid
   d. Where surfactant is triethanol amine
   e. Where emulsifier is diethylene glycol

3. 10 - 90% primary lubricant, 0 - 50% secondary lubricant, 0 - 25% anti-static
agent, 0 - 25% surfactant;
   a. Where primary lubricant is isobutyl stearate
   b. Where secondary lubricant is PEG-600 monolaurate
   c. Where anti-static agent is acid phosphate ester of oleyl alcohol
   d. Where surfactant is sodium dioctyl sulfosuccinate

4. 10 - 100% primary lubricant, 0 - 50%, secondary lubricant
   a. Where primary lubricant is random co-polymer of ethylene
      oxide/propylene oxide
   b. Where secondary lubricant is oleic acid
5. 10 – 100% primary lubricant, 0 - 50%, secondary lubricant
   a. Where primary lubricant is block co-polymer of ethylene oxide/propylene oxide
   b. Where secondary lubricant is oleic acid
6. 100% primary lubricant
   a. Where primary lubricant is silicone polymer or copolymer, which may be in an emulsion.

Specific examples of compositions of overlay fiber finish include, but are not limited to:

1. 63% primary lubricant, 21% secondary lubricant, 8% tertiary lubricant, 3.5% surfactant, 1.5% emulsifier, 1.5% water, 1.5% potassium hydroxide;
   a. Where primary lubricant is isobutyl stearate
   b. Where secondary lubricant is sulfated peanut oil
   c. Where tertiary lubricant is oleic acid
   d. Where surfactant is triethanol amine
   e. Where emulsifier is diethylene glycol
2. 63% primary lubricant, 21% secondary lubricant, 8% tertiary lubricant, 3.5% surfactant, 1.5% emulsifier, 1.5% water, 1.5% potassium hydroxide;
   a. Where primary lubricant is isobutyl stearate
   b. Where secondary lubricant is POE (4) lauryl alcohol
   c. Where tertiary lubricant is oleic acid
   d. Where surfactant is triethanol amine
   e. Where emulsifier is diethylene glycol
3. 64% primary lubricant, 13% secondary lubricant, 13% anti-static agent, 10% surfactant;
   a. Where primary lubricant is isobutyl stearate
   b. Where secondary lubricant is PEG-600 monolaurate
   c. Where anti-static agent is acid phosphate ester of oleyl alcohol
   d. Where surfactant is sodium dioctyl sulfosuccinate
4. 99.8% primary lubricant, 0.02%, secondary lubricant
   a. Where primary lubricant is random co-polymer of 50% ethylene oxide/50% propylene oxide
   b. Where secondary lubricant is oleic acid
5. 99.8% primary lubricant, 0.02%, secondary lubricant
   a. Where primary lubricant is block co-polymer of 10% ethylene oxide/90% propylene oxide
   b. Where secondary lubricant is oleic acid
6. 100% primary lubricant
   a. Where primary lubricant is a 35% active polydimethylsiloxane emulsion

Further examples of compositions useful for the overlay (second) fiber finish may include:
1. 10 - 90% primary lubricant, 0 - 50% secondary lubricant, 0 - 33% tertiary lubricant, 0 - 15% surfactant, 0 - 10% emulsifier, 0 - 5% water, 0 - 5% potassium hydroxide;
   a. Where primary lubricant is isobutyl stearate
   b. Where secondary lubricant is sulfated peanut oil
   c. Where tertiary lubricant is oleic acid
   d. Where surfactant is triethanol amine
   e. Where emulsifier is diethylene glycol
2. Same finish as finish 1, but primary lubricant is random co-polymer of ethylene oxide/propylene oxide
3. Same finish as finish 1, but primary lubricant is block co-polymer of ethylene oxide/propylene oxide
4. Same finish as finish 1, but primary lubricant is a silicone polymer or copolymer, such as polydimethylsiloxane
5. 10 - 90% primary lubricant, 0 - 50% secondary lubricant, 0 - 33% tertiary lubricant, 0 - 15% surfactant, 0 - 10% emulsifier, 0 - 5% water, 0 - 5% potassium hydroxide;
   a. Where primary lubricant is isobutyl stearate
   b. Where secondary lubricant is POE (4) lauryl alcohol
Where tertiary lubricant is oleic acid
d. Where surfactant is triethanol amine
e. Where emulsifier is diethylene glycol

