

Feb. 10, 1970

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 PATTERNED NONWOVEN FABRIC OF HYDRAULICALLY ENTANGLED
 TEXTILE FIBERS AND REINFORCING FIBERS
 Filed Jan. 6, 1967

3,494,821

FIG. 1

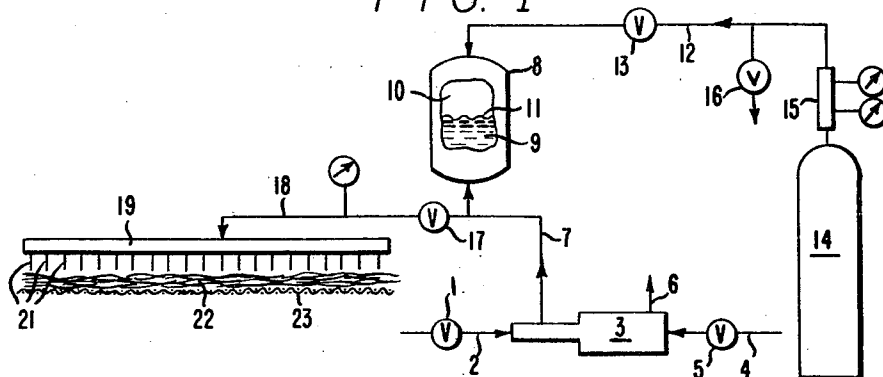
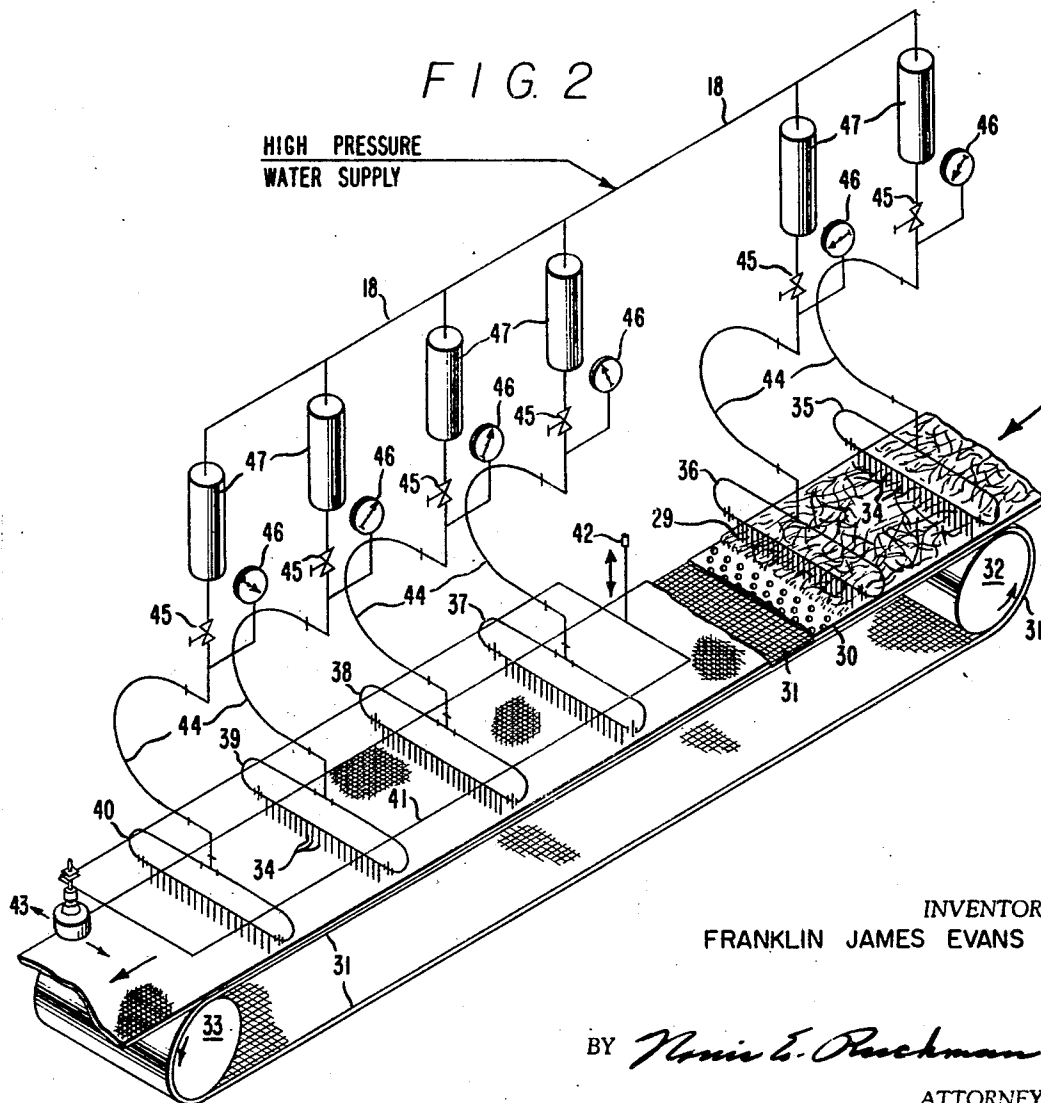


FIG. 2



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PATTERNED NONWOVEN FABRIC OF HYDRAULICALLY ENTANGLED TEXTILE FIBERS AND REINFORCING FIBERS

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Continuation-in-part of applications Ser. No. 299,805, Aug. 5, 1963, Ser. No. 391,641, Aug. 24, 1964, Ser. No. 442,251, Mar. 24, 1965, Ser. No. 462,169, June 8, 1965, Ser. No. 462,183, June 8, 1965, and Ser. No. 550,209, May 16, 1966. This application Jan. 6, 1967, Ser. No. 607,748

Int. Cl. B32d 5/02; D21f 11/14

U.S. Cl. 161—169

6 Claims

ABSTRACT OF THE DISCLOSURE

Nonwoven fabrics of highly entangled staple fibers reinforced with fibers or strands (continuous filaments or yarns) are produced by assembling layers of reinforcing strands and staple-length textile fibers on a patterning member and hydraulically entangling the fibers by high energy treatment with liquid streams of very small diameter formed at unusually high pressures. Upon removal from the patterning member, the product is strong and durable without further treatment. Fabrics may be prepared to resemble woven fabrics in appearance and properties such as strength, hand, extensibility and resilience (tensile recovery).

CROSS-REFERENCES TO RELATED APPLICATIONS

This is a continuation-in-part of my applications Ser. No. 299,805 filed Aug. 5, 1963, Serial No. 391,641 filed Aug. 24, 1964, Ser. No. 442,251 filed Mar. 24, 1965, Ser. No. 462,169 filed June 8, 1965, Ser. No. 462,183 filed June 8, 1965, and Ser. No. 550,209 filed May 16, 1966, all now abandoned.

This invention relates to new and improved nonwoven fabrics. More particularly it relates to nonwoven fabrics of textile-like pattern reinforced with fibers and relatively continuous strands.

The reinforcement of nonwoven webs by warp sheets, woven fabrics, bonded scrim, etc., is old in the art. However, the prior art products have had to resort to felting needle punching or bonding by adhesives, thermal fusion, or solvent fusion to attain even a minimum degree of integrity of the final webs. Such bonding has detracted from the textile-like aesthetic properties of the products by making them relatively stiff, harsh and nonabsorbent. The use of felting or needle punching is restricted to relatively high weight webs and results in an increasingly stiff, unpatterned web as the integrity of the web is increased by further treatment. Yarn-reinforced, fluid-patterned nonwoven fabrics of the prior art have lacked integrity, e.g., the surface stability and bias tensile strength of textile fabrics, and require binders or needle punching for development of functional properties.

The present invention provides strong, durable, nonwoven fabrics which resemble textile fabrics in their appearance, hand, resistance to yield and recovery from strain. Fabric patterned to resemble conventional woven fabric may be provided.

In general, the products prepared as illustrated in Examples I to XIV are textile-like nonwoven fabrics of staple-length textile fibers highly entangled in a repeating pattern of entangled regions and reinforced with 3% to 90% of substantially continuous fibrous strands, based on the weight of the fabric, the fiber entanglement frequency for non-bonded fabric being at least 10 per inch with a

fiber entanglement completeness of at least 0.5, and the fiber 90/0 ratio being at least 0.3 when tested as described later. Preferably the reinforcing strands constitute 10% to 70% of the weight of the fabric.

