FIG. 1

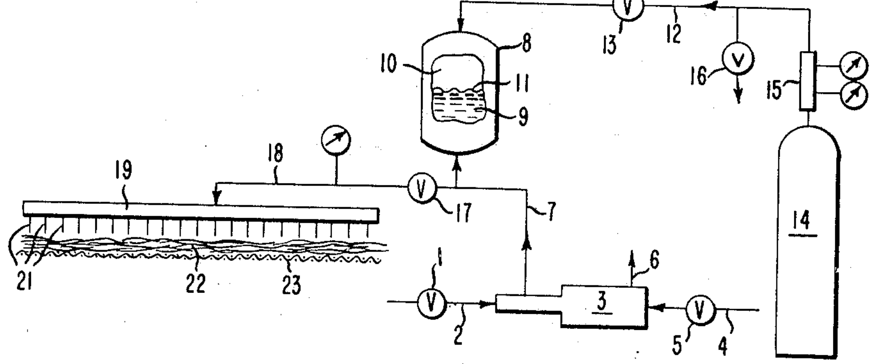

FIG. 2

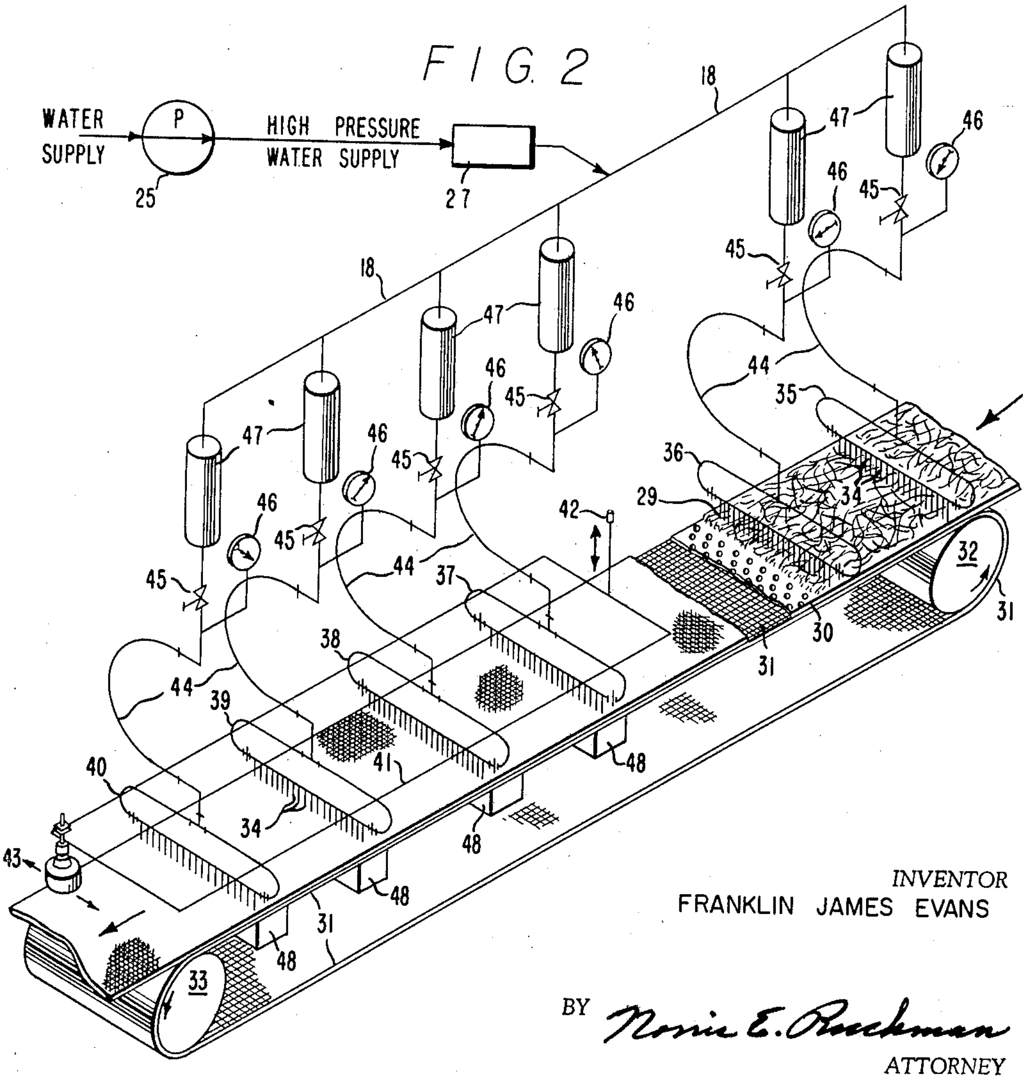

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FIG. 3

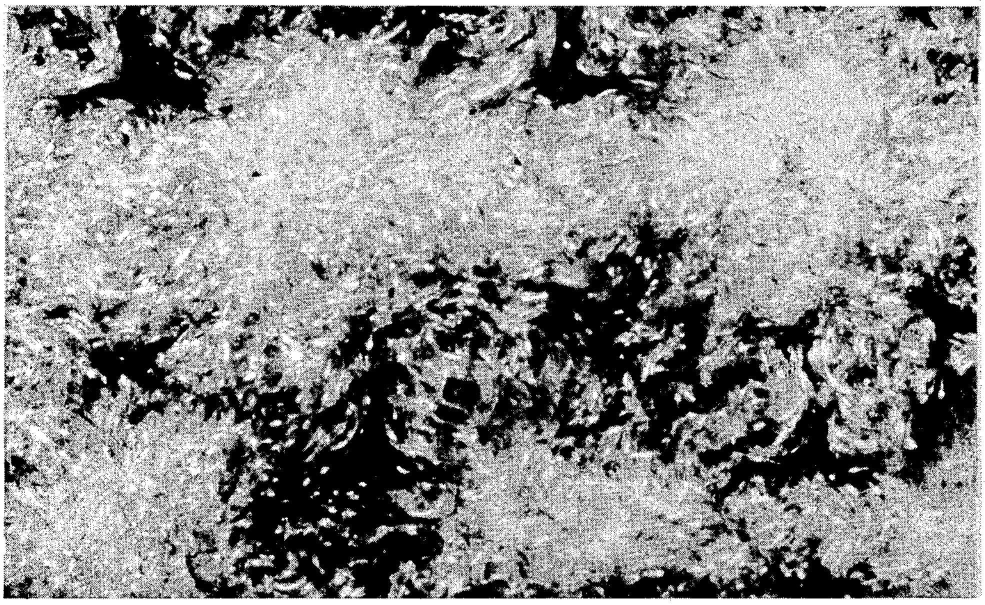

FIG. 4

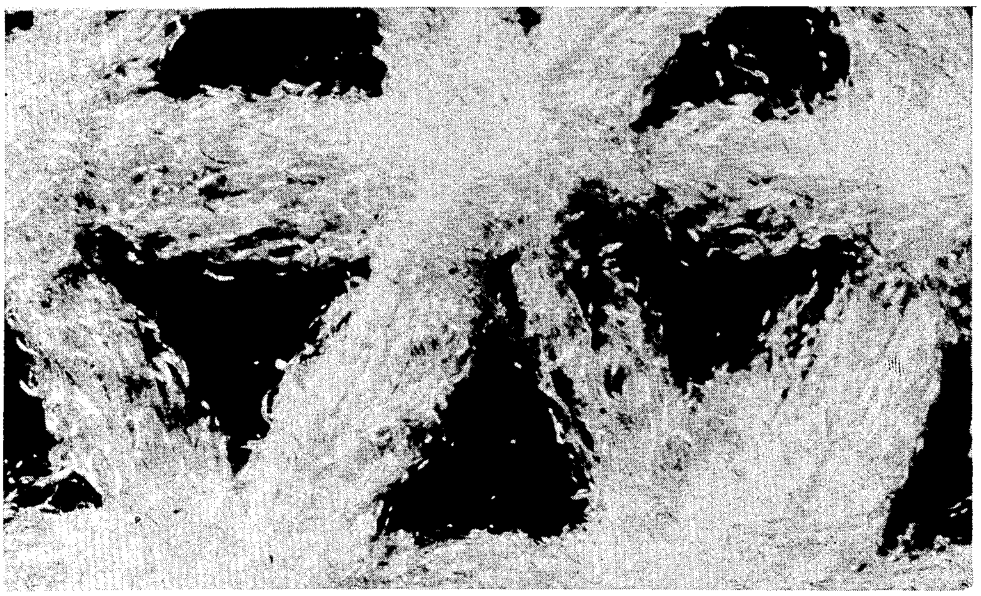