6. Same finish as finish 5, but primary lubricant is random copolymer of ethylene oxide/propylene oxide.

7. Same finish as finish 5, but primary lubricant is a block copolymer of ethylene oxide/propylene oxide

8. Same finish as finish 5, but primary lubricant is a silicone polymer or copolymer, such as polydimethylsiloxane

9. 10 - 90% primary lubricant, 0 - 50% secondary lubricant, 0 - 33% tertiary lubricant, 0 - 15% surfactant, 0 - 10% emulsifier, 0 - 5% water, 0 - 5% potassium hydroxide;
   a. Where primary lubricant is isobutyl stearate
   b. Where secondary lubricant is PEG-600 monolaurate
   c. Where tertiary lubricant is oleic acid
d. Where surfactant is triethanol amine
e. Where emulsifier is diethylene glycol

10. Same finish as finish 9, but primary lubricant is random copolymer of ethylene oxide/propylene oxide.

11. Same finish as finish 9, but primary lubricant is a block copolymer of ethylene oxide/propylene oxide

12. Same finish as finish 9, but primary lubricant is a silicone polymer or copolymer, such as polydimethylsiloxane

13. 10 - 90% primary lubricant, 0 - 50% secondary lubricant, 0 - 25% anti-static agent, 0 - 25% surfactant;
   a. Where primary lubricant is isobutyl stearate
   b. Where secondary lubricant is PEG-600 monolaurate
   c. Where anti-static agent is acid phosphate ester of oleyl alcohol
d. Where surfactant is sodium dioctyl sulfosuccinate

14. Same finish as finish 13, but primary lubricant is random copolymer of ethylene oxide/propylene oxide
15. Same finish as finish 13, but primary lubricant is a block copolymer of ethylene oxide/propylene oxide

16. Same finish as finish 13, but primary lubricant is a silicone polymer or copolymer, such as polydimethylsiloxane

17. 10 - 90% primary lubricant, 0 - 50% secondary lubricant, 0 - 25% anti-static agent, 0 - 25% surfactant;
   a. Where primary lubricant is isobutyl stearate
   b. Where secondary lubricant is sulfated peanut oil
   c. Where anti-static agent is acid phosphate ester of oleyl alcohol
   d. Where surfactant is sodium dioctyl sulfosuccinate

18. Same finish as finish 17, but primary lubricant is random copolymer of ethylene oxide/propylene oxide

19. Same finish as finish 17, but primary lubricant is a block copolymer of ethylene oxide/propylene oxide

20. Same finish as finish 17, but primary lubricant is a silicone polymer or copolymer, such as polydimethylsiloxane

21. 10 - 90% primary lubricant, 0 - 50% secondary lubricant, 0 - 25% anti-static agent, 0 - 25% surfactant;
   a. Where primary lubricant is isobutyl stearate
   b. Where secondary lubricant is POE (4) lauryl alcohol
   c. Where anti-static agent is acid phosphate ester of oleyl alcohol
   d. Where surfactant is sodium dioctyl sulfosuccinate

22. Same finish as finish 21, but primary lubricant is random copolymer of ethylene oxide/propylene oxide

23. Same finish as finish 21, but primary lubricant is block copolymer of ethylene oxide/propylene oxide

24. Same finish as finish 21, but primary lubricant is a silicone polymer or copolymer, such as polydimethylsiloxane

25. 10 - 100% primary lubricant, 0 - 50%, secondary lubricant
   a. Where primary lubricant is random co-polymer of 50% ethylene oxide/50% propylene oxide
Where secondary lubricant is oleic acid

26. Same finish as finish 25, but primary lubricant is isobutyl stearate

27. Same finish as finish 25, but primary lubricant is block copolymer of ethylene oxide/propylene oxide

28. Same finish as finish 25, but primary lubricant is a silicone polymer or copolymer, such as polydimethylsiloxane

General descriptions of the lubricants useful for inclusion in the overlay finish are described below, performance of the finishes in needling is based on the frictional properties. The other components (anti-static agents, emulsifiers, surfactants, etc.) may help to improve the usability of a finish. One or more of these may be included in any finish composition.