The above products are produced by assembling a layer of staple-length textile fibers on a layer of substantially continuous fibrous strands, supporting the assembly on an apertured supporting member for treatment, jetting liquid supplied at pressures of at least 200 pounds per square inch to form fine liquid streams having over 23,000 energy flux in foot-pounds/inch² second at the treatment distance, and traversing the supported assembly with the streams until a total energy of at least 0.2 horsepower-hours per pound of treated fabric has been applied to entangle the fibers at an entanglement frequency of at least 10 per inch with a fiber entanglement completeness of at least 0.5. Preferably the liquid streams are essentially columnar streams which are spaced 10 to 100 per inch in line and are substantially parallel to each other. Liquid streams which are formed by orifices having diameters of 3 to 15 mils are preferred. For products which most closely resemble conventional woven fabrics, a preferred supporting member is a woven wire screen.

In the drawing, which illustrates equipment for carrying out the above process,

FIGURE 1 is a schematic view of a simple form of apparatus, and

FIGURE 2 is a schematic isometric view of an apparatus for continuous production of the reinforced nonwoven fabrics.

By the expression "substantially continuous fibrous strands" is included separate continuous filaments, multiple continuous filament yarns, and spun staple yarns. One important aspect of these filaments or yarns is their free length in the composite web. The use of straight continuous filaments (as separate filaments or in a yarn) or spun yarns or straight staple fibers, which have little or no free length, affords a product wherein the filaments or yarns are themselves not interentangled, but serve as tie-points for entangled staple fibers. By using crimped separate continuous filaments, or crimped, textured or bulked multiple continuous filament yarns, the free length of the filaments is increased and the amount of inter-entangling with other filaments and/or staple fibers is increased.

The continuous fibrous strands (filaments or yarns) may be present in the form of a simple warp sheet wherein the members are substantially parallel. A second warp sheet can be placed above the first at right angles to it to give a crossed warp. If desired, two warps can be inclined at any angle. Multiple warps can be used which are in contiguous planes or are separated by layers of staple in the initial assembly before treatment. Both the type of fiber employed and its concentration for reinforcement strongly influence properties of the composite structure such as tensile strength, modulus and/or tensile recovery. The use of a crimped filament or yarn (e.g., a gear-crimped yarn) provides a stretchable fabric with a low initial modulus for the elongation needed to straighten the crimp, an increased tensile strength and improved fabric-like drape.

The continuous length filaments or yarns may be present in the form of an isotropic or unoriented array, as by a random laydown of fibers. Such a random reinforcing element affords form stability by an increased tensile recovery or yield resistance in all directions. Tensile strengths of such products are generally increased but the moduli are relatively unaffected by the presence of the reinforcing elements.

The invention also comprehends nonwoven fabrics of types illustrated in Examples XV and XVI. These differ

from the products previously defined in being reinforced with staple fibers which have not been spun into yarns. They are prepared by assembling at least one layer of staple-length textile fibers, which are relatively easily entangled, with at least one layer of staple reinforcing fibers which have a length of at least two inches and are relatively difficult to entangle, and treating the assembly as described above. In the resulting product the textile fibers are highly entangled with each other and are entangled around the reinforcing fibers, but the reinforcing fibers are not entangled with each other. The product is characterized by a mean fiber entanglement completeness of at least 0.5 (the geometric mean of measurements in two fabric directions at right angles), and a fiber verticality of at least 0.3 as measured by the 90/0 ratio test. The textile fibers may be from 10% to 97% of the total weight of the fibers present, and are preferably 30% to 90% of the fabric weight.

The important aspect of the reinforcing fibers is their resistance to entangling. Fiber characteristics which govern this include composition, denier per filament, fiber length, and free length due to crimp or non-linearity. For otherwise equal conditions, polyester, rayon or cotton fibers are more easily entangled than 66-nylon fibers, and poly-acrylonitrile or polypropylene fibers are more difficult to entangle than 66-nylon fibers. For fibers of the same composition and length, small denier fibers are more easily entangled than higher deniers. When using the same fiber composition and denier shorter fibers are more readily entangled than longer fibers, and fibers with higher free length are more easily entangled than lower free length or straight fibers.

All types of fibers are suitable for use as the "staple-length textile fibers"; they may have a length of from about 6 mm. to 15 cm. and deniers of from about 0.5 to about 10. The staple fibers are conveniently used as carded webs or random webs. Blends of different lengths, deniers and/or compositions may be used.

Useful products can also be made by the substitution of a highly crimped continuous filament web for the staple fiber layer in the process.

Both the staple fibers and the fibers constituting the continuous fibrous strands may be natural or synthetically produced, single component or multicomponent, straight or crimped or possess a latent ability to elongate, crimp, or shrink upon subsequent treatments such as by heating. All manner of novel fabrics can be made by different combinations of the staple fibers and the reinforcing fibers.

The appearance of the products of this invention as made, i.e., before any after-treatments such as heating to crimp, shrink or elongate fibers, etc., depends upon the weight of the fabric and to a greater extent upon the nature of the patterning member.

The patterning member may be any screen, perforated or grooved plate or the like on which the fiber assembly is supported during the hydraulic treatment and which by reason of its apertures and/or surface contours influences the movement of fibers into a pattern in response to the fluid streams. The patterning member may have a planar or nonplanar surface or a combination of the two types.

In perforated planar patterning members the holes are usually arranged in a uniform pattern of about 25 to 4000 holes per square inch of backing member. Tangle-laced regions of the nonwoven fabric are formed in areas corresponding to the apertures of the patterning member. Composite webs of the type described above may be successfully processed into patterned, tanglelaced textiles on apertured backing members having the following characteristics:

Proportion of open area ----- 10% to 98%
Aperture size ----- 0.01 to 0.25 inch (0.025-0.63 cm.)

If the planar backing members has apertures aligned in parallel rows, the tanglelaced fabric will have a square-mesh pattern, simulating that of a plain weave fabric. If the apertures are arranged in staggered rows, the tanglelaced fabric will have a triangular-mesh pattern. Fancy patterns, such as a simulated herringbone weave or the like, may also be produced in the web by proper choice of the backing member.

Woven wire screens provide a useful class of patterning members. Coarse, regular or fine-wire plain weave screens ranging from 3 mesh to 200 mesh (wires per inch) having wire diameters ranging from 0.005 to 0.025 inch (0.127 to 0.635 cm.) and having about 10% to 75% open area can be used. In addition to plain woven wire, special weaves such as twill, Dutch twill, etc., can be used to modify the appearance of the product.

When using screens of 40% or less open area and up to 40 mesh, products may be prepared which show actual visible holes corresponding to the screen pattern when the products are of low weight, e.g., 1 oz./yd.² (34 g./m.²), while with a higher weight such as 2 oz./yd.² (68 g./m.²) the screens should be about 30 mesh or coarser to give this type of product. Those products which show no gross pattern of apertures will generally have a pattern of fine furrows or grooves on one face of the fabric.

The patterning member can also consist of a parallel grill, a solid plate with protrusions or rows of grooves or combinations of any of the afore-mentioned surfaces.

In some of the examples a coarse screen of large open area is used as a top screen to insure good contact of the web and the patterning member for the initial treatment. Such contact can also be obtained by other means such as tension or a vacuum.

The orifices used for producing the liquid streams may be drilled, etched or punched and should provide essentially columnar streams of liquid having a total divergence angle of no greater than about 5°. The orifices preferably have a diameter of about 3 to 15 mils (0.076 to 0.38 mm.).

The orifices are conveniently formed in a metal strip, having a length corresponding to the width of the composite web, which is mounted in a manifold supplied with liquid under pressure. Other arrangements of the orifices may be used but they should be equivalent to substantially parallel streams from orifices spaced 10 to 100 per inch (per 2.54 cm.) in line, and preferably 20 or more per inch. The orifices may be located from 0 to as much as 6 inches (15 cm.) above the composite web. Unless otherwise stated the orifices in the examples are located within about 1 inch (2.5 cm.) of the top of the web.

Unless stated to the contrary in the examples, the orifices remain stationary. This produces a fine pattern of very shallow grooves and furrows on the top of the composite web facing the orifices. This effect is reduced when the orifices are oscillated or when the spacing between orifices is decreased.

It may be desirable to reverse the composite web on the support screen so that the original top layer of fibers faces the screen for a finishing step. This is termed "flipping" and is often used to entangle both surfaces of the nonwoven to the same extent.

In order to obtain the high-strength patterned, tanglelaced products of the present invention, it is essential that the initial material be subjected to the action of streams of a non-compressible fluid at sufficiently high energy flux and for a sufficient amount of treatment to pattern and tanglelace the fibers thereof. The energy flux (EF) of the streams will depend upon the jet device used, the pressure of the liquid supplied to the jet orifice, and the orifice-to-web spacing during treatment. The liquid initially forms a "solid" stream, i.e., an unbroken, homogeneous liquid stream. The initial energy flux, in foot-pounds per square inch per second, is readily calculated by the formula,

$$EF_1 = 77 PG/a$$

where:

P=the liquid pressure in pounds per square inch (p.s.i.),
G=the volumetric flow of the stream in cu. ft./min., and
a=the initial cross-sectional area of the stream in square inches.