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FIG. 11

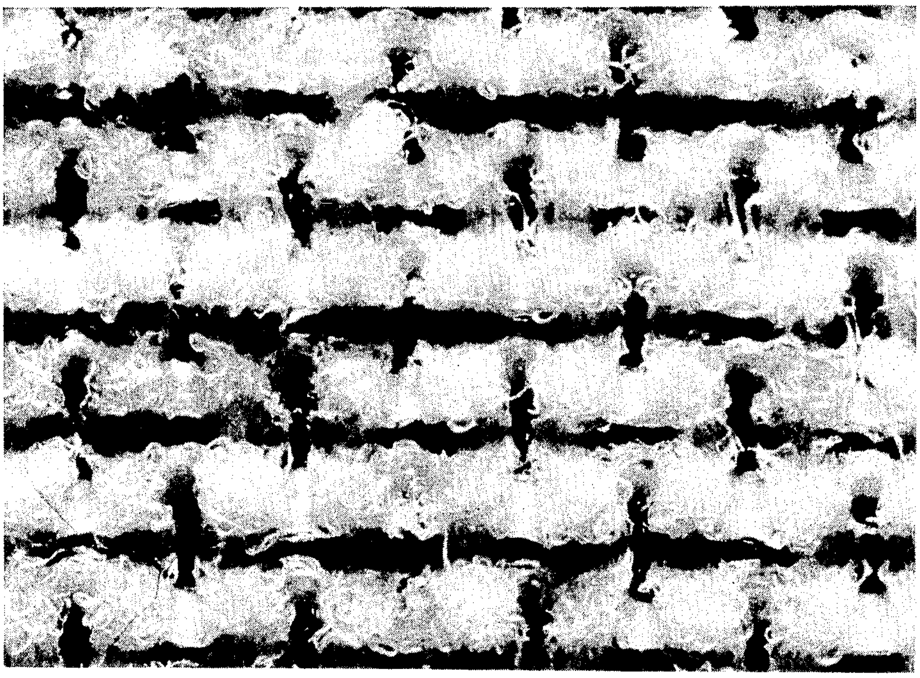

FIG. 5

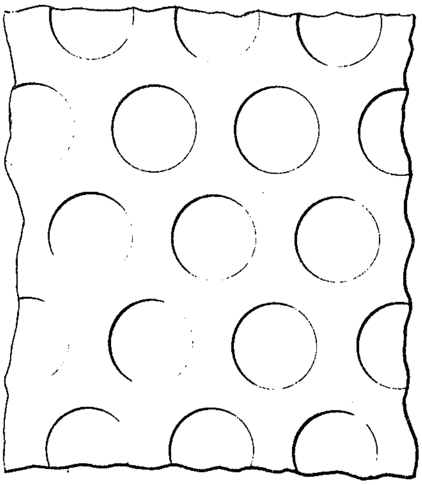

FIG. 12

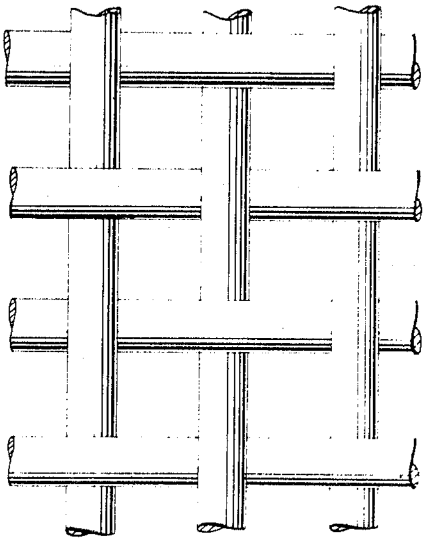

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FIG. 6