Finish formulations

10 - 100% primary lubricant(s), 0 - 90% other finish components, where other finish components may include, secondary lubricants in addition to the primary lubricant(s). Primary lubricants listed below can be combined such that more than one primary lubricant makes up the 10 - 100% composition.

Where primary lubricants can be selected from:

1. Isobutyl stearate or other esters of stearic acid (other long-chain fatty acid esters would work as well)

2. Random copolymer of ethylene oxide/propylene oxide, typically 50% EO/50% PO or 75% EO/25% PO.

3. Block copolymer of ethylene oxide/propylene oxide

4. Silicone polymer or copolymer, including emulsions of these materials

Where secondary lubricants can be selected from the following list, which is not meant to be limiting, but provide examples of a few materials that have been effective:

1. Sulfated peanut oil

2. POE (4) lauryl alcohol

3. Oleic acid

4. PEG-600 monolaurate
Overlay fiber finish friction requirement:
Overlay finishes selected from overlay finish formulations that possess a fiber-to-metal hydrodynamic friction coefficient of less than 1.00, preferably less than 0.90. Measured using friction testing process described in NOI.

Overlay finish application method
Not sure if this needs to be specified in claims, but finish can be applied neat (pure finish) or as a finish-water emulsion. Finish-water emulsion can be any concentration. For actual testing, finishes were applied at 25% concentration.

Improvement in needling efficiency provided by overlay finish
Improved needling efficiency described as the % difference in one or more properties of needled nonwoven felt with overlay finish compared to needled nonwoven felt without overlay finish. Needled nonwoven felts with and without overlay finish are fabricated using same fiber, same batt making processes and same needling process.

1. Increase in tensile strength of at least 5% in cross-machine direction of felt
2. Increase in tensile strength of at least 5% in machine direction of felt
3. Increase in density of felt of at least 5%
4. Decrease in air permeability of at least 5%

While the present invention has been described in an illustrative manner, it should be understood that the terminology used is intended to be in a nature of words or description rather than of limitation. Furthermore, while the present invention has been described in terms of several illustrative embodiments, it is to be appreciated that those skilled in the art will readily apply these teachings to other possible variations of the invention.
Claims:

1. A method for preparing a needle punched nonwoven fabric comprising:
   (a) preparing a first fiber batt from an array of fibers including:
       (1) applying a first fiber finish to an array of fibers; and
       (2) combining said fibers to provide a substantially uniformly aligned fibers in a cohesive web;
   (b) applying a second fiber finish after preparation of said first fiber batt; and
   (c) needle punching said first fiber batt to a base layer;

   wherein said first fiber finish exhibits a fiber-to-metal coefficient of friction for said first fiber finish, and said second fiber finish provides a lower fiber-to-metal coefficient of friction for said second fiber finish compared to said fiber-to-metal coefficient of friction for said first fiber finish.

2. The method of claim 1, further comprising needle punching said first fiber batt to one or more additional fiber batts.

3. The method of claim 1, wherein said first fiber finish is selected from any of known finish formulations that provide good carding performance typically containing a plurality of components. The components are selected from one or more of the following materials: lubricants, such as mineral oils, fatty acids from natural products, waxes, silicones, ethoxylated alcohols, and PEG esters of fatty acids; anti-static agents, such as quaternary amines and phosphate alcohols; emulsifiers; surfactants; softeners; biocides; anti-foaming agents; and other additives.

4. The method of claim 1, wherein said first fiber finish is applied in an amount of about 0.05% to about 5% based on the weight of the first fiber batt.