The valve of G for use in the above formula can be obtained by measuring the flow rate of the stream. The initial cross-sectional area a, which is inside the jet device, can be determined by measuring the actual orifice area and multiplying by the discharge coefficient (usually 0.64 to 0.80), or it can be calculated from measured flow rates. Since the area a corresponds to solid stream flow, the above formula gives the maximum value of energy flux which can be obtained at the pressure and flow rate used. The energy flux of the stream will decrease slightly, as the stream travels away from the orifice, when highly coherent, columnar streams are employed and will decrease rapidly with diverging streams. The stream diverges to an area A prior to impact against the web and the kinetic energy of the stream is spread over this larger area. The cross-sectional area A can be estimated from photographs of the stream with the web removed, or can be measured with micrometer probes. The energy flux is then equal to the initial energy flux times the stream density ratio a/A . Therefore, the formula for energy flux at the web being treated is:

$$EF_w = 77 PG/A \text{ ft.-poundsals/in.}^2 \text{ sec.}$$

The value of A increases with the orifice-to-web spacing and, at a given treatment distance, the value depends upon the jet device and the liquid supply pressure used. A pressure of 200 p.s.i. can provide sufficient energy flux for several inches when using a highly efficient jet device. With other jet devices, the energy flux of a stream may become too low in a relatively short distance even when using higher pressures, due to the stream breaking up and losing its columnar form. When this occurs, there is a sudden increase in the value of A and the energy flux drops rapidly. Since the stream may become less stable when higher pressures are used, the energy flux at a given treatment distance may actually decrease when the jet orifice pressure is increased to provide a higher initial energy flux PG/a . Some stream density a/A and energy flux determinations for water streams from drilled-tube orifice manifolds, of types used in Examples 1-3 and 8-11 are given in the following tables:

ENERGY FLUX VALUES FOR DRILLED TUBE ORIFICES

For 3 mil orifice diameter	Distance below orifice		
	1/8 inch	3/4 inch	1.5 inch
200 p.s.i.:			
Stream density (a/A).....	0.0758	0.0625	0.0545
Energy flux.....	85,000	70,000	61,000
500 p.s.i.:			
Stream density (a/A).....	0.0758	0.0522	0.0405
Energy flux.....	330,000	230,000	180,000
1,000 p.s.i.:			
Stream density (a/A).....	0.0758	0.0441	0.0349
Energy flux.....	940,000	540,000	430,000
1,500 p.s.i.:			
Stream density (a/A).....	0.0758	0.0405	0.0304
Energy flux.....	1,720,000	920,000	690,000
For 5 mil orifice diameter	Distance below orifice		
	1/8 inch	3/4 inch	1.5 inch
200 p.s.i.:			
Stream density (a/A).....	0.241	0.103	0.0785
Energy flux.....	270,000	115,000	88,000
500 p.s.i.:			
Stream density (a/A).....	0.214	0.0763	0.0565
Energy flux.....	930,000	330,000	250,000
1,000 p.s.i.:			
Stream density (a/A).....	0.190	0.0595	0.0108
Energy flux.....	2,340,000	730,000	130,000

For 7 mil orifice diameter	Distance below orifice		
	1/8 inch	3/4 inch	1.5 inch
200 p.s.i.:			
Stream density (a/A).....	0.357	0.125	0.0563
Energy flux.....	400,000	140,000	63,000
500 p.s.i.:			
Stream density (a/A).....	0.281	0.097	0.037
Energy flux.....	1,225,000	421,000	162,000
1,000 p.s.i.:			
Stream density (a/A).....	0.235	0.079	0.0195
Energy flux.....	2,910,000	972,000	242,000
1,500 p.s.i.:			
Stream density (a/A).....	0.235	0.0645	0.0125
Energy flux.....	5,370,000	1,460,000	283,000

The high strength, tanglelaced, patterned products of the present invention can be produced by treating the web with streams of water jetted at sufficiently high pressure and having an energy flux (EF) of at least 23,000 ft.-poundals per inch² second. Such streams are preferably obtained by propelling a suitable, noncompressible fluid, such as water, at high pressure through small-diameter orifices under conditions such that the emerging streams remain essentially columnar at least until they strike the initial material. By "essentially columnar" is meant that the streams have a total divergence angle of not greater than about 5 degrees. Particularly strong and surface-stable, tanglelaced, patterned fabrics are obtained with high-pressure fluid streams having an angle of divergence of less than about 3 degrees, such as are used in Examples 4-7 and 12-14. The use of essentially columnar streams provides the further advantage of minimizing air turbulence at the surface of the web during processing.

It has been found that low-energy-flux diffuse sprays of water, such as the sprays which emerge from conventional, solid-cone spray nozzles at throughputs of up to 5 gallons/minute (18.9 l./min.) and water pressures of up to 150 p.s.i. (10.5 kg./cm.²) are unsuited to prepare the patterned, tanglelaced products of the present invention inasmuch as they lack sufficient energy flux and because they entrain large amounts of air, thereby generating a high degree of air turbulence at the surface of the web. High air turbulence leads to non-uniformities in the final product. A web may be protected from air turbulence by interposing a woven wire screen or other foraminous member at the surface of the web between the web and the source of the stream, but this has an undesirable secondary effect of further lowering the energy flux at the web surface. Thus, for example, a conventional, solid-cone spray nozzle, having a divergence angle of 22° and issuing water at about 1 gallon/minute at a water pressure of 100 p.s.i. exerts an energy flux (EF) of 670 ft.-poundals/in.² sec. at a distance of about 4 inches from the nozzle. If a 200-mesh screen is interposed between such a spray and the web being treated, the energy flux (EF) is reduced by 55% to 305 ft.-poundals/in.² sec.

The process of the present invention may be used to produce patterned, tanglelaced textiles from any type of loose fibrous web, batt, or sheet. The ease with which a given web can be patterned and tanglelaced is dependent upon many factors, and process conditions may be chosen accordingly. For example, webs of low density may be processed more easily than comparable webs of higher density. Fiber mobility also has a bearing on the ease with which a web can be processed. Factors which influence fiber mobility include, for example, the density, modulus stiffness, surface-friction properties, denier and/or length of the fibers in the web. In general, fibers which are highly wettable, or have a high degree of crimp, or have a low modulus or low denier, can also be processed more readily.

If desired, the initial fibers or layer may be treated first with a wetting agent or other surface agent to increase the ease of processing, or such agents may be included in the fluid stream.

Depending upon the nature of the initial fibrous layer and the pattern to be produced, the energy flux exerted by the fluid streams may be adjusted as desired by vary-

ing the size of the orifices from which the streams emerge, the pressure at which the non-compressible fluid is supplied to the orifices, the distance the web is separated from the orifices, and the type of orifice. Other process variables, which may be manipulated in order to achieve the desired patterning and tanglelacing, include the number of times and speed the web is passed into the path of the streams, and/or the directions in which the web is passed into the path of the streams.

The amount of treatment must be sufficient and is measured by the energy expended per pound of fabric produced. The energy (E_1) expended during one passage under a manifold in the preparation of a given nonwoven fabric, in horsepower-hours per pound of fabric, may be calculated from the formula:

$$E_1 = 0.125 (YPG/sb)$$

where:

Y=number of orifices per linear inch of manifold,

P=pressure of liquid in the manifold in p.s.i.g.,

G=volumetric flow in cu. ft./min./orifice,

s=speed of passage of the web under the streams, in ft./min., and

b=the weight of the fabric produced, in oz./yd.².

The total amount of energy expended in treating the web is the sum of the individual energy values for each pass under each manifold, if there is more than one.

When treating the fibrous material with streams of water impinged on the material at an energy flux (EF) of at least 23,000 ft.-poundals/in.² sec., patterned, tanglelaced nonwoven fabrics can be prepared at expenditures of energy of at least about 0.2 hp.-hr./lb. of fabric. At any given set of processing conditions, surface stability of the nonwoven fabric obtained (i.e., the resistance of the fabric to surface pilling and fuzzing) can be improved by increasing the total amount of energy (E) used in preparing the fabric. For products with sufficient surface stability to withstand repeated launderings, such as might be required for certain apparel and other uses, an energy flux (EF) of at least 100,000 ft.-poundals/in.² sec. and an energy (E) greater than 1 hp.-hr./lb. of fabric are preferred.

