

March 3, 1970

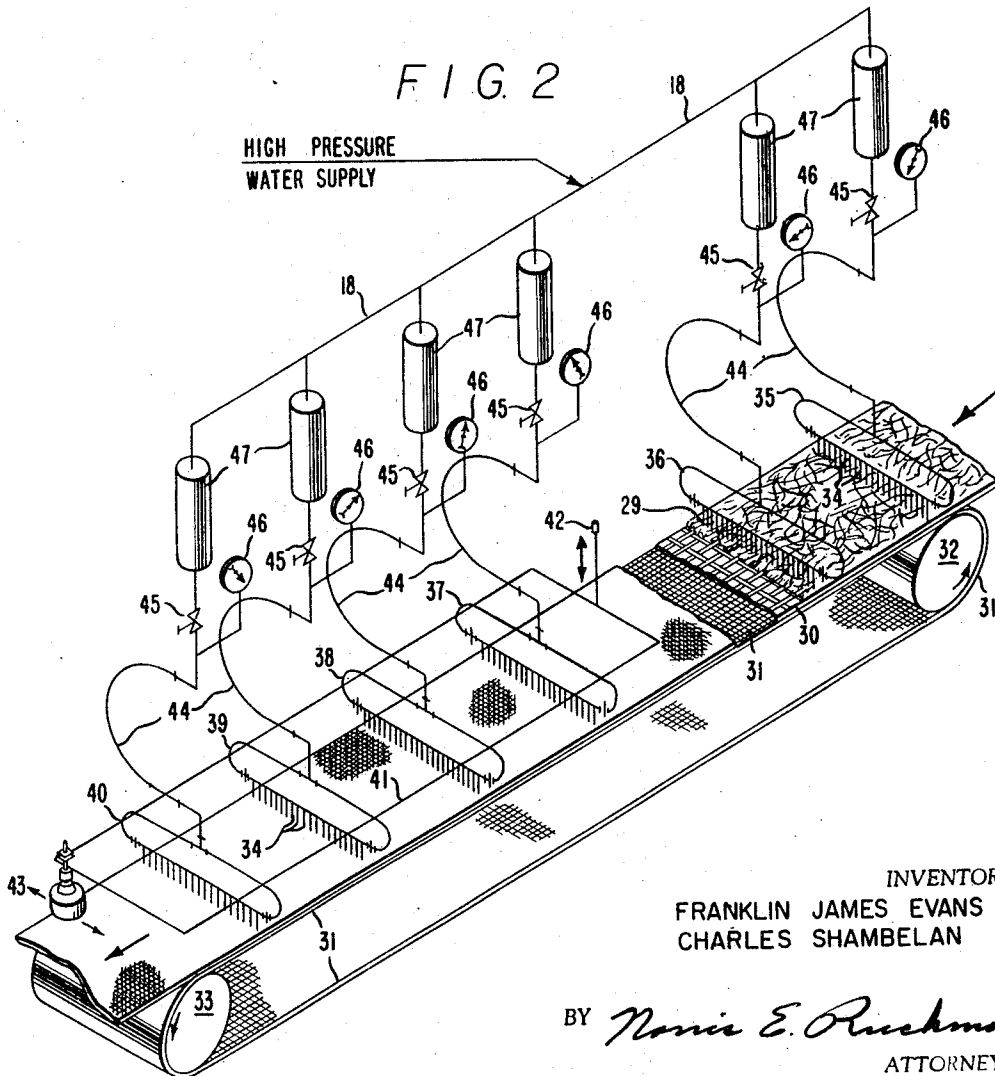
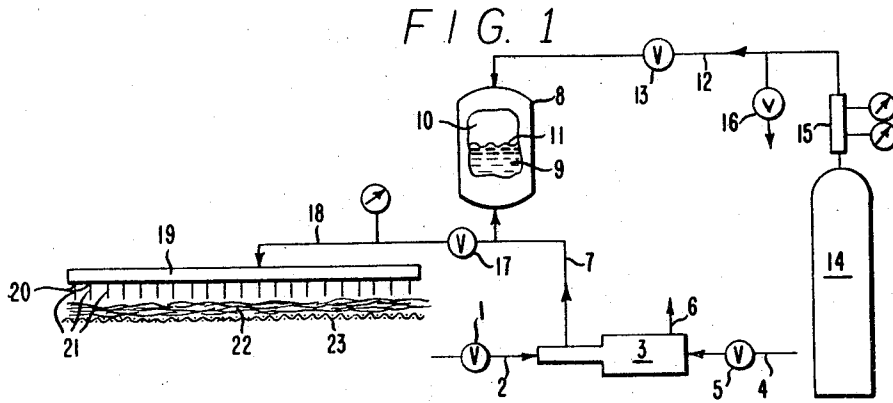
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3,498,874

APERTURED TANGLELACED NONWOVEN TEXTILE FABRIC

Filed June 18, 1969

6 Sheets-Sheet 1



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FIG. 3

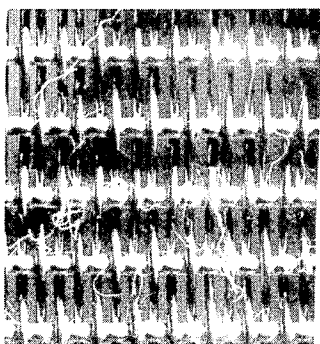


FIG. 4

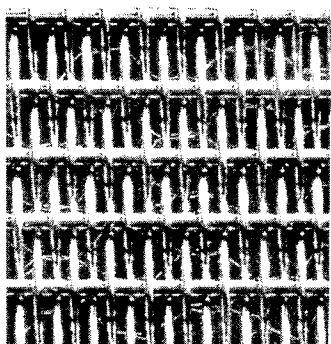


FIG. 5



FIG. 6

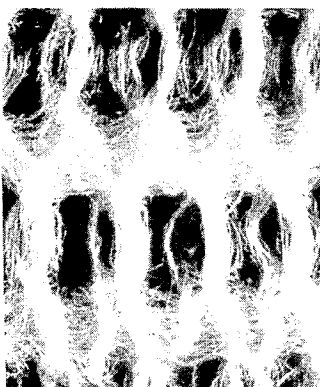


FIG. 7

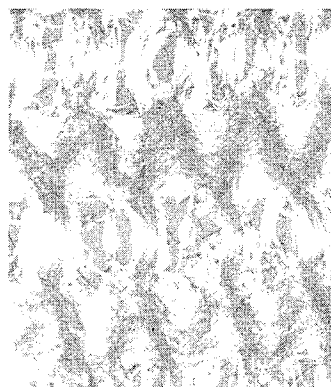


FIG. 8

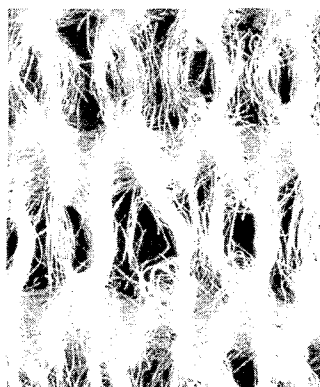


FIG. 9



FIG. 10

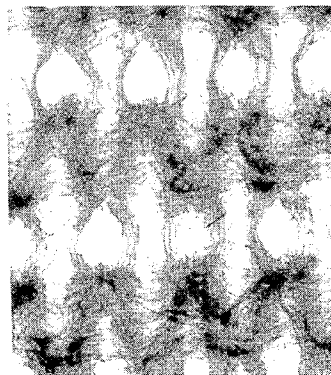
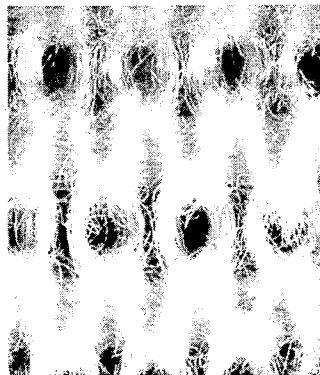