5. The method of claim 1, wherein said second fiber finish is applied in an amount of about 0.1% to about 25% based on the weight of said needle punched nonwoven fabric.
6. The method of claim 1, wherein said second fiber finish is selected from any number of finish formulations wherein said finish formulation contains one or more constituents known to provide good fiber-to-metal lubrication as the primary constituent, which is greater than 10% by weight of the total concentrated finish formulation. Said constituents include: long-chain fatty acid esters, preferably those based on stearic acid or other esters with chain lengths of 12 carbons or longer; polymeric materials, such as waxes and silicones; and co-polymeric materials, such as random and block copolymers of ethylene oxide and propylene oxide.

7. The method of claim 1, wherein said second fiber finish is selected from any number of finish formulations wherein said finish formulation contains a primary constituent, which is greater than 10% by weight of the total concentrated finish formulation, with viscosity of less than 90 centistokes at 25°C. Preferably said primary constituent has viscosity of less than 20 centistokes at 25°C.

8. The method of claim 1, wherein said second fiber finish is selected from any number of finish formulations wherein said finish formulation exhibits a fiber-to-metal friction coefficient that is at least 10% less than the fiber-to-metal friction coefficient of said first fiber finish. Preferably said fiber-to-metal friction coefficient that is at least 25% less than the fiber-to-metal friction coefficient of said first fiber finish.

9. A method for selecting suitable fiber finishes for preparation of a needle punched nonwoven fabric comprising:
   (a) preparing a first fiber batt including a first fiber finish;
   (b) applying a second fiber finish to said first fiber batt;
   (c) needle punching said first fiber batt to a base layer to provide a needle punched nonwoven fabric; and
   (d) evaluating said needle punched nonwoven fabric.

10. The method of claim 9, further comprising needle punching said first fiber batt to one or more additional fiber batts.
11. The method of claim 9, wherein said second fiber finish is selected by chemical identity of the constituents in the formulation.

12. The method of claim 11, wherein said second fiber finish primary constituent is a long-chain fatty acid ester with chain length of 12 carbons or longer.

13. The method of claim 11, wherein said second fiber finish primary constituent is a microcrystalline wax.

14. The method of claim 11, wherein said second fiber finish primary constituent is a silicone polymer or copolymer.

15. The method of claim 11, wherein said second fiber finish primary constituent is a random ethylene oxide-propylene oxide copolymer.

16. The method of claim 11, wherein said second fiber finish primary constituent is a block ethylene oxide-propylene oxide copolymer.

17. The method of claim 9, wherein said second fiber finish is selected by the measurement of the viscosity of one or more of the primary constituents, as defined by the constituent comprising 10% or greater by weight of the total concentrated finish formulation. The said second finish formulation would be expected to perform well if one or more of the primary constituents have a viscosity of less than 90 centistokes at 25°C, preferably less than 20 centistokes at 25°C.

18. The method of claim 9, wherein said second fiber finish is selected by measuring the fiber-to-metal coefficient of friction of said first fiber finish and measuring the fiber-to-metal coefficient of friction of said second finish and comparing the two measurements. The said second finish formulation would be expected to perform well if the measured fiber-to-metal coefficient of friction of said second fiber finish is at least 10% less than
the measured fiber-to-metal coefficient of friction of said first fiber finish, preferably at least 25% less.

19. The method of claim 9, wherein said evaluating includes using analytical test methods to characterize the structure and properties of the said needle punched nonwoven fabric and comparing these results to a control needle punched nonwoven fabric that was produced without the use of a second fiber finish, but with all other processes for preparing and needling the fabric being carried out the same. These test methods could include measurements of air permeability, tensile strength in the longitudinal direction, tensile strength in the transverse direction, fabric density,

20. The method of claim 9, wherein said evaluating includes measuring performance of said needle punched nonwoven fabric on simulated, pilot-scale paper machine process and comparing this performance to a control needle punched nonwoven fabric that was produced without the use of a second fiber finish. Performance of said needle punched nonwoven fabric can be measured by fiber loss during simulated operation, retained tensile strength in longitudinal direction following simulated operation, retained tensile strength in transverse direction following simulated operation, change in caliper of said needle punched nonwoven fabric following simulated operation, change in density of said needle punched nonwoven fabric following simulated operation, capability of said needle punched nonwoven fabric of transmitting water through its structure during simulated operation.