EQUIPMENT

A relatively simple form of equipment for treating fibrous webs with water at the required high pressure is illustrated in FIGURE 1. Water at normal city pressure of approximately 70 pounds per square inch (p.s.i.) (4.93 kg./cm.²) is supplied through valve 1 and pipe 2 to a high pressure hydraulic pump 3. The pump may be a double-acting, single-plunger pump operated by air from line 4 (source not shown) through pressure-regulating valve 5. Air is exhausted from the pump through line 6. Water at the desired pressure is discharged from the pump through line 7. A hydraulic accumulator 8 is connected to the high-pressure water line 7. The accumulator serves to even out pulsations and fluctuations in pressure from the pump 3. The accumulator is separated into two chambers 9 and 10 by a flexible diaphragm 11. Chamber 10 is filled with nitrogen at a pressure of one-third to two-thirds of the desired operating water pressure and chamber 9 is then filled with water from pump 3. Nitrogen is supplied through pipe 12 and valve 13 from a nitrogen bottle 14 equipped with regulating valve 15. Nitrogen pressure can be released from system through valve 16. Water at the desired pressure is delivered through valve 17 and pipe 18 to manifold 19 supplying orifices 20. Fine, essentially columnar streams of water 21 emerge from orifices 20 and impinge on the loose fibrous web 22 supported on apertured patterning member 23.

The streams are traversed over the web, by moving the patterning member 23 and/or the manifold 19, until all parts of the web to be treated are patterned and tanglelaced at high impact pressure. In general, it is preferred

that the initial fibrous layer be treated by moving patterning layer 23 under a number of fine, essentially columnar streams, spaced apart across the width of the material being treated. Rows or banks of such spaced-apart streams can be utilized for more rapid, continuous production of tanglelaced fabrics. Such banks may be at right-angles to the direction of travel of the web, or at other angles, and may be arranged to oscillate to provide more uniform treatment. Streams of progressively increasing impact pressure may be impinged on the web during travel under the banks. The streams may be made to rotate or oscillate during production of the patterned, tanglelaced fabrics, may be of steady or pulsating flow, and may be directed perpendicular to the plane of the web or at other angles, provided that they impinge on the web at sufficiently high impact pressure.

Apparatus suitable for use in the continuous production of tanglelaced, patterned fabrics in accordance with the present invention is shown in FIGURE 2. A fibrous layer 29 on apertured patterning member 30 is supplied continuously to moving carrier belt 31 of flexible foraminous material such as a screen. The carrier belt is supported on two or more rolls 32 and 33 provided with suitable driving means (not shown) for moving the belt forward continuously. Six banks of orifice manifolds are supported above the belt to impinge liquid streams 34 on the fibrous layer at successive positions during its travel on the carrier belt. The fibrous layer passes first under orifice manifolds 35 and 36, which are adjustably mounted. Orifice manifolds 37, 38, 39 and 40 are adjustably mounted on frame 41. One end of the frame is supported for movement on a bearing 42, which is fixed in position. The opposite end of the frame is supported on oscillator means 43 for moving the frame back and forth across the fibrous layer to provide more uniform treatment.

High pressure liquid is supplied to the orifice manifolds through pipe 18, as in FIGURE 1. Each manifold is connected to pipe 18 through a separate line which includes flexible tubing 44, a needle valve 45 for adjusting the pressure, a pressure gage 46, and a filter 47 to protect the valve from foreign particles. As indicated on the gages in the drawing, the valves are adjusted to supply each successive orifice manifold at a higher pressure, so that the fibrous layer 29 is treated at increasingly higher impact pressure during travel under the liquid streams 34. However, the conditions are readily adjusted to provide the desired patterning and tanglelacing treatment of different initial fibrous layers.

The fabrics prepared in accordance with the present invention are stable, coherent, strong and ready for fabric use. If desired, they may be dyed, printed, heat-treated, or otherwise subjected to conventional fabric processing. Thus, for example, they may be treated with resins, binders, sizes, finishes and the like, surface-coated and/or pressed, embossed, or laminated with other materials, such as foils, films, or the like.

The products of the present invention have many applications. Thus, they may be employed in the same uses as are conventional woven or knitted fabrics. Typical applications include apparel, linings, home furnishings, towels, upholstery and other decorative materials, padding and/or insulating materials, covering materials, and the like.

TESTS FOR EVALUATING PHYSICAL PROPERTIES

In the examples, the tensile properties are measured on an Instron tester at 70° F. and 65% relative humidity. Strip tensile strength is determined for a sample 0.5-inch wide, using a 2-inch sample length and elongating at 50% per minute and reported to the nearest 0.1 unit. The 5% secant modulus (termed "modulus") is determined by A.S.T.M. Standards E6-61, part 10, page 1836 and reported as the nearest whole number. Drap flex or bending length is determined by using a sample 1 inch wide

and 6 inches long and moving it slowly in a direction parallel to its long dimension so that its end projects from the edge of a horizontal surface. The length of the overhang is measured when the tip of the sample is depressed under its own weight to the point where the line joining the tip to the edge of the platform makes an angle of 41.5° with the horizontal. One-half of this length is the bending length of the specimen, reported in centimeters. Opacity is determined by T.A.P.P.I. Test T425M-60. Density is calculated from thickness measured with Ames thickness gauges [using a pressure of 4.3 p.s.i. (300 g./cm.²)] and the fabric weight.

Tensile recovery of a fabric is determined with an Instron tester, using a 3-inch (7.6 cm.) by 1-inch (2.54-cm.) sample, a 2-inch (5.08-cm.) gauge length, and elongating at 50% per minute. A stress-strain curve is run on the specimen out to 15% elongation (original elongation) or to 2 pounds force, whichever is reached first. After 30 seconds, the tester is reversed and returned to the original 2-inch (5.08-cm.) gauge length. After another 30 seconds, the tester is started again and run until the residual slack in the sample is taken up, at which point the percent elongation is recorded (permanent set). Tensile recovery is calculated from the following equation:

Tensile Recovery

$$= \frac{\text{Original elongation} - \text{permanent set}}{\text{Original elongation}} \times 100$$

EVALUATION OF TANGLELACING

The impenetrability rating (I) is determined by testing the impenetrability to a needle of entangled areas of fibers in a bond free state. The fibers must not be adhered with binder or inter-fiber fusion bonds. The needle has a shank about 0.015 inch (0.038 cm.) in diameter with a conical point having sides making an angle of about 26° with the axis. The needle is held by an L. S. Starrett "C" pin vise, the total weight of the assembly being about 24 grams. This is used in conjunction with a support plate, 1/32 inch (0.078 cm.) in thickness, having a series of holes of different diameters drilled in it. These holes are suitably marked for diameter-identification.

To obtain an impenetrability rating (I), a section of of the fabric is marked so as to delineate a region containing 25 circular entangled areas. The average diameter of the entangled areas is estimated with a hand comparator and the specimen is placed on the above-mentioned plate, so that for hydraulically processed fabric the fabric face upstream to the fluid stream during processing is adjacent the plate and the selected entangled area is placed over a plate-hole having a diameter approximately 75% of the diameter of the entangled area being tested. For other fabrics, either face may be used. For testing entangled areas which are smaller in diameter than about 1.33× the needle-shank diameter the entangled area may be placed over a plate-hole having a diameter slightly larger than that of the needle-shank. A light source under the plate-hole and suitable optical magnification are used to assist in achieving the correct placement over the hole. The needle is placed vertically above the entangled area in a central position. The weight of the needle assembly is then allowed to rest on the entangled area by lightly supporting the assembly with the hand to keep the needle vertical. Record is kept of whether it is penetrated or not, using 25 tests as the standard sample. The impenetrability rating (I) is the ratio of the number of entangled areas not penetrated to the total number tested. This test allows for the variation in entanglement in the various areas in a given sample and provides the average fraction of representative entangled areas which will not be penetrated. The highly entangled areas in the products of the present invention have an impenetrability rating of at least 0.5.

Entanglement frequency and completeness test

In preferred tests, nonwoven fabrics are characterized according to the frequency f and the completeness c of the fiber entanglement in non-bonded fabric, as determined from strip tensile breaking data using an "Instron" tester.

Entanglement frequency f is a measure of the extent of fiber entanglement along individual lengths of fiber in the nonwoven fabric. The higher the value of f the greater is the surface stability of the fabric, i.e., the resistance of the fabric to the development of pilling and fuzzing upon repeated laundering.

Entanglement completeness c is the proportion of fibers that break (rather than slip out) when a long and wide strip is tested. It is related to the development of fabric strength. A completeness c rating of 1 means that all of the fibers are being utilized in the development of fabric strength.

Entanglement frequency f and completeness c are calculated from strip tensile breaking data, using strips of the following sizes:

	Strip width (in.)	Instron gauge length (in.)	Elongation rate (in./min.)
Strip width symbol:			
w_0	0.8	0	0.5
w_1	0.3	1.5	5
w_2	1.9	1.5	5

For patterned fabrics, strips are cut in two directions: (a) in the direction of pattern ridges or lines of highest basis weight (i.e., weight per unit area), and (b) in the direction at 90° to the direction specified in (a). In unpatterned fabrics any two directions at 90° will suffice.