FIG. 11



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FIG. 12



FIG. 13

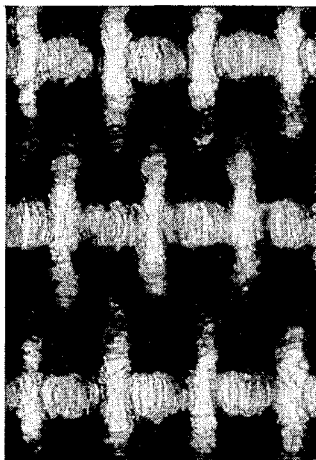


FIG. 14

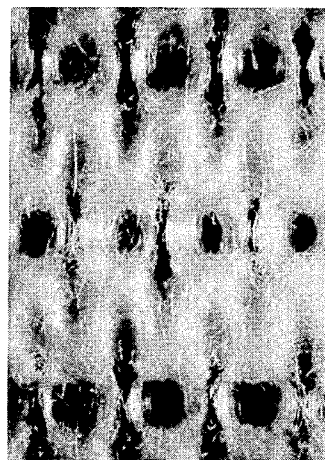


FIG. 15



FIG. 16

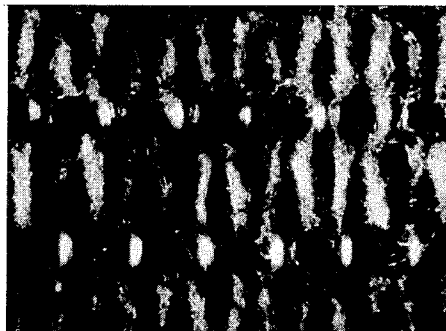
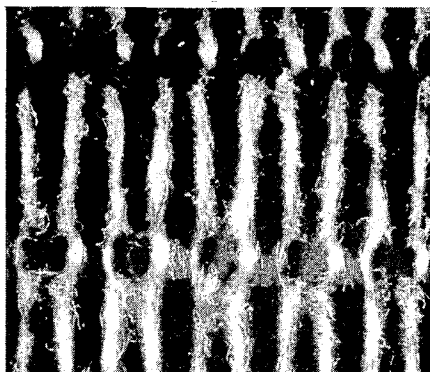


FIG. 17



FIG. 18



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FIG. 19

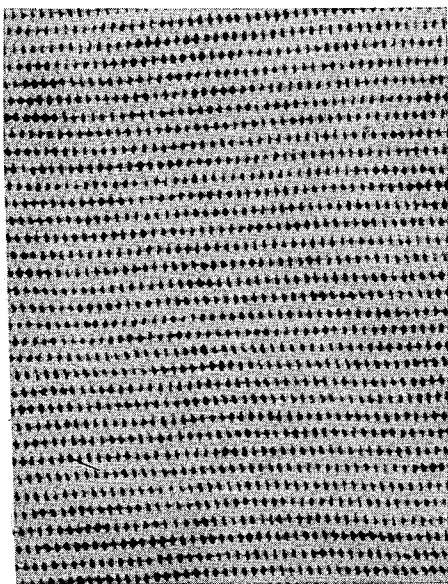


FIG. 20

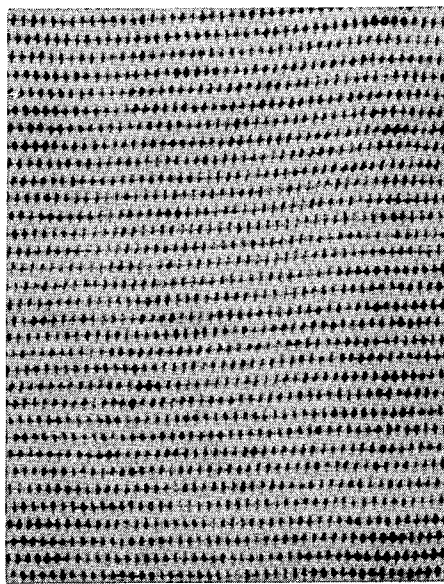


FIG. 21

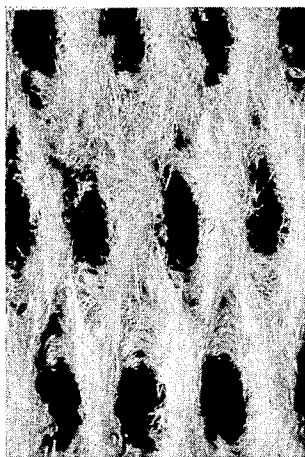


FIG. 22



FIG. 23



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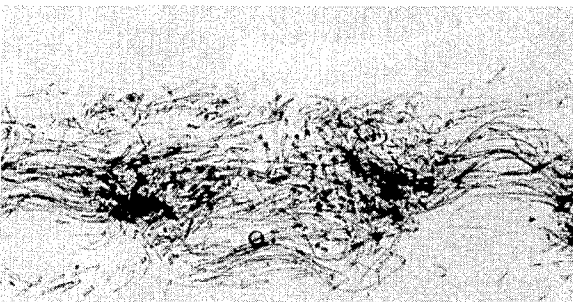
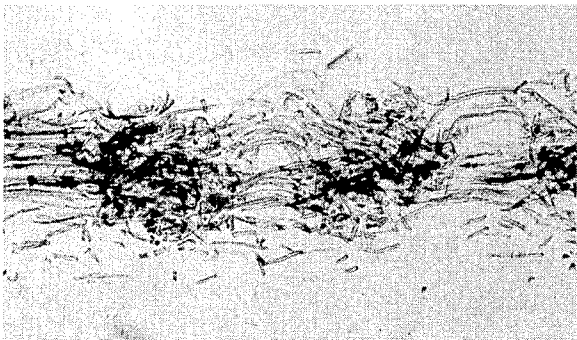
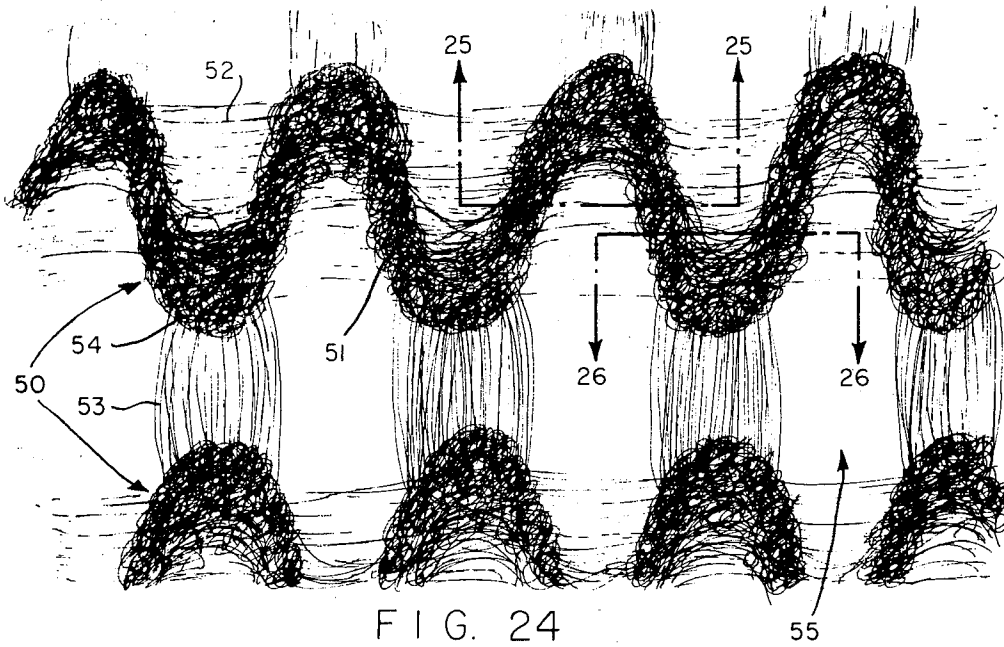
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FIG. 27