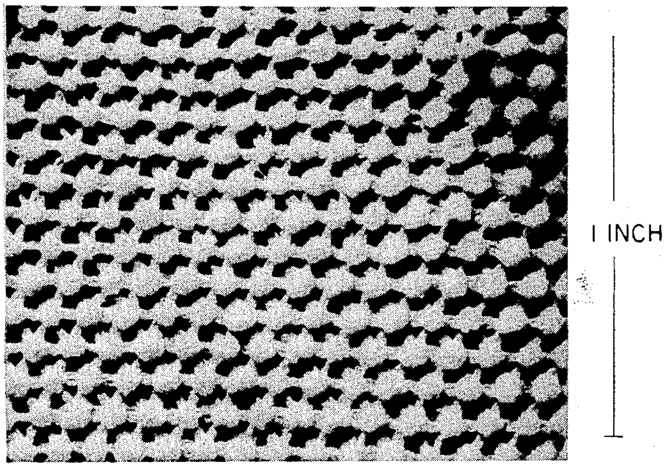

FIG. 8

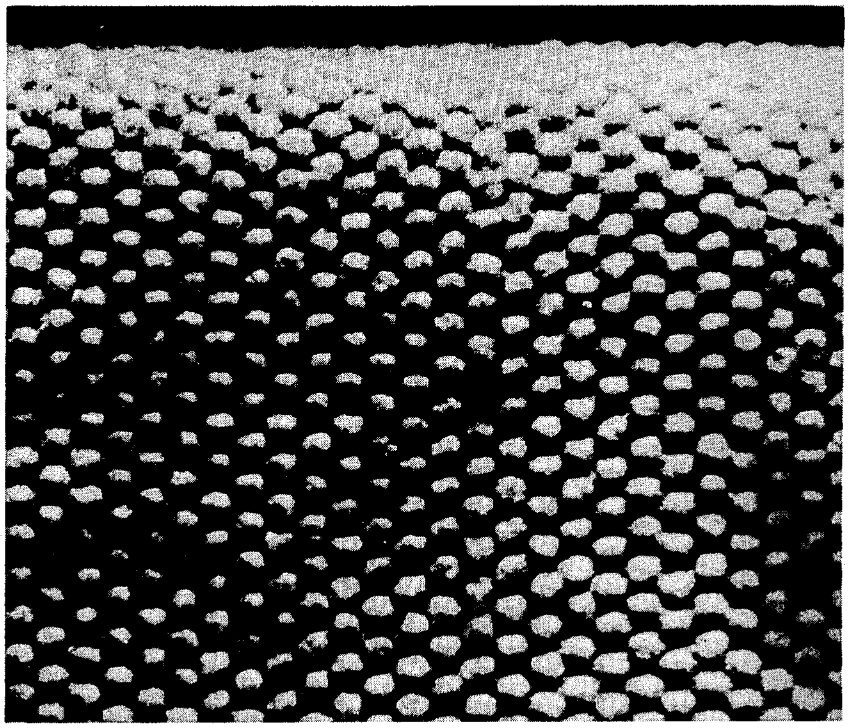

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FIG. 7

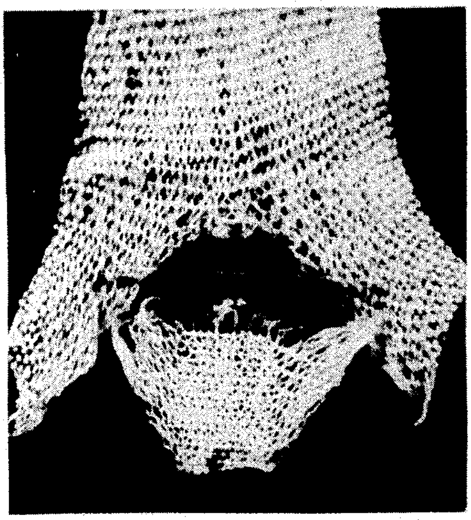

FIG. 10

FIG. 9

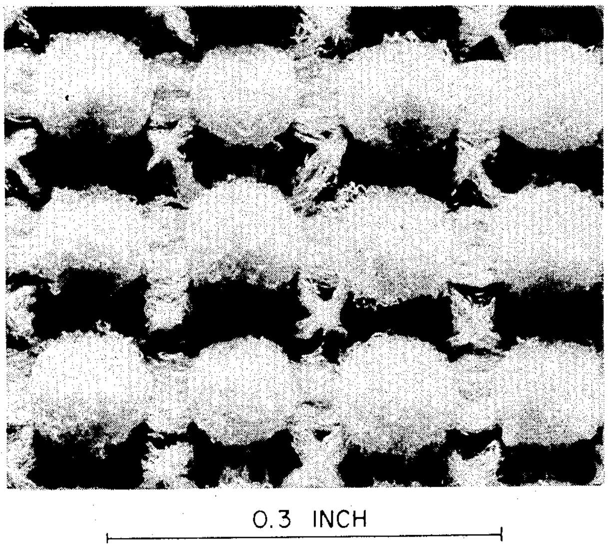