In cutting the strips from fabrics having a repeating pattern of ridges or lines of high and low basis weight, integral numbers of repeating units are included in the strip width, always cutting through the low basis weight portion attempting in each case to approximate the desired widths (w_0 , w_1 , w_2) closely. Ten or more specimens are tested at w_1 and 5 or more at w_2 and w_0 using an "Instron" tester with rubber-coated, flat jaw faces and the gauge lengths and elongated rates listed above. Average tensile breaking forces for each width (w_0 , w_1 , and w_2) are correspondingly reported as T_0 , T_1 , and T_2 . It is observed that:

$$\frac{T_1}{w_1} \leq \frac{T_2}{w_2} \leq \frac{T_0}{w_0}$$

It is postulated that the above inequalities occur because:

- (1) there is a border zone of width D at the cut edges of the long gauge length specimens, which zone is ineffective in carrying stress; and
- (2) with zero gauge length, fibers are clamped jaw-to-jaw and all fibers carry stress up to the breaking point, while with long gauge length, some poorly-entangled fibers slip out without breaking. The proportion of stress-carrying fiber is called entanglement completeness c .

Provided that D is less than $1/2 w_1$, then:

$$\frac{T_1}{w_1 - 2D} = \frac{T_2}{w_2 - 2D} = \frac{T_0}{w_0}$$

and D and c are:

$$D = \frac{w_1 T_2 - w_2 T_1}{2(T_2 - T_1)} \quad c = \frac{T_2 - T_1}{2T_0}$$

From testing various specimens, it is observed that when c is greater than 0.5, the value $D/\sqrt{d/1.5}$, where d is the effective fiber denier, is a measure of the average distance required for fibers in the fabric to become completely entangled so that they cannot be separated with-

out breaking. This value is practically independent of fiber length. The reciprocal of the value is the entanglement frequency f per inch, i.e.,

$$f = (1/D)\sqrt{d/1.5}$$

If the fabric contains fibers of more than one denier, the effective denier d is taken as the weighted average of the deniers.

Both c and f are determined in both major directions as defined above, and the geometric means are reported as the proper values. In any determination of f , if f turns out to be negative this is equivalent to a very high entanglement frequency and $f=100$ per inch is taken as the value to be used. When c is less than 0.5, it has been found that D and hence f may be influenced by factors other than entanglement. Accordingly, when c is less than 0.5, calculation of f as described above is not meaningful.

EVALUATION OF RELATIVE FIBER POSITIONS

The relative fiber positions in papers or fabrics are evaluated by passing light through microtomed sections of these materials. First, a sample of the fabric or paper is embedded in a clear plastic of index of refraction at 6328 Å, differing by at least 0.01 from the index of refraction of the fibers in the sample. An axis is fixed arbitrarily on the sample face and a second axis 90° to the first is then drawn. Sixty consecutive cross-sections are then cut along each axis. The sections are 30 microns thick, 4 mm. wide and 10 mm. long. Out of each group of sixty, the first and every sixth section thereafter are kept and the remainder discarded. The ten retained are glued between two glass slides with the same plastic in which the samples are embedded.

The scanning apparatus consists of:

- (1) a source of a collimated, circularly polarized beam of 6328 Å. wave length light which is used to illuminate a .8 x 6 mm. area of sample section. A typical source is a helium-neon laser operating in the TEM₀₀ mode, equipped with a quarter-wave plate. The more uniform the light intensity over the .8 x 6 mm. area, the more accurately the relative length can be measured;
- (2) a lens;
- (3) a thin opaque plate with a narrow slit which is partially blocked by a relatively wide opaque blocking patch perpendicular to the slit;
- (4) a second lens similar to the first;
- (5) a photocell with a .8 x 6 mm. aperture;
- (6) a recorder to pick up the signal from the photocell; and
- (7) a projection lens.

The focal length of the lenses, the slit length and width, and blocking patch size are in proper proportion such that the photocell signal from a straight fiber segment goes from maximum to ½ value when the fiber is rotated 9±3° from the angle at which the maximum signal occurs.

To effect the measurement, a cross section is placed one focal length from one of the lenses. One focal length on the other side of that lens is placed the thin plate with the slit. That location is also one focal length from the second lens which is located on the other side of the slit. On the other side of the second lens and one focal length from it is placed the (removable) photocell. The projection lens is placed behind the photocell position.

The light beam is thus directed through a cross section, first lens, on the blocking patch over the slit (and an equal distance from the edges of the slit), through the second lens and to the photocell or projection lens.

The section image is formed on a screen by the projection lens and the section is aligned with the sample length perpendicular to the slit with a region containing no fiber segments in the .8 x 6 mm. field. The slit is rotated

through 90° and the signal from the photocell is recorded when the slit makes an angle of 0° and 90° with the width of the sample. The section is then aligned with the center area of the sample in the .8 x 6 mm. field. If the sample is thicker than .8 mm. then the section is placed with one surface of the fabric just within the .8 x 6 mm. field (regions near the edge of the section are avoided). The signal is recorded with the slit length at an angle of 0° and 90° to the width of the sample. The angles are determined with an accuracy of ±6° and a precision of ±1°. The relative light intensity is determined with an accuracy of ±10% and a precision of ±2%.

The photocell signal from the sample minus the signal from the clear region is summed at 0° and at 90° for each set of ten sections cut along an axis. The total at 90° is divided by the total at 0°. The smallest value found for the two sets of sections is called the 90/0 ratio. If a sample has a low enough density, the fiber segments in the microtomed sections will be separated from each other and the 90/0 ratio is a measure of the fiber length oriented at 90° to the sample plane, to the fiber length oriented at 0°. If a sample has a high enough density, the fiber segments in the microtomed sections will be compacted and the 90/0 ratio is the ratio of the sample surface area which is oriented at 90° to the sample plane, to the surface area oriented at 0°.

EXAMPLE I

A bundle of poly(ethylene terephthalate) continuous filaments that have been drawn 4× is forwarded by an air jet to a moving screen to give a web of filaments in which the majority of the filaments are oriented in one direction. The web is removed from the screen and 2 lengths of the web are crossed at right angles to give a loose cross-warp web of about 3.3 oz./yd.² (112 g./m.²) weight. This is placed on a 30 x 30 mesh screen and covered with a carded web of a self-crimpable, bicomponent, polyester staple having a weight of 0.3 oz./yd.² (10 g./m.²). The whole assembly is slowly passed under a row of water streams from a row of closely spaced 3 mil (0.076 mm.) diameter orifices at 1500 p.s.i. (105 kg./cm.²) located about 2 cm. above the web. The web is treated twice in one direction, turned 90° and treated twice more. The fibrous assembly is removed from the screen and replaced with the staple-fiber side facing the screen. Another carded web as above is placed on top of the assembly and the hydraulic treatment is repeated. The resulting nonwoven fabric is squeezed, ironed dry and embossed by pressing with a cold twill screen.

Properties are given in Table I.

The product is reinforced drapeable structure with a felt-like surface.

EXAMPLE II

A crosswarp is made from a yarn containing 27 filaments (1.5 d.p.f.) of poly(ethylene terephthalate) by laying a warp of 100 yarns per inch in 1 direction and a warp of 100 yarns per inch over and at right angles to the first. The crossed warps are temporarily sized together by spraying with a 6% aqueous solution of polyvinyl alcohol. After drying, the crossed warp is placed on a 30 x 30 mesh screen. A carded web of 0.5 oz./yd.² (17 g./m.²) weight, composed of 1.5 inch (3.8 cm.), 1.5 d.p.f. polyester staple, is placed on top of the warp and the assembly slowly passed under streams of water, once in one direction and a second time in a direction at right angles to the first. The fiber assembly is turned over, another layer of staple is added and the above treatment is repeated. The sample is then reversed and given 2 more passes on each side for a total of 8 passes. The water streams are formed by jetting water, supplied at 1500 p.s.i. (105 kg./cm.²), through a closely spaced row of 2.8 mil (0.071 mm.) diameter orifices in a tube.

The product is a strong, well-reinforced structure containing 40% staple fibers and 60% warp fibers bonded by

13

the interentangling of the staple. The temporary size (or binder) is removed by the hydraulic treatment. Properties of the patterned, apertured product are given in Table I.

EXAMPLE III

A cross warp weighing about 1 oz./yd.² (34 g./m.²) is prepared from polyester yarn of 27 continuous filaments and a total denier of 40. The cross warp has 20 yarns per inch running in one direction and 20 yarns per inch at right angles. Four layers of cross warp are supported on a 30 x 30 mesh screen and a carded web of polyester staple is laid on the cross warp. The assembly is slowly passed under streams of water jetted from a row of closely spaced, 2.8 mil (0.071 mm.) diameter orifices at 1500 p.s.i. (105 kg./cm.²). The composite web is reversed on the screen, hydraulically entangled, reversed again and the treatment repeated for a third time. The properties of two products with different ratios of warp and staple are given in Table I.

The products are felt-like nonwovens.