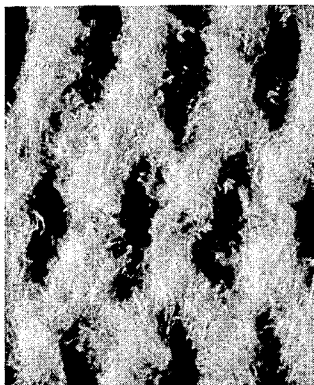


FIG. 28

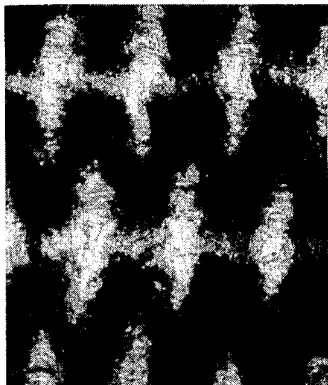


FIG. 29

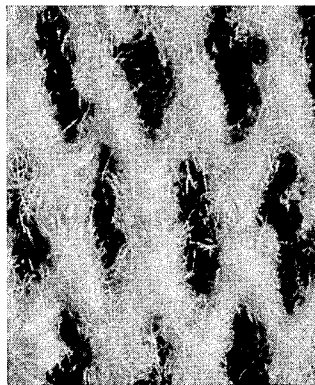


FIG. 30

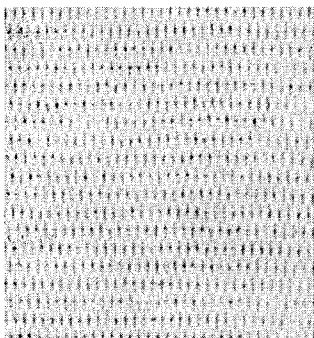


FIG. 31

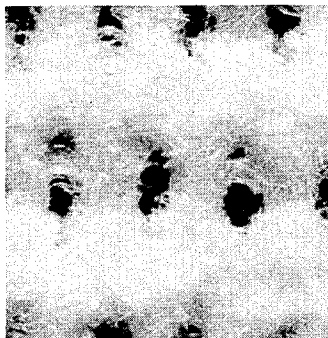


FIG. 32

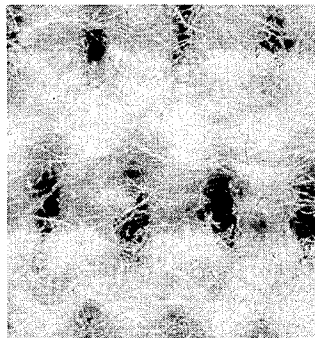


FIG. 33

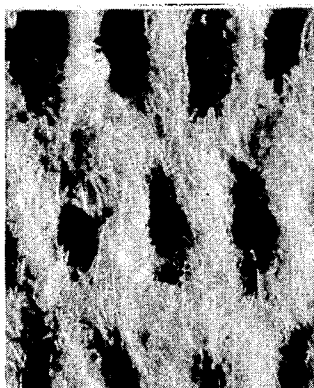
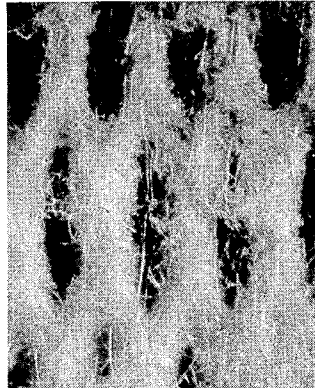


FIG. 34



FIG. 35



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APERTURED TANGLELACED NONWOVEN  
TEXTILE FABRIC

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Continuation-in-part of application Ser. No. 486,502,  
Sept. 10, 1965. This application June 18, 1969,  
Ser. No. 834,462

Int. Cl. B32b 5/02, 3/10; D04h 1/46

U.S. Cl. 161—109

10 Claims

## ABSTRACT OF THE DISCLOSURE

Apertured nowoven fabric which closely resembles woven fabric is characterized by fibers locked into place by tangelacing that extends in a zig-zag pattern along parallel bands interconnected laterally by fiber bundles defining rows of apertures between the bands. Preparation of the fabric from a loose layer of fibers, such as a random web, is illustrated by processing fiber layers on screens woven of heavier wires in one direction and 3 to 5 times as many finer wires per inch in the other screen direction. The fiber layer is traversed with fine, essentially columnar liquid streams from a manifold supplied with high pressure liquid to entangle the fibers.

## REFERENCE TO RELATED APPLICATION

This is a continuation-in-part of our copending application Ser. No. 486,502 filed Sept. 10, 1965, and now abandoned.

This invention relates to nonwoven fabrics resembling woven textile fabrics in appearance and properties, but which can be prepared directly from a web of loose fibers by treatment with high-impact-pressure liquid streams. The present invention is more particularly concerned with apertured tangelaced nonwoven fabrics of fibers entangled in a repeating pattern of parallel bands interconnected laterally by fiber bundles which define rows of apertures between the bands, the fibers being locked in place by tangelaced areas which extend in a characteristic zig-zag pattern along the bands.

Soft, porous fabrics having the strength of woven textile fabrics are required for many purposes. The present invention provides nonwoven fabrics having unique and aesthetically pleasing patterns, which are strong and durable solely by virtue of interentanglement of the component fibers with one another, without the use of added adhesives or binders or otherwise bonding the fibers in place. A wide variety of types and lengths of fibers can be used, and fabrics can be provided with properties equivalent or superior to conventional soft weave fabrics. Further advantages will become apparent from the disclosure and claims.

In the accompanying illustrations,

FIGURE 1 is a schematic view of apparatus suitable for preparing the fabrics.

FIGURE 2 is a schematic isometric view of an apparatus for high-speed, continuous production of the fabrics.

FIGURES 3 and 4 are photomicrographs of two types of wire screen patterning supports used for preparing the fabrics, shown in plan view.

FIGURE 5 is a photograph at 1× magnification of a representative sample of fabric produced as disclosed in Example 1A, taken of the top face by direct illumination.

FIGURE 6 is a photomicrograph at 10× magnification of a portion of the fabric, viewed as in FIGURE 5.

FIGURE 7 is a photomicrograph at 10× magnification corresponding to FIGURE 6, but taken by light trans-

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mitted through the fabric and using partially crossed polarizers to show differences in fiber density in the fabric structure.

FIGURE 8 is a photomicrograph at 10× magnification corresponding to FIGURE 6, but showing the bottom face of the fabric which is next to the screen support during production.

FIGURES 9, 10 and 11 are photomicrographs at 10× magnification of fabric produced as disclosed in Example 1B, the views being taken as in FIGURES 6, 7 and 8, respectively.

FIGURES 12, 13 and 14 are photomicrographs at 10× magnification of fabric produced as disclosed in Example 1C, the views being taken as in FIGURES 6, 7, and 8, respectively.

FIGURES 15 and 16 are photomicrographs at 8× magnification of the top and bottom faces of fabric produced as disclosed in Example 2A.

FIGURES 17 and 18 are photomicrographs at 8× magnification of the top and bottom faces of fabric produced as disclosed in Example 2B.

FIGURES 19 and 20 are photographs at 1× magnification of the top and bottom faces of fabric produced as disclosed in Example 3A.