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FIG. 13

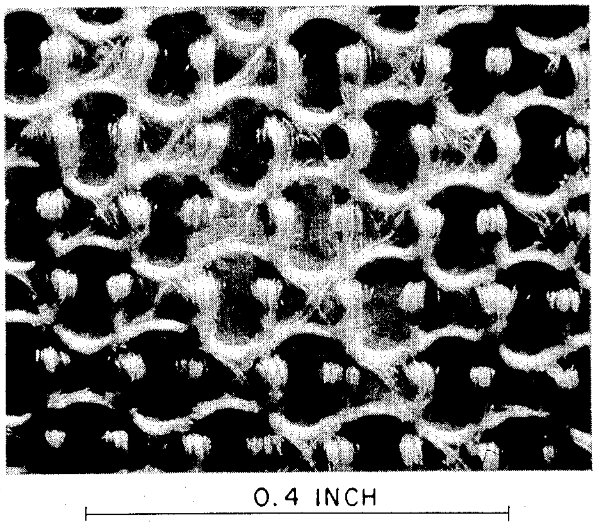

FIG. 14

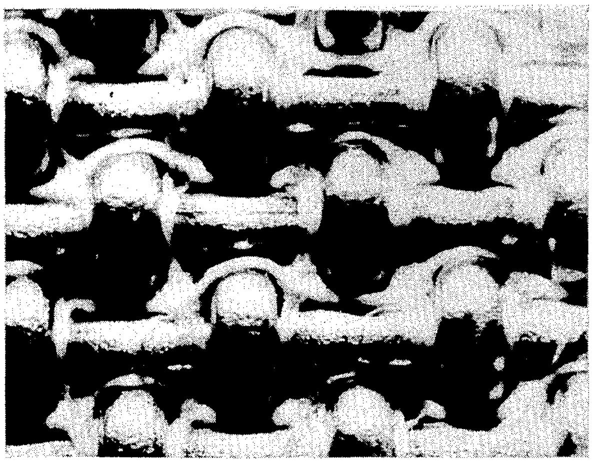

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FIG 15