EXAMPLE IV

A warp of continuous polyester filament yarn (54 filaments with a total denier of 70) is made by stringing the yarn in parallel lines on a frame by hand as closely as possible, fastening the ends with adhesive tape, and then cutting the warp from the frame. The warp is sandwiched between two random webs of acrylic fiber having equal weights of 1.5 inch (3.8 cm.) and 0.25 inch (6.3 mm.) lengths.

The above composite is placed on a 20 x 20 mesh screen formed of wires which are more highly crimped in one direction. With the warp parallel to the more highly crimped wires in the screen, the assembly is passed at a speed of 2 y.p.m. (1.8 m.p.m.) under a row of substantially cylindrical, unbroken vertical streams of water. The streams are produced by a row of 7 mil (0.17 mm.) diameter orifices spaced 20 per inch located in an oscillating manifold about 2 cm. above the web. The following sequence of treatments is used:

Passes:	Pressure		Top screen
	P.s.i.	(Kg./cm. ²)	
2.....	1,000	(70)	Yes.
Reversal of the web on the screen			
2.....	1,000	(70)	Yes.
4.....	1,500	(105)	No.

This affords a total treatment of about 3.5 hp.-hrs./lb. of product (4.9 Calories/gram).

Properties of products made with different proportions of staple fiber in the fabrics are given in Table I. The products are well patterned, foraminous, extremely drapable and bulky nonwoven fabrics.

Repetition of the above with finer supporting screens gives products with similar properties but with higher tensile recoveries in the machine (warp) direction:

Percent staple fibers:	Tensile recovery screen mesh		
	20	24	30
97.....	76%	85%	79%
94.....	75%	83%	91%
91.....	76%	90%	84%

EXAMPLE V

A 70 denier yarn containing 34 bicomponent, self-crimpable (upon shrinking) polyester filaments is made into a warp containing 40 yarns per inch with a weight of about 0.36 oz./yd.² (12 g./m.²).

A random web weighing 1 oz./yd.² (34 g./m.²) containing equal weights of 1.5 inch (3.8 cm.) length, 1.5

14

d.p.f. acrylic fiber and 0.25 inch (6.3 mm.) length, 1.5 d.p.f. rayon fiber is prepared.

A composite is made by adding the following layers in sequence:

- 5 (a) 10 x 10 mesh screen (35% open area),
- (b) a web from above,
- (c) a warp from above parallel to 1 set of wires in the screen with the ends of the warp secured taut to edges of screen, and
- 10 (d) a web from above.

This assembly is passed at about 5 y.p.m. (4.5 m.p.m.) under a row of substantially cylindrical, unbroken, vertical streams of water from a row of orifices of 7 mil (0.17 mm.) diameter spaced 20 per inch (per 2.54 cm.) located about 2 cm. above the top web using the following sequence:

Passes:	Pressure		Top screen
	P.s.i.	(Kg./cm. ²)	
1.....	300	(21)	Yes.
1.....	600	(42)	Yes.
1.....	900	(63)	Yes.
6.....	500	(35)	No.
25 6.....	1,000	(70)	No.
6.....	1,500	(105)	No.

Then the following layers are placed on top of the structure in sequence:

- 30 (e) a warp from above at right angles to the lower warp and ends of warp secured taut to edges of screen, and
- (f) a web from above as the top layer.

The entire assembly is hydraulically treated as above omitting the first three passes. The entire fiber structure is removed from the screen and flipped back onto the screen and the above procedure (last 18 passes) is repeated for a total treatment of about 8.0 hp.-hrs./lb. of product (11.0 Cal./gram).

The resulting well-tangled and strong nonwoven fabric containing about 19% warp yarn has a foraminous structure with holes resulting from the wire screens aligned with the warp yarns.

Upon steaming in a relaxed condition, the fabric shrinks about 16% linearly in both directions and then has a woven-like design of nearly closed elongated holes, with 20% recoverable stretch in both the warp directions and about 40% bias (diagonal) stretch.

EXAMPLE VI

A tow of acrylic continuous filaments having a potential shrinkage of about 25% is combined to obtain a uniform warp of filaments with a weight of 0.5 oz./yd.² (17 g./m.²). The warp is sandwiched between two random webs containing equal weights of 1.5 inch (3.8 cm.) long acrylic fibers of 1.5 d.p.f. and 0.25 inch (6.3 mm.) long rayon fibers of 1.5 d.p.f. Each web has a weight of 1 oz./yd.² (34 g./m.²).

The above fiber assembly is placed on a 20 x 20 mesh screen (36% open area) with the warp fibers oriented 45° from the wires and passed at about 5 y.p.m. under the water streams of Example V using the following sequence:

Passes:	Pressure	
	P.s.i.	(Kg./cm. ²)
6.....	300	(21)
6.....	600	(42)
6.....	900	(63)
6.....	1,200	(84)
65 6.....	1,500	(105)

The entire web is then reversed on the screen and the procedure repeated for a total treatment of 14 hp.-hrs./lb. (19.5 Cal./g.).

The strong, apertured nonwoven fabric is heated to 120° C. which affords 39% shrinkage in the warp direc-

15

tion and 10% extension in the opposite direction. The final fabric is strong and soft with elongated apertures.

Properties of the product are given in Table I.

EXAMPLE VII

The crimpable polyester yarn of Example V is used to make a warp containing 40 yarns per inch. The warp is laid taut upon a random web of Example V with a weight of 1.5 oz./yd.² (51 g./m.²) and covered with a second web of the same type and weight.

The patterning plate consists of a grip of parallel, 0.094 inch (2.4 mm.) diameter rods, spaced 5.3/inch and secured at the ends, resting on a perforated plate.

The fiber composite is placed on the patterning plate with the warp yarns oriented perpendicular to the grooves in the plate and the entire assembly hydraulically treated using the apparatus and procedure of Example VI for a total treatment of about 4.5 hp.-hrs. per pound of product (6.4 Cal./g.) on one side only.

The product of 3.5 oz./yd.² (120 g./m.²) weight is a corduroy-like fabric tanglelaced along the ridges and having the warp yarns and parallel web fibers connecting the ridges. Treatment with steam causes the warp fibers to shrink and crimp to yield a strong stretch corduroy-like fabric, of high modulus along the ridges, having a weight of about 5.0 oz./yd.² (170 g./m.²) and a 25% stretch at right angles to the ridges.

EXAMPLE VIII

This example illustrates the preparation of tanglelaced, multilevel patterned structures from a layered initial material wherein at least one component is a web of continuous fibers running in one direction, such as a warp.

A uniform warp of about 1.5 oz./yd.² is prepared from high tenacity nylon yarn containing 68 filaments and having a total denier of 140 (15.7 tex.). The filaments have a tenacity of 7.4 g./denier (66 g./tex.). This warp is sandwiched between two 0.5 oz./yd.² webs of randomly disposed, polyethylene terephthalate staple fiber having a denier per filament of 1.5 (0.168 tex.) and a length of 1.5 inches. The composite of the warp and random overlays is placed on a 10 mesh, 21% open area, plain weave, wire screen having a wire diameter of 0.054 inch. The wires running in one direction have a low crimp amplitude, forming minor protrusions in that direction; the wires running transverse thereto have a high crimp amplitude to form major protrusions in the transverse direction. The composite is placed on the screen so that the fibers of the warp run in the direction corresponding to the major crimp axis of the screen.

The composite, while on the screen, is treated with high-energy-flux streams of water (about 65° C.) issuing from 0.005 inch orifices arranged along an 8 inch line in a manifold having a diameter of 0.25 inch at a density of 40 orifices/inch. A top plate is placed on the composite and the assembly is passed under the streams 10 times at 1900 p.s.i. water pressure. The top plate has 726 holes/inch² and 50% open area and serves only to hold the composite in place during initial treatment, i.e., it does not serve to influence patterning. The top plate is then removed and the composite is given about 10 additional passes under the streams, all passes being made in the direction of the warp fibers.

During treatment, the warp fibers are caused to separate into parallel ribbon-like bundles of continuous fibers following the deeply recessed grooves of the screen running parallel to the major-crimp-wire axis. In generally transverse direction to the ribbon-like bundles are parallelized-fiber bundles having a substantially round cross-section, following sinusoidal paths across the fabric, and protruding as ridges from one face of the fabric. The latter yarn bundles are formed of parallelized-fiber segments interconnected axially by tanglelacing in the region of intersection with the ribbon-like bundles, certain fiber

16

segments passing above and below the ribbon-like bundles at these intersections. The resulting fabric is dried and removed from the screen. The impenetrability rating (I) of tanglelaced areas is 1.0.

Properties of the fabric after drying, are as follows:

	MD	XD
Weight (oz./yd. ²).....	2.65	
Strip tensile strength (lbs./in./oz./yd. ²).....	40	1.5
Elongation (percent).....	33	66
Initial modulus (lbs./in./oz./yd. ²).....	127	2.1

MD=Measured in warp direction.

XD=Measured 90° to warp direction.