FIGURES 21, 22 and 23 are photomicrographs at 10× magnification of fabric produced as disclosed in Example 3A, showing a view of the top face by direct illumination, a view by light transmitted through the fabric, and a view of the bottom face by direct illumination.

FIGURE 24 is a schematic illustration of characteristic structural features seen in FIGURE 22.

FIGURES 25 and 26 are photomicrographs at 50× magnification of cross sections taken as indicated in FIGURE 24 of fabric produced as disclosed in Example 3A.

FIGURES 27, 28 and 29 are photomicrographs at 10× magnification of fabric produced as disclosed in Example 3B, showing a view of the top face by direct illumination, a view by transmitted light, and a view of the bottom face by direct illumination.

FIGURES 30 is a photograph at 1× magnification of the top face of fabric produced as disclosed in Example 3C after boil-off.

FIGURES 31 and 32 are photomicrographs at 10× magnification of the top and bottom faces of fabric produced as disclosed in Example 3C.

FIGURES 33, 34 and 35 are photomicrographs at 10× magnification of the fabric shown in FIGURES 30 to 32, but as obtained when drum dried under tension in the machine direction, showing a view of the top face by direct illumination, a view by transmitted light, and a view of the bottom face by direct illumination.

As illustrated in the above figures of the drawing, the products of this invention are apertured tangle-laced nonwoven textile fabrics of fibers entangled in a repeating pattern of fiber bands which extend continuously along spaced parallel axes between rows of apertures in one fabric direction. The bands, which are of substantially greater width than thickness, are characterized by tangle-laced areas which proceed obliquely back and forth along each band in a zig-zag pattern. This pattern is clearly visible when the fabric is viewed by transmitted light, as in several of the above figures, where the dense tangle-laced areas appear much darker than the other portions of the fabric. The bands also comprise interstitial arrays of generally parallelized fibers which extend lengthwise along the band between adjacent sides of zig-zag tangle-laced areas and are locked into place in the tangle-laced areas. The parallel bands are interconnected by bundles of generally parallelized fibers which extend laterally between corresponding elbows of zig-zag tangle-laced areas in adjacent bands and are locked into place by the tangle-

laced areas. These interconnecting bundles are located between the apertures referred to above.

These basic structural features are indicated schematically on a greatly enlarged scale in FIGURE 24 for one embodiment of the invention. The fiber bands 50 extend continuously along substantially straight parallel central axes. The bands comprise tangled areas 51 which proceed continuously back and forth along each band in a zig-zag pattern, and interstitial arrays of generally parallelized fibers 52 which extend lengthwise along each band between tangled areas and are locked into place in the tangled areas. The bands are interconnected by bundles of generally parallelized fibers 53 which extend laterally between corresponding elbows 54 of the tangled areas and are locked into place by the tangled areas. The band-interconnecting bundles are spaced regularly along the edges of the bands and define rows of apertures 55. The apertures of adjacent rows are offset obliquely to the band axes, and each aperture is of oblong shape with its major axis aligned perpendicular to the band axes.

The tangled areas usually form high density ridges on at least one fabric face, which have the characteristic zig-zag pattern of the tangled areas discussed. In many of the figures these ridges have the general configuration of chevron molding. The bands are preferably centered on parallel axes which are evenly spaced at a distance greater than the maximum dimension of each aperture. A product having the general appearance of a woven leno cellular fabric, when viewed without magnification by reflected light, can be prepared as disclosed in Example 1 which has a band axes spacing less than twice the maximum dimension of the apertures. However, this spacing will usually be about 2 to 4 times the maximum dimension of the apertures. It is generally desirable to have the apertures on uniformly spaced centers with the center-to-center spacing between adjacent rows of apertures about 1.5 to 5.0 times the center-to-center spacing of adjacent apertures in the same row. Fabrics may be prepared in which the bands are rounded to bulge outward, and which may have the general appearance of a pique weave when viewed with the unaided eye by reflected light, as illustrated in Example 3.

The preferred embodiments illustrated in the figures are discussed specifically in the examples, which describe how the fabrics are prepared directly from loose nonwoven webs of staple fibers on patterning screens of types shown in FIGURES 3 or 4, having heavier wires in one screen direction and about 3 to 5 times as many finer wires per inch in the other screen direction. These are oblong screens of plain weave having 5 to 12 heavier wires per inch, although other screen meshes can also be used to modify the pattern obtained in the product.

The screens shown differ in the configuration of the heavier wires. Those shown in FIGURE 3 are highly crimped, which is achieved by precrimping the wires before the screen is woven. The heavier wires are perfectly straight in FIGURE 4. The fabrics of Example 3 are prepared on this type of screen. In the schematic illustration of FIGURE 24, the band-interconnecting fiber bundles 53 extend uniformly between the elbows 54 of tangled areas. The fabrics of Examples 1 and 2 are prepared on screens of the type shown in FIGURE 3, and the protruding crimps of the heavier wires spread the band-interconnecting bundles to form additional apertures in lighter weight fabrics or indentations visible in heavier weight fabrics on the face next to the screen. The fibers of the interconnecting bundles bow outward around these wire crimps and are locked in place in the tangled areas to provide the interesting pattern shown on the screen face of the products of Examples 1 and 2.

All of the fabrics of the present invention are patterned structures in which the fibers are randomly interentangled in a remarkable manner designated "tanglelacing." The fibers proceeding through the fabric are locked into place in the tangled areas by a fiber inter-

action which alone, without the need for binder or other supplementary treatment, imparts high strength to the fabric. This fiber interaction is so complex and random that special methods of characterizing the tangled areas have been devised.

By "locked into place" is meant that individual fibers of the structure not only have no tendency to move from their respective positions in said patterned structure but are actually physically restrained from such movement by interaction with themselves and/or with other fibers of the structure, said interaction occurring at least at the areas of intersection of the fiber groups in said structure.

By "interaction" is meant that the fibers turn, wind, twist back-and-forth, and pass about one another in all dimensions of the structure, both individually and severally within the aforementioned geometric pattern, in so intricate a fashion and with so great a frequency per fiber length that they cooperate with, act upon, and interlock with one another when the web is subjected to stress to thereby provide coherency and strength to the web. For the purpose of the present invention, the various fiber gyrations, interentanglements, entwinings and the like, which result in the above-described fiber-to-fiber interaction, will hereinafter be referred to simply as "tanglelacing." The fibers are locked into place in the tangled areas by a three-dimensional fiber entanglement characterized by a fiber-interlock value of at least 7 and an internal bond value of at least 0.2 foot-pound, as determined by the following tests (made in the absence of binder):

#### FIBER-INTERLOCK TEST

The fiber-interlock value is the maximum force in grams per unit fabric weight needed to pull apart a given sample between two hooks.

Samples are cut 0.5 inch x 1.0 inch with the long dimension in the specified fabric direction (e.g., machine direction or cross direction) and weighed, and each sample is marked with two points 0.5 inch apart symmetrically along the midline of the fabric so that each point is 0.25 inch from the sides near an end of the fabric.

The eye end of a hook (Carlisle-6 fish hook with the barb ground off or a hook of similar wire diameter and size) is mounted on the upper jaw of an Instron tester so that the hook hangs vertically from the jaw. This hook is inserted through one marked point on the fabric sample.

A second hook is inserted through the other marked point on the sample, and the eye end of the hook is clamped in the lower jaw of the Instron. The two hooks are now opposed but in line, and hold the sample at 0.5-inch interhook distances.

The "Instron" tester is set to elongate the sample at 0.5 inch per minute (100% elongation/minute) and the force in grams to pull the sample apart is recorded. The maximum load in grams divided by the fabric weight in grams per square meter is the single fiber interlock value. The average of 3 determinations in the machine direction and 3 in the cross direction (or 3 samples cut in directions at 90° to each other) is reported to two significant figures as the average fiber interlock value.