21. A method for preparing a needle punched nonwoven fabric comprising:
   (a) preparing a first fiber batt from an array of fibers including combining said fibers to provide a substantially uniformly aligned fibers in a cohesive web;
   (b) applying an overlay fiber finish after preparation of said first fiber batt; and
   (c) needle punching said first fiber batt to a base layer;
wherein said overlay fiber finish provides a sufficiently low fiber-to-metal coefficient of friction.
INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2013/073641

A. CLASSIFICATION OF SUBJECT MATTER
D04H 1/498(2012.01)i, D04H 1/4374(2012.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
D04H 1/498; D04H 3/10; B32B 5/26; D04H 1/48; D02G 1/20; B32B 5/06; D04H 3/00; F16D 69/00; B32B 7/08; D04H 1/4374

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & Keywords: needle, punched, nonwoven fabric, fiber finish, fiber-to-metal coefficient, friction

C. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
<thead>
<tr>
<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>JP 2002-069821 A (TEIJIN LTD. et al.) 08 March 2002 See abstect ; paragraphs [0009]- [0015] ; and claims 1-15.</td>
<td>1-21</td>
</tr>
<tr>
<td>A</td>
<td>US 4418104 A (KIVOMURA, Y. et al.) 29 November 1983 See column 6, lines 22-31; and claims 1, 7.</td>
<td>1-21</td>
</tr>
<tr>
<td>A</td>
<td>US 5989375 A (BORTZ, D. N.) 23 November 1999 See column 17, lines 44-63 ; claim 1; and figures 1, 2.</td>
<td>1-21</td>
</tr>
</tbody>
</table>

Further documents are listed in the continuation of Box C. See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search 31 March 2014 (31.03.2014)

Date of mailing of the international search report 31 March 2014 (31.03.2014)

Name and mailing address of the ISA/KR
International Application Division
Korean Intellectual Property Office
189 Cheongna-ro, Seo-gu, Daejeon Metropolitan City, 302-701, Republic of Korea
Facsimile No. +82-42-472-7140

Authorized officer
CHOL Sung Hee
Telephone No. +82-42-481-8740

FormPCT/ISA/210 (second sheet) July 2009
<table>
<thead>
<tr>
<th>Patent document cited in search report</th>
<th>Publication date</th>
<th>Patent family member(s)</th>
<th>Publication date</th>
</tr>
</thead>
<tbody>
<tr>
<td>JP 2002-069821 A</td>
<td>08/03/2002</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>JP 2010-515837 A</td>
<td>13/05/2010</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TW 200912071 A</td>
<td>16/03/2009</td>
</tr>
<tr>
<td></td>
<td></td>
<td>WO 2008-084233 Al</td>
<td>17/07/2008</td>
</tr>
<tr>
<td>US 4418104 A</td>
<td>29/11/1983</td>
<td>CA 1117285 Al</td>
<td>02/02/1982</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DE 3071412 D1</td>
<td>20/03/1986</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EP 0028015 Al</td>
<td>06/05/1981</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EP 0028015 B1</td>
<td>05/02/1986</td>
</tr>
<tr>
<td></td>
<td></td>
<td>JP 56-063057 A</td>
<td>29/05/1981</td>
</tr>
<tr>
<td></td>
<td></td>
<td>JP 59-027420 B</td>
<td>05/07/1984</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CN 100359073 C</td>
<td>02/01/2008</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CN 1446277 A</td>
<td>01/10/2003</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EP 1298240 Al</td>
<td>02/04/2003</td>
</tr>
<tr>
<td></td>
<td></td>
<td>JP 2001-355173 A</td>
<td>26/12/2001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TW 593822 B</td>
<td>21/06/2004</td>
</tr>
<tr>
<td></td>
<td></td>
<td>WO 01-96640 Al</td>
<td>20/12/2001</td>
</tr>
</tbody>
</table>