Similar products can be made with other overlays and/or underlays of carded fibers or random webs, using a unidirectional or cross-warp fiber array as reinforcement.

EXAMPLE IX

A high-bulk acrylic staple spun yarn of 2/30 worsted count, a twist of 9Z/4S is made into a warp with 10 yarn ends per inch. A second such warp is placed above the first at 90° to it to give a crossed warp with a weight of 1.2 oz./yd.² (41 g./m.²). A carded batt of 1 d.p.f., 1.5 inches (3.8 cm.) long acrylic fiber staple of about 0.9 oz./yd.² (30 g./m.²) weight is placed on the top of the crossed warp. The composite web is hydraulically entangled by passing it on a 30 x 30 mesh screen slowly under jets of water at 1500 p.s.i. (105 kg./cm.²) pressure from a row of 0.003 inch (0.076 mm.) diameter orifices spaced 40 per inch for 1 treatment in one direction and 1 treatment in a direction 90° to the first. The sample is turned over on the screen, a carded batt as above placed on top and the above hydraulic treatment repeated. Finally the product is again reversed on the screen and the hydraulic treatment conducted for a third time. The product contains about 60% of staple fibers. Properties of the product are given in Table I.

The product is a non-foraminous, felt-like, reinforced, drapeable structure.

EXAMPLE X

A cotton yarn (40/1 cotton count) is used to make 2 warps having 40 yarns per inch. One warp is crossed over the other at 90° and the crossed warp placed between 2 carded batts of 1.5 d.p.f., 1.5 inch (3.8 cm.) long polyester staple each having a weight of 0.9 oz./yd.² (30 g./m.²). The composite is hydraulically entangled as in Example IX. Properties of the product containing about 58% staple are given in Table I.

The product is a non-foraminous, felt-like, reinforced, drapeable nonwoven fabric.

EXAMPLE XI

A polyester continuous filament yarn (40 denier total for the 27 filaments) is textured by the process of Breen U.S. Patent No. 2,852,905 issued Sept. 23, 1958, to give a bulked yarn in which the filaments are individually looped upon themselves at random intervals into crunodal loops. A crossed warp is made by taping 4 layers of the yarn on a support, each layer containing 20 yarns per inch, and then taping 4 similar layers at 90° to the first for a total weight of 2.6 oz./yd.² (80 g./m.²). The crossed warp is placed on a "fakir bed" (34's card clothing) and covered with a carded batt of 1.5 d.p.f., 1.5 inch (3.8 cm.) long polyester staple of 0.9 oz./yd.² (30 g./m.²). The composite web is hydraulically entangled similar to Example X using 750 p.s.i. (53 kg./cm.²) with 2 passes at 90° to each other on both sides. The entangled composite web is then reversed and placed on a 30 mesh screen and hydraulically entangled similar to Example X, using 1500 p.s.i. (105 kg./cm.²) with 2 passes at 90° to each other on both sides.

The properties of the apertured product having a very attractive hand are given in Table I. The yarns are held

together at the crossover points by the entangled staple fibers which are also interentangled with the loops of the textured yarns.

EXAMPLE XII

Using the method of British Patent No. 932,482 a zero twist continuous filament yarn (34 filaments, 70 toal denier of 66 nylon) is passed over a rotating electrode charged to 1500 volts and then through an oscillating forwarding air jet onto a 40-inch (102-cm.) wide piece of paper on a moving belt. Web weights of 0.3 and 0.57 oz./yd.² (10 and 19 g./m.²) are made for items A and B. The resulting random web of separate, uncrimped continuous filaments is sandwiched between 2 random webs each having a weight of 1 oz./yd.² (34 g./m.²) consisting of 1.5 d.p.f., acrylic staple containing equal weights of 1.5 and 0.25 inch lengths (38 and 6.3 mm.). The composite web is placed on a 24 x 24 mesh screen (27% open area) and hydraulically entangled using the speed and orifices of Example IV as follows:

Passes:	Pressure		Top screen
	p.s.i.	(kg./cm. ²)	
1.....	500	(35)	Yes.
1.....	1,000	(80)	Yes.
1.....	1,500	(105)	Yes.
5.....	1,500	(105)	No.

The procedure used above for items A and B is repeated, substituting a random web of the above acrylic staple fibers with a weight of 0.5 oz./yd.² (17 g./m.²) for the middle layer of random continuous filaments to make item C. The process gives a total treatment of 7.3 hp.-hrs./lb. (10.3 Cal./g.) for items B and C, and 8.0 hp.-hrs./lb. (11.2 Cal./g.) for item A. Properties of the 3 products are given in Table I.

Apart from the improved tensile strengths of the web-reinforced items A and B, the surprising result is the Tensile Recovery of the items as shown below:

Item:	Recovery MX x CD, percent
A	69 x 71
B	98 x 99.0
C	64.0 x 72

The nylon web fibers are not entangled in the process but rather serve as support for the entangling of the staple fibers. This is readily seen when one of the above products is treated in a solvent for the acrylic fibers. A patterned web of nylon fibers remains which is easily pulled into a loose web by hand.

EXAMPLE XIII

A 70 denier spandex yarn of coalesced multi-filaments is made into a warp having 25 yarns/inch and stretched about 200%. The stretched warp, weighing about 0.1 oz./yd.² (3.4 g./m.²) in the stretched condition, is sand-

wiched between two 1.1 oz./yd.² (37 g./m.²) weight random webs of 1.5 d.p.f. polyester staple and supported on a 24 mesh screen (16% open area). The polyester staple is a mixture of 70% 1.5 inch staple and 30% 0.25 inch staple. The supported assembly is passed at about 2.0 y.p.m. (1.8 m.p.m.) under streams of water from the orifices of Example V for a treatment as follows:

Passes:	Pressure		Top screen
	p.s.i.	(kg./cm. ²)	
1.....	1,000	(70)	Yes.
2.....	1,000	(70)	No.
Fabric removed (shrank about half its length) and flipped.			
1.....	1,000	(70)	No.
The total treatment is 2.0 hp.-hrs./lb. (2.8 Cal./g.)			

The product is a bulky, puckered fabric with high elasticity in the machine (warp) direction. Properties are given in Table I.

EXAMPLE XIV

The reinforcing web is a 1.9 oz./yd.² (65 g./m.²) weight random web containing about 88% 2.5 d.p.f. poly (ethylene terephthalate) continuous filaments (prepared so that they have a spontaneous elongation upon heating at 200° C. or higher of about 6%) and about 12% continuous filaments, about 2.5 d.p.f., of a copolymer poly (ethylene terephthalate/isophthalate) (80/20 weight percent). The random web is prepared by the process of British Patent No. 932,482 granted Nov. 20, 1963, and the homopolymer fibers are processed according to Kitson et al., U.S. Patent No. 2,952,879 issued Sept. 20, 1960, to provide the potential self-elongation. The random web is compressed at about 100° C. to consolidate the web without fusing the copolymer binder fibers.

The staple web is a random web of 1.5 d.p.f. rayon containing equal parts of 1.5 and 0.25 inch (38 and 6.3 mm.) lengths with a weight of 1.5 oz./yd.² (51 g./m.²).

The reinforcing web is placed on a 30 x 30 mesh screen, covered with the above staple web and passed under streams of water from a row of 5 mil (0.125 mm.) diameter orifices spaced 40 per inch. A coarse top screen placed at 45° to the wires of the bottom screen is used for the first treatment at 500 p.s.i. (35 kg./cm.²). Additional treatments at 1000 and 1500 p.s.i. (70 and 105 kg./cm.²) are given to afford a total treatment of 1.0 hp.-hrs./lb. (1.5 Cal./g.) of starting product.

The strong product is dried and is then bonded by passing air at 230° C. through the web for a period of about 20 seconds as it is held between 2 coarse wire screens (35 x 35 mesh) which are tensioned to give a pressure of about 0.5 p.s.i. (35 g./cm.²) over a rotating, perforated drum. Properties of the apertured, patterned product are given in Table I.