#### INTERNAL BOND TEST

(A) The internal bond value of the nonwoven fabric is determined by a procedure described in Technical Association of the Pulp and Paper Industry (TAPPI) "RC-308 Test for Interfiber Bond Using the Internal Bond Tester." Further information regarding this procedure, particularly about the equipment used, is disclosed by Blockman and Wikstrand, TAPPI, March 1958, volume 41, Number 3, pages 190A to 194A, "Interfiber Bond Strength of Paper." The faces of the steel anvils, striking bar, samples of non-woven fabric and double-faced pressure-sensitive tape are each one inch square. The samples are mounted at 200 p.s.i., applied for one second. Five samples are tested in the machine direction of the fabric

and five in the cross direction, and the average value is reported in foot-pounds.

The referenced TAPPI RC-308 procedure specifies a commercial brand of double-faced pressure-sensitive tape. This tape is 1 inch wide, with combined thickness of adhesive layers of  $0.0015 \pm 0.0005$  inch (measured under about 1 p.s.i. pressure), and with an adhesion to steel of  $35 \pm 5$  ounces/inch (measured according to Federal Specification UU-T-91C of May 10, 1961). It should be a routine practice to check the tape by running the test on two layers of tape without fabric between; a value of at least 0.5 foot-pound should result. If a lower value is obtained, some tape is stripped off the roll and the tape calibration is repeated until proper values are obtained. The tapes should be adhered to clean metal surfaces, preferably cleaned with acetone and dried between determinations.

Meaningful results may not be obtained by the above Method (A) on (1) products having an open area of more than about 15% or (2) very thin fabrics having a fabric weight of less than 1.0 oz./yd.<sup>2</sup>, due to adhesion of the two layers of tape to each other. For these products the following Method (B) should be used:

(B) The sample is fastened to the lower fixed steel plate with the tape. This assembly is then pressed (sample face down) into a thin, flat bed of aluminum oxide (grade 400 "Lionite Floated Flour" made by General Abrasive Co., Inc., of Little Rock, Arkansas) at a pressure of 100 p.s.i. The assembly is removed from the bed and the bottom of the steel plate held firmly against the vertical shaft of a laboratory vibrator (providing an amplitude of 0.5 mm. at a frequency of 60 cycles per second) for 30 seconds. This treatment effectively removes the aluminum oxide from the fabric but not from any tape face exposed through openings in the fabric. The assembly is replaced in the mounting jig and fastened to the upper striking bar with tape at 200 p.s.i. and tested as in Method A.

The unique tanglelaced structure of the products of the present invention is also evident from the launderability of these products. Thus, the highly tanglelaced, patterned fabrics of the present invention, in the absence of binder, can be laundered in conventional, household washing machines and dried in conventional driers without loss of their utility as a fabric.

The tanglelaced fabrics can be composed of any fibers or fiber blends used in conventional woven or knitted textile fabrics or industrial fabric. The term "fiber" as employed herein is meant to include all types of fibrous materials, whether naturally or synthetically produced and whether of staple lengths or longer, including continuous filaments. Desirable products are produced from conventional textile fibers, which may be straight or crimped, and other desirable products are obtained by using highly crimped and/or elastic fibers in the fabric material. Particularly desirable patterned, tanglelaced fabrics are prepared of material comprising fibers having a latent ability to elongate, crimp, shrink, or otherwise change in length, and the patterned, tanglelaced structure is subsequently treated to develop the latent properties of the fibers so as to alter the free length of the fibers. This may partially or completely obscure the surface patterns discussed, including the apertures present, but stretching or pulling the fabric taut will again reveal the pattern. Such structures are particularly desirable for use as apparel fabrics, since they provide a high degree of conformability, stretchability, drape and covering power in addition to the basic requisites of strength and durability.

Preferred processes for preparing the fabrics of this invention are illustrated subsequently in the examples. In general, these involve assembling the fiber material in a loose initial layer, supporting the layer on a patterning member having a non-planar surface which defines a regular pattern of channels and protrusions, and tra-

versing the supported layer with fine, essentially columnar streams of liquid at high impact pressure to tanglelace the fibers into a patterned fabric having the structural characteristics already discussed. The initial layer may consist of any web, matt, or batt of loose fibrous elements, disposed in random relationship with one another or in any degree of alignment, such as might be produced by carding and the like. The fibrous elements may be of any natural, cellulosic, and/or wholly synthetic material. The initial layer may be made by any desired technique, such as by carding, random laydown, air or slurry deposition, etc. It may consist of blends of fibers of different types and/or sizes. If desired, the initial layer may be an assembly of loose fiber webs, such as, for example, crosslapped carded webs. The initial layer may include scrim, or other reinforcing material, which is incorporated into the final product by the treatment. Particularly desirable products may be obtained by utilizing highly crimped fibers or fibers which have a latent ability to elongate, crimp, shrink or the like and then, after the formation of the patterned textile, developing the latent properties of the fibers. The processibility of stiff fibers can be improved by plasticization with solvent or heat, e.g., by use of hot water.

Different effects can be achieved by the use of multi-colored fibers and/or webs. For example, striped, tanglelaced fabrics may be made by the use of a starting web comprising parallel fiber groups of different colors. By cross-laying two such webs, in forming the initial layer for the process, plaid tanglelaced fabrics may be prepared.

The apertured, tanglelaced, patterned products of the present invention can be produced with essentially columnar streams exerting an impact pressure of greater than about 300 ft.-lb./sec.<sup>2</sup> in.<sup>2</sup> (6.43 kg. M/sec.<sup>2</sup> cm.<sup>2</sup>). Such streams can be obtained by propelling a suitable, non-compressible fluid, such as water, at high pressures through small-diameter orifices under conditions such that the emerging streams remain essentially columnar at least until they strike the fiber web. 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. 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 impact-pressure, 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.<sup>2</sup>) are unsuited to prepare the patterned, tanglelaced products of the present invention inasmuch as they lack sufficient impact pressure 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 impact pressure 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 (3.79 l./min.) at a water pressure of 100 p.s.i. (7.04 kg./cm.<sup>2</sup>) exerts an impact pressure of only 11 ft.-lb./sec.<sup>2</sup> in.<sup>2</sup> (0.24 kg. M/sec.<sup>2</sup> cm.<sup>2</sup>) at a distance of about 4 inches (10.2 cm.) from the nozzle. If a 200-mesh screen is interposed between such a spray and the web being treated, impact pressure is reduced to about 5 ft.-lb./sec.<sup>2</sup> in.<sup>2</sup> (0.11 kg. M/sec.<sup>2</sup> cm.<sup>2</sup>). The products of the present invention cannot be prepared using such sprays.

Products of the present invention may be prepared from any type of loose web, batt, or sheet of fibers. The case 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 webs. In general, webs from 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, batt or web 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 fibers, initial web and the pattern to be produced, the impact pressure exerted by the fluid streams may be adjusted as required by varying the size of the orifices from which the streams emerge, the pressure at which the non-compressible fluid is delivered, the distance the web is separated from the orifices, and/or the fluid itself. Other process variables, which may be manipulated in order to achieve the desired patterning and tanglelacing, include the number of times 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. In general, webs having a weight ranging from 0.25 oz./yd.<sup>2</sup> (8.5 gm./M<sup>2</sup>) or less to about 12 oz./yd.<sup>2</sup> (406 gm./M<sup>2</sup>) or more and composed of natural, cellulosic, and/or wholly synthetic fibers, can be readily converted into patterned textiles through the use of water as the fluid and process conditions within the following ranges:

Orifice size—0.003 to 0.030 inch (0.0076–0.076 cm.)  
 Orifice spacing—0.01 to 0.1 inch (0.025–0.25 cm.)  
 Water pressure—200 to 5000 p.s.i. (14–352 kg./cm.<sup>2</sup>)  
 Web to orifice separation—0 to 6 inches (0–15.2 cm.)  
 Number of passes—1 to 100.