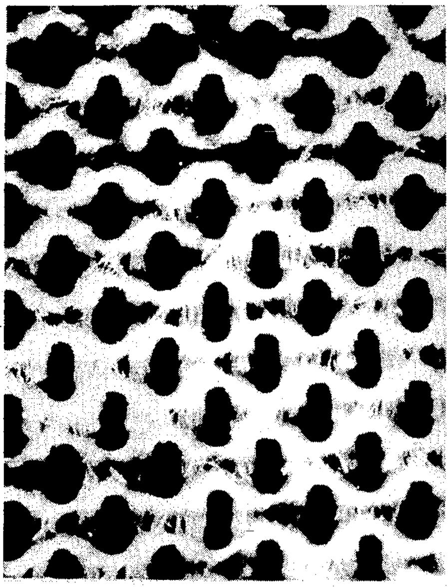

FIG 15a

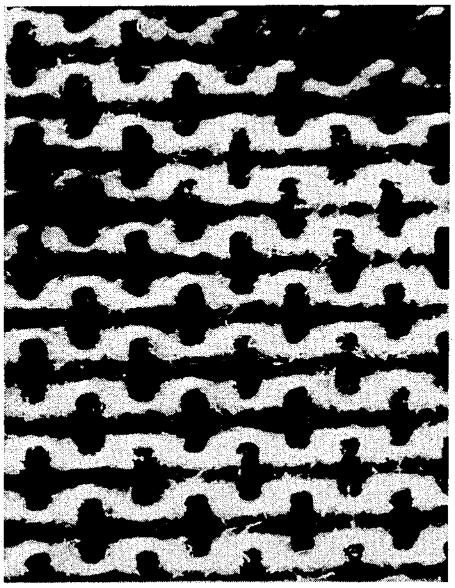

FIG 16

FIG 16a

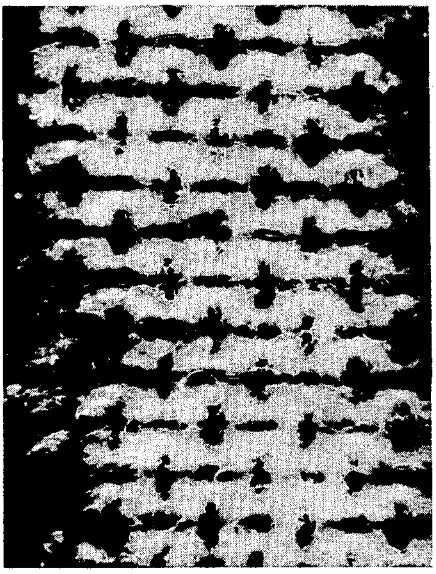

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FIG. 18

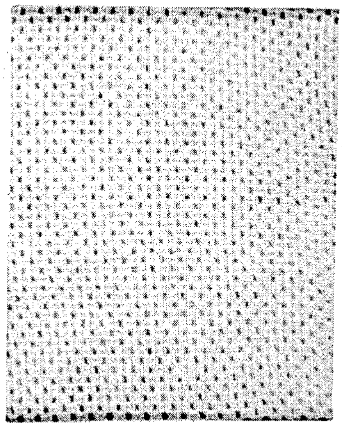

FIG. 19