TABLE I

	Percent staple fibers	B.W., oz./yd. ²	Strip Tensile, lb./in./oz./yd. ²			Elongation, percent			Modulus MD/CD/Bias	Tensile recovery, percent MD x CD
			MD	CD	Bias	MD	CD	Bias		
Example:										
1.....	15	3.9	2.0	-----	1.4	12	-----	52	3/0/2	-----
2.....	40	2.4	18.2	-----	0.9	41	-----	44	166/0/2	-----
3A.....	15	1.2	23	-----	0.3	36	-----	66	191/0/0.2	-----
3B.....	57	2.3	10.9	-----	5.3	33	-----	93	93/0/0.8	-----
4A.....	97	3.9	3.6	4.1	-----	77	53	-----	8/5/0	76 x 71
4B.....	94	3.5	4.7	4.5	-----	33	54	-----	19/5/0	75 x 74
4C.....	91	3.8	7.1	4.0	-----	40	52	-----	32/4/0	76 x 71
5.....	82	3.7	-----	-----	-----	-----	-----	-----	-----	-----
6.....	80	2.8	6.2	2.9	-----	25	33	-----	50/13/0	-----
7.....	88	5.0	-----	-----	-----	-----	-----	-----	-----	-----
8.....	40	2.7	40	1.5	-----	33	66	-----	127/2/0	-----
9.....	60	3.0	5.9	-----	0.7	18	-----	31	55/0/0.3	-----
10.....	58	3.2	6.5	7.4	0.8	24	25	89	43/32/0.2	-----
11.....	10	2.9	8	-----	2.9	-----	-----	-----	40/0/0.6	-----
12A.....	88	2.6	3.8	4.0	-----	71	73	-----	2.6/1.8/0	73 x 70
12B.....	83	2.9	5.1	5.3	-----	75	63	-----	1.4/1.6/0	100 x 99
12C.....	100	2.5	3.5	3.4	-----	65	71	-----	0.9/0.5/2.2	75 x 67
13.....	96	5.3	1.1	3.1	-----	560	100	-----	-----	-----
14.....	42	3.3	6.7	6.4	-----	-----	-----	-----	16/14/0	80 x 81

19 EXAMPLE XV

This example shows the use of staple as a reinforcing fiber which is relatively resistant to entangling due to its composition and high denier.

An industrial grade 66 nylon yarn containing 210 continuous filaments of 6 d.p.f. is mechanically crimped (in tow) by a stuffer-box to an extent of about 30 crimps/inch of crimped length. Some of the crimped yarn is cut and carded into webs of about 0.35 oz./yd.² (12 g./m.²) weight. Three layers of a carded web are plied so that each web is oriented at 60° to other webs with one web in the machine direction. Measurement of fibers in the webs indicates a free length due to crimp alone and of crimp plus non-linearity of the fiber of 5 to 10 and 30 to 45%, respectively. Free length is defined as 100 × (extended length=length in web)/extended length.

Commercial, crimped staple fibers of poly(ethylene terephthalate) of 1.5 d.p.f. and containing equal weights of 1.5 and 0.25 inch lengths (3.8 and 0.6 cm.) are made into a random web with a weight of 1 oz./yd.² (34 g./m.²) to be used as the fill staple.

A composite consisting of a bottom layer of the polyester web, a middle layer of the plied nylon web and a top layer of the polyester web is placed on a 24 x 24 mesh screen (16% open area) and passed at 2 y.p.m. (1.8 m.p.m.) under the water streams of Example IV with the following sequence of treatments:

20

A composite is made using the random polyester staple web of Example XV as the bottom and top layers. The squares of the nylon fiber web are carefully placed on the bottom layer abutting adjacent squares. A second layer of the square is placed on top so that the center of each upper square is over the cross point of 4 lower squares.

Products using assemblies of different cut squares of the nylon web and the original uncut nylon web (item k) are made.

The fibers are sampled by pulling 10 fibers each from the center and the corners of a square and measured. The results are given below with the majority value in parentheses.

Item:	Unit squares	Fiber length, inches	
		At center	At corners
h.....	2" x 2"	2-ca. 6 (ca. 3)	0.25-ca. 1 (0.5-1)
i.....	4" x 4"	4-12 (ca. 9)	0.25-2 (0.5-1)
j.....	6" x 6"	6-25 (12-20)	0.25-4 (1)

All composites are hydraulically treated using the apparatus and conditions of Example XV.

Properties of the products are given in Table II. It is seen that items h-k containing a reinforcing element of random fibers have higher tensile strength, modulus and tensile recovery than item l containing only polyester staple.

TABLE II

Item	Reinforcing fiber length (inches)	Percent fill staple	B.W. weight, oz./yd. ²	Strip tensile, lb./in./oz./yd. ² MD x CD	Modulus, lb./in./oz./yd. ² MD x CD	Tensile recovery, percent MD x CD
a.....	Not used....	100	2.9	3.4 x 3.7	1.0 x 1.7	61 x 59
b.....	2.5	74	2.7	6.9 x 2.7	1.0 x 1.4	63 x 59
c.....	4.0	69	2.9	7.9 x 4.0	1.4 x 1.3	65 x 60
d.....	6.0	63	3.2	6.9 x 5.1	1.4 x 2.5	66 x 58
e.....	6.0	39	5.2	7.2 x 7.5	1.1 x 3.6	80 x 85
f.....	8.0	60	3.3	7.9 x 5.7	1.9 x 1.7	62 x 63
g.....	Continuous..	56	3.6	6.4 x 2.3	7.1 x 1.3	77 x 65
h.....	0.25-6	63	3.2	4.0 x 4.9	2.9 x 3.3	55 x 69
i.....	0.25-12	54	3.7	6.4 x 6.6	4.4 x 5.5	69 x 74
j.....	0.25-25	50	4.0	7.3 x 7.1	2.0 x 6.1	64 x 73
k.....	Continuous..	61	3.3	6.3 x 6.5	6.1 x 5.8	67 x 70
l.....	Not used....	100	2.8	2.7 x 3.4	1.6 x 1.3	52 x 57

	Pressure		Top screen	Oscillation
	p.s.i.	(kg./cm. ²)		
Passes:				
1.....	500	(35)	Yes....	No.
1.....	1,000	(70)	No....	Yes.
1.....	1,500	(105)	No....	Yes.
Web flipped:				
1.....	500	(35)	No....	No.
1.....	1,000	(70)	No....	Yes.
2.....	1,500	(105)	No....	Yes.

The total treatment is 4.0 hp.-hrs./lb. of starting product (5.6 Cal./g.).

The above procedure is used to make a control sample of 100% polyester staple (item a) and other samples using various cut lengths of the nylon fiber as shown in Table II. Item g of Table II utilizes a hand spread tow of the continuous, crimped nylon filaments as the middle layer.

Properties of the products are given in Table II. All samples have elongations-at-the-break in the range from 48 to 126%.

EXAMPLE XVI

This example shows the use of randomly oriented staple as a reinforcing fiber which is relatively resistant to entangling due to a combination of its composition, denier, length and free length.

A random web with a weight of 0.5 oz./yd.² (17 g./m.²) is made from a zero twist continuous filament nylon yarn (34 filaments, 70 total denier) having no crimp, by the method of British Patent 932,482. The web is collected on a paper by hand and then cut into small squares.

Since many different embodiments of the invention may be made without departing from the spirit and scope thereof, it is to be understood that the invention is not limited by the specific illustrations except to the extent defined in the following claims.

What I claim is:

1. A textile-like nonwoven fabric of staple-length textile fibers highly entangled in a repeating pattern of tanglelaced regions and reinforced with 3% to 90%, based on the weight of the fabric, of reinforcing staple fibers which have a length of at least two inches and are unentangled with each other, said textile fibers being entangled around the reinforcing fibers, the fibers of the fabric being locked into place by a three-dimensional fiber entanglement characterized by a fiber entanglement frequency of at least 10 per inch with a fiber entanglement completeness of at least 0.5 wherein fibers in said tanglelaced regions turn, wind, twist back-and-forth and pass about one another in all three dimensions of the structure in so intricate a fashion that fibers interlock with one another when the fabric is subjected to stress to thereby provide coherency and strength to the fabric.

2. The product defined in claim 1 wherein said reinforcing fibers constitute 10% to 70% of the weight of the fabric.

3. The product defined in claim 1 wherein said reinforcing fibers are straight staple fibers.

4. The product defined in claim 1 wherein said reinforcing fibers are crimped industrial grade fibers,

21

5. The product defined in claim 1 wherein said textile fibers are 0.25 to 1.5 inch in length.

6. The fabric defined in claim 1 wherein said tangle-laced regions are arranged in an ordered pattern which provides an appearance similar to that of a conventional woven fabric.

References Cited

UNITED STATES PATENTS

2,862,251 12/1958 Kalwaites ----- 161—169 X
3,033,721 5/1962 Kalwaites ----- 161—109 X

22

3,042,576 7/1962 Harmon et al. ---- 161—109 X
3,113,349 12/1963 Nottebahr et al. ---- 19—161 X
3,129,466 4/1964 L'Hommedieu ----- 19—161 X
3,214,819 11/1965 Guerin ----- 28—72.2

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U.S. Cl. X.R.

10 19—161; 28—1, 76; 162—115, 204

Dedication

3,494,821.—*Franklin James Evans*, Wilmington, Del. PATTERNED NON-WOVEN FABRIC OF HYDRAULICALLY ENTANGLED TEXTILE FIBERS AND REINFORCING FIBERS. Patent dated Feb. 10, 1970. Dedication filed Mar. 29, 1976, by the assignee, *E. I. du Pont de Nemours and Company*.

Hereby dedicates to the Public the entire remaining term of said patent.
[*Official Gazette May 25, 1976.*]