#### 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.<sup>2</sup>) 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 pattern-

ing 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 aperture 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 invention will be better understood from the examples of specific embodiments of tanglelaced, patterned products and processes for producing them. The examples illustrate preferred forms of new and useful products of this invention, but are not intended to be limitative.

#### Example 1

This example illustrates the preparation of products of this invention of different weights from loose webs of randomly-disposed staple fibers on an oblong patterning screen of the type shown in FIGURE 3.

The patterning screen is of plain weave but has 30 wires per inch of 0.018-inch diameter in one direction and 8 wires per inch of 0.032-inch diameter in the other direction. The heavier wires are precrimped, prior to weaving, to obtain the configuration shown in FIGURE 3.

An initial web is prepared of blended staple fibers, which are randomly disposed by an air-laying technique. The loose web consists of 50% by weight of 1.5-inch, 1.5 denier per filament acrylic fibers and 50% by weight of 1.5-inch, 1.5 denier per filament rayon fibers. The web is supported on the patterning screen during treatment to form a tanglelaced fabric.

(A) Using apparatus of the type shown in FIGURES 1 and 2, the assembly of the web on the screen is passed under high impact-pressure streams of water issuing from 0.005-inch diameter orifices arranged in line at a density

of 40 orifices per inch. The assembly is passed under the streams at a distance of about one inch from the orifices, at a rate of about one yard per minute. During the first pass, water is supplied to the orifices at a pressure of 500 p.s.i., and a high open-area top screen (14 x 18 mesh) is placed on top of the web. The top screen does not influence patterning; it merely helps to hold the web in place during the initial pass. The assembly is then passed, without any top screen, under streams formed at 1650 p.s.i. to prepare the 1 oz./yd.<sup>2</sup> (one ounce per square yard) fine, lacy fabric shown in top view at 1× in FIGURE 5. A corresponding view at 10× magnification is shown in FIGURE 6. A 10× view of the bottom face of the fabric, which is the face adjacent the patterning screen during processing, is shown in FIGURE 8. The complex fiber arrangement is shown at 10× by transmitted light in FIGURE 7. As best seen in FIGURE 7, dense tanglelaced areas of the fabric (darker areas in the figure) follow zig-zag paths along the parallel bands of the fabric. The bands are interconnected by groups of generally parallelized fibers which extend between corresponding elbows of the tanglelaced areas in adjacent bands and define rows of apertures between the bands. These interconnecting groups have a somewhat random appearance in FIGURES 6 to 8, although this is less evident when the fabric is viewed under normal conditions as in FIGURE 5. The fabric has a fiber-interlock value of 14.9 grams per gm./m.<sup>2</sup> and an internal bond value of 0.38 foot-pound when tested as described previously.

(B) A fabric weighing approximately twice as much is prepared on the same screen from a heavier initial web which has been prepared as above. The web is treated as described in (A) except that a water pressure of 2000 p.s.i. is used throughout, preliminary passes are made with the web held in place with a perforated top plate having 462 holes/in.<sup>2</sup> and 50% open area, the top plate is then removed and the web is treated directly with the high-impact streams until a strong, uniformly patterned fabric is obtained. The fabric is dried on the patterning screen in an oven at 40° C. and is then removed.

The resulting fabric is shown at 10× magnification in FIGURES 9 to 11. This is basically similar to the fabric of 1(A) but is more regular in appearance. The tangle-laced areas form high density ridges on the screen face (FIGURE 11), which are arranged in a uniform zig-zag pattern suggestive of chevron molding. The high density of these ridges is shown by transmitted light in FIGURE 10. The band-interconnecting groups are much more regular than in Fabric (A). They have an interesting bowed configuration which gives the fabric the general appearance of a woven leno cellular fabric, particularly when viewed with the naked eye (without magnification) by reflected light. The apertures between the bands are alternately of narrow oblong and of relatively circular shape. The narrow oblong apertures are formed where the finer wires cross over the heavier wires in the patterning screen. The relatively circular apertures are formed by the raised crimps in the heavier wires. The fibers are locked into place in the tanglelaced areas, which causes the band-interconnecting fibers to remain in a bowed configuration after the fabric is removed from the screen. The fabric has a fiber-interlock value of 14.6 grams per gm./m.<sup>2</sup> and an internal bond value of 0.40 foot-pound. Properties of the fabric after washing for 1 cycle in a household washing machine of the agitator type, are as follows:

|                                                   | MD  | XD  |
|---------------------------------------------------|-----|-----|
| Weight (oz./yd. <sup>2</sup> )                    | 2.3 | 2.4 |
| Tensile strength (lb./in./oz./yd. <sup>2</sup> )  | 3.6 | 3.5 |
| Elongation (percent)                              | 36  | 39  |
| 5% secant modulus (lb./in./oz./yd. <sup>2</sup> ) | 1.7 | 2.3 |

(C) A 3.6 oz./yd.<sup>2</sup> fabric is prepared as described in 1(B). The fabric is shown at 10× magnification in FIGURES 12 to 14 and has a highly regular appearance even at this magnification. The top face (FIGURE 12) has a smooth, soft appearance, with bands of uniform width, and the above-mentioned circular-shaped apertures have been filled in by fibers. The remaining narrow oblong apertures are of uniform size and spacing. The screen face (FIGURE 14) has the clearly-defined zig-zag ridges and bowed interconnecting fibers observed in FIGURE 11, but the heavy wire crimps have formed indentations rather than apertures. The tanglelaced area, shown by the darkest portions in FIGURE 13, are highly regular. The fabric has a fiber-interlock value of 12.8 grams per gm./m.<sup>2</sup> and an internal bond value of 0.55 foot-pound. Properties of the fabric, measured in two directions after washing for 1 cycle in a household washing machine of the agitator type, are as follows:

|                                                   | MD  | XD  |
|---------------------------------------------------|-----|-----|
| Weight (oz./yd. <sup>2</sup> )                    | 3.6 | 3.7 |
| Tensile strength (lb./in./oz./yd. <sup>2</sup> )  | 3.9 | 3.0 |
| Elongation (percent)                              | 49  | 43  |
| 5% secant modulus (lb./in./oz./yd. <sup>2</sup> ) | 2.1 | 1.7 |

Example 2

This example illustrates the preparation of patterned structures on oblong screens of different mesh sizes.

Products A and B are prepared in the same manner from polyester staple fiber, but different oblong patterning screens are used. The initial material is a web of randomly-disposed fibers prepared by an air-laying technique. The web weighs 2.5 oz./yd.<sup>2</sup> and is prepared from post-shrinkable polyethylene terephthalate fibers having a denier per filament of 1.5 (0.17 tex) and a length of 1.5 inches. The fibers are capable of shrinking about 40% long wise when immersed in boiling water.

Using apparatus of the type shown in FIGURE 1, and oblong screens of the general type shown in FIGURE 3, webs of the above description are patterned on each of the following screens:

| Product shown in Figures | Patterning Screen     |                      |               |
|--------------------------|-----------------------|----------------------|---------------|
|                          | Mesh Size (wires/in.) | Wire diameter (inch) |               |
| Product Code:            |                       |                      |               |
| A                        | 15, 16                | 30 x 8               | 0.018 x 0.035 |
| B                        | 17, 18                | 24 x 5               | 0.025 x 0.032 |

The assembly is passed under high impact streams of water (about 50° C.) issuing from 0.005-inch diameter orifices arranged in line along a 5-inch length of pipe at a density of 40 orifices per inch. A perforated plate having 50% open area, 462 holes/in.<sup>2</sup> and 0.037-inch diameter holes, is laid on top of the assembly to hold the web in place during the initial part of the treatment and is then removed. The web is treated, using water supplied at 2000 p.s.i. pressure, until a highly-tanglelaced ridge pattern is obtained. Passes are made in directions of the screen wires and the web is held approximately 1 inch from the orifices during treatment. The patterned structures thus obtained are dried on the patterning screen at about 40° C. in an air oven.

Properties of Products A and B are measured along each major axis of the fabric, and in the 45° bias direction, and are reported in Table I below. As may be seen from the table, these products have very desirable, fabric-like properties. It is notable that the secant moduli of these fabrics in the bias direction is very low, leading to the good drape properties of the fabric. The ridges of the fabrics are continuously tanglelaced along their lengths.

FIGURE 15 shows the top face of Product A, illuminated from above at an angle to emphasize the surface

configuration. FIGURE 16 is a similar view of the bottom face of the fabric which is next to the screen during production. The structure resembles that of the fabric illustrated in FIGURES 9 to 11, but a sharper pattern of ridges is obtained with the different type of fibers. The fabric has a fiber-interlock value of 21.0 grams per gm./m.<sup>2</sup> and an internal bond value of 0.49 foot-pound.

Product B is shown in FIGURES 17 and 18, which are views corresponding to FIGURES 15 and 16. Product B has wider bands, and the sides of the ridges are longer and more nearly parallel, due to the different screen used, but the structure is the same as in Product A. Product B has a fiber-interlock value of 22.4 grams per gm./m.<sup>2</sup> and an internal bond value of 0.52 foot-pound.

A product C is prepared in a similar way, but of different fibers on a patterning screen of finer mesh. The screen has 38 wires/inch of 0.015-inch diameter in one direction and 12 wires/inch of 0.020 inch diameter in the other direction. The initial web weighs about 2.5 oz./yd.<sup>2</sup> and is prepared from blended staple fibers, which are randomly disposed by an air-laying technique. The web consists of 50% by weight of 1.5 inch, 1.5 denier per filament acrylic fiber and 50% by weight of 0.25 inch, 1.5 denier per filament rayon fibers. Processing involves treatment with the high impact streams of water (about 60° C.) issuing from 0.005-inch diameter orifices arranged in line along a 24-inch length of pipe at a density of 40 orifices/inch. A high open area top screen (14 x 18 mesh) is laid on top of the assembly to help hold the web in place and the assembly is passed under the streams once at 500 p.s.i. and 3 times at 1500 p.s.i. The top screen is then removed and the web on its patterning screen is passed under the streams 6 times at 1500 p.s.i. Treatment is at about 1 yard per minute and about 1 inch from the orifices. The patterned product is dried on the patterning screen at room temperature.

Product C resembles that of Example 1B, which is also prepared from a blend of acrylic fibers with rayon fibers and is illustrated in FIGURES 9 to 11. Product C has a fiber-interlock value of 12.5 grams per gm./m.<sup>2</sup> and an internal bond value of 0.39 foot-pound.

TABLE I

| Weight<br>(oz./yd. <sup>2</sup> ) | Tensile Strength<br>(lb./in./oz./yd. <sup>2</sup> ) |     |      | Elongation<br>(percent) |    |      | 5% Secant Modulus<br>(lbs./in./oz./yd. <sup>2</sup> ) |     |      | Drapeflex (cm.) |     |      |
|-----------------------------------|-----------------------------------------------------|-----|------|-------------------------|----|------|-------------------------------------------------------|-----|------|-----------------|-----|------|
|                                   | MD                                                  | XD  | BIAS | MD                      | XD | BIAS | MD                                                    | XD  | BIAS | MD              | XD  | BIAS |
| Product code:                     |                                                     |     |      |                         |    |      |                                                       |     |      |                 |     |      |
| A-----                            | 2.4                                                 | 5.0 | 5.1  | 5.6                     | 57 | 55   | 63                                                    | 2.1 | 2.1  | 0.4             | 1.8 | 1.7  |
| B-----                            | 2.4                                                 | 6.8 | 5.4  | 6.4                     | 56 | 67   | 71                                                    | 4.1 | 1.4  | 0.6             | 2.2 | 1.6  |

MD: Values measured in direction of ridges shown in Figures 16 and 18.

XD: Measured 90° to MD.

BIAS: Measured 45° to MD.

### Example 3

This example illustrates production of additional forms of fabrics in continuous lengths on an oblong patterning screen of the type shown in FIGURE 4.

The patterning screen is of plain weave but has 30 wires per inch of 0.018-inch diameter in one direction and 8 wires per inch of 0.032-inch diameter in the other direction. The heavier wires are straight as shown in FIGURE 4, and the fabrics obtained differ significantly from the previous illustrations where crimps in the heavier wires produced additional apertures or depressions between the parallel bands.

An initial web is prepared of blended staple fibers, which are randomly disposed by an air-laying technique. The loose web consists of 50% by weight of 1.5-inch, 1.5 denier per filament acrylic fibers and 50% by weight of 0.25-inch, 1.5 denier per filament rayon fibers. Webs of 3, 4 and 5 oz./yd.<sup>2</sup> are treated in the same manner to produce tanglelaced fabrics.

The web is supported on the patterning screen and is passed in continuous lengths at 0.6 to 1 yard per minute under high impact-pressure streams of water issuing from

0.007-inch diameter orifices at a distance of about 1 inch from the web. The orifices are arranged in manifolds in straight lines at a density of 20 orifices per inch. The orifices of each manifold provide fine columnar streams which impinge perpendicularly on the web along a straight line extending completely across the web at right angles to the direction of movement. Four such manifolds are used, spaced about 8 inches apart in the direction of web travel. These manifolds are supplied with water at pressures of 500, 1000, 1500 and 1500 p.s.i., respectively. The fabric produced by this treatment proceeds directly to a conventional drum drier, where the fabric is dried under some tension in the machine direction. A temporary set is introduced in the fabric by the drying operation, but this is released in subsequent conventional finishing operations, as in the boil-off, e.g., relaxing it for 10 minutes in water at 100° C. The stretching during drying of continuous lengths of fabric as well as post-treatments such as boil-off of the samples may tend to close some of the apertures and result in further differences.

(A) A fabric weighing about 3 oz./yd.<sup>2</sup> is shown after boil-off in FIGURES 19 and 20, which are photographs at 1× magnification of the top and bottom faces, respectively. The top face has smooth parallel bands which alternate with parallel rows of evenly-spaced, oblong-shaped apertures. The bottom face, which is next to the screen during production, has a sharply-defined zig-zag pattern of ridges along the bands which is highly regular in appearance. These ridges are densely tanglelaced.

FIGURES 21 to 23 show the fabric at 10× magnification as dried on the drum drier, before boil-off. A zig-zag pattern of ridges is observed on both the top face (FIGURE 21) and the bottom face (FIGURE 23). FIGURE 22, a view by light transmitted through the fabric, shows the characteristic zig-zag pattern of dark tanglelaced areas along the bands which lock the fibers in place in the fabric.

A schematic drawing of the fabric structure after boil-off is shown in FIGURE 24. The extremely straight band-interconnecting fibers shown in FIGURE 23 and shown

schematically at 53 in FIGURE 24 are a result of drying the fabric under tension. When the fabric is dried without stretching, regions 53 show a more random fiber orientation. This is particularly true in the heavy weight fabrics, e.g., 4 oz./yd.<sup>2</sup> or more. FIGURE 25 is a photomicrograph at 50× magnification of a longitudinal cross section taken through the center of a band as indicated in FIGURE 24. The tanglelaced areas appear as dense masses of almost circular cross section in which the fibers run in all directions. Extending between these tanglelaced masses are parallelized band fibers which are locked into place in the tanglelaced masses. A similar arrangement is observed in FIGURE 26 of a cross section taken nearer to the edge of the band. Here two tanglelaced masses are so close together that they are nearly consolidated. The appearance of the band-interconnected fibers in a lateral cross section is similar to that of the parallelized band fibers; they extend between tanglelaced masses and are locked in place in the masses.

The fabric is soft, strong and drapable. The properties before and after boil-off are given below, where XD is

the direction along the parallel bands and MD is the cross direction.

| Fabric (A)                                        | After<br>Drying |      | After<br>Boil-Off |      |
|---------------------------------------------------|-----------------|------|-------------------|------|
|                                                   | XD              | MD   | XD                | MD   |
| Weight (oz./yd. <sup>2</sup> )                    | 2.49            | 2.66 | 2.91              | 3.01 |
| Tensile strength (lbs./in./oz./yd. <sup>2</sup> ) | 3.16            | 4.74 | 3.61              | 4.13 |
| Elongation (percent)                              | 52.2            | 31.8 | 43.5              | 48.4 |
| 5% secant modulus (lb./in./oz./yd. <sup>2</sup> ) | 2.24            | 21.7 | 3.36              | 1.55 |
| Bending length (cm.)                              | 1.58            | 2.64 | 1.72              | 1.64 |

(B) A fabric weighing about 4 oz./yd.<sup>2</sup> is shown after boil-off at 10× magnification in FIGURES 27 to 29. This fabric is made in the same way as the previous fabric. However, partly because of the heavier weight and primarily because it is shown after boil-off, the fabric has a softer and more regular appearance than in FIGURES 21 to 23 of Fabric (A). In the top view (FIGURE 27), random fibers of fluffy appearance obscure the tanglelaced areas and most of the parallelized fibers. A zig-zag pattern of ridges is apparent in the bottom view (FIGURE 29) but the ridges are rounded and softer in appearance. The transmitted light view (FIGURE 28) shows the characteristic fiber structure of dense zig-zag tanglelaced areas discussed previously.

(C) A fabric weighing about 5 oz./yd.<sup>2</sup> after boil-off is shown in FIGURES 30 to 32. FIGURE 30 shows the top face at 1× magnification; the highly regular arrangement of oblong-shaped apertures is the most notable feature. The apertures of adjacent rows are offset in a uniform direction along lines oblique to the band axes. Each of the apertures is of oblong shape with the longer dimension aligned perpendicular to the band axes.

FIGURES 31 and 32 show the top and bottom faces at 10× magnification by direct illumination. The bands are rounded on both faces and are covered with a soft overlay of fibers which obscures the structural features observed in the previous fabrics. The fabric has the general appearance of a piqué weave.

FIGURES 33 to 35 show the fabric at 10× magnification after drum drying under tension and before boil-off. The fibers of the top face (FIGURE 33) have been pressed down and set to give an almost flat appearance between the apertures. On the other hand, the ridges are more prominent on the bottom face (FIGURE 35) than in the corresponding view after boil-off (FIGURE 32). The band-interconnecting fibers have been straightened to such an extent that there is little or no indication of the depressions visible between the bands after boil-off. The transmitted light view (FIGURE 34) shows the characteristic fiber structure of dense zig-zag tanglelaced areas. Physical properties of the drum dried fabric are as follows:

| Fabric (C)                                        | MD   |      | XD |
|---------------------------------------------------|------|------|----|
|                                                   |      |      |    |
| Weight (oz./yd. <sup>2</sup> )                    | 4.83 | 4.99 |    |
| Tensile strength (lb./in./oz./yd. <sup>2</sup> )  | 2.32 | 3.29 |    |
| Elongation (percent)                              | 41.2 | 53.4 |    |
| 5% secant modulus (lb./in./oz./yd. <sup>2</sup> ) | 5.51 | 2.29 |    |
| Bending length (cm.)                              | 1.92 | 2.03 |    |

In the foregoing 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. The 5% secant modulus is determined by A.S.T.M. Standards E6-61, part 10, page 1836.

Drape 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.

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.

We claim:

1. An apertured tanglelaced nonwoven textile fabric of fibers entangled in a repeating pattern of fiber bands of substantially greater width than thickness which extend continuously along spaced parallel axes between rows of apertures in one fabric direction; the bands being characterized by tanglelaced fiber areas which proceed obliquely back and forth along each band in a zig-zag pattern, the pattern being clearly visible when the fabric is viewed by transmitted light, and by interstitial arrays of generally parallelized fibers which extend lengthwise along each band between tanglelaced areas and are locked into place in the zig-zag tanglelaced areas; said bands being interconnected by bundles of generally parallelized fibers which extend laterally between corresponding elbows of zig-zag tanglelaced areas in adjacent bands, are located between said apertures and are locked into place by the tanglelaced areas; said fibers being locked into place in the tanglelaced areas by a three-dimensional fiber entanglement characterized by a fiber-interlock value of at least 7 and an internal bond value of at least 0.2 foot-pound, said values being determined in the absence of binder; and wherein fibers in the tanglelaced areas turn, wind, twist back-and-forth, and pass about one another in all dimensions of the structure in such an intricate entanglement that fibers interlock with one another when the fabric is subjected to stress, to thereby provide coherency and strength to the fabric.

2. A tanglelaced fabric as defined in claim 1 wherein said zig-zag tanglelaced areas form high density ridges on at least one face of the fabric.

3. A tanglelaced fabric as defined in claim 2 wherein said zig-zag pattern of tanglelaced ridges has the general configuration of chevron molding.

4. A tanglelaced fabric as defined in claim 1 wherein the spacing between said parallel band axes is evenly spaced at a distance greater than the maximum dimension of each of said apertures.

5. A tanglelaced fabric as defined in claim 4 wherein the spacing between said band axes is less than twice the maximum dimension of the apertures and the fabric has the general appearance of a woven leno cellular fabric when viewed with the naked eye by reflected light.

6. A tanglelaced fabric as defined in claim 1, of fibers entangled in a repeating pattern of fiber bands of substantially greater width than thickness which extend continuously along substantially straight parallel axes spaced regularly in one fabric direction; the bands comprising tanglelaced fiber areas characterized by ridges on at least one fabric face which proceed continuously back and forth along each band in a zig-zag pattern, and interstitial arrays of generally parallelized fibers which extend lengthwise along each band between tanglelaced areas and are locked into place in the zig-zag tanglelaced areas; said bands being interconnected by bundles of generally parallelized fibers which extend laterally between corresponding elbows of tanglelaced areas in adjacent bands and are locked into place by the tanglelaced areas, the band-interconnecting fiber bundles being spaced regularly along the edges of the bands and defining rows of apertures therebetween; the apertures of adjacent rows being offset in a uniform direction oblique to said band axes,

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and each of said apertures being of oblong shape with the major axis aligned perpendicular to said band axes.

7. A tanglelaced fabric as defined in claim 6 wherein said apertures are on uniformly spaced centers and the center-to-center spacing between adjacent rows of apertures is from 1.5 to 5.0 times the center-to-center spacing of adjacent apertures in the same row.

8. A tanglelaced fabric as defined in claim 6 wherein the spacing between said parallel band axes is about 2 to 4 times the maximum dimension of each of said apertures.

9. A tanglelaced fabric as defined in claim 6 wherein said tanglelaced fiber areas form zig-zag ridges on both faces of the fabric.

10. A tanglelaced fabric as defined in claim 6 which has the general appearance of a piqué weave when viewed with the naked eye by reflected light.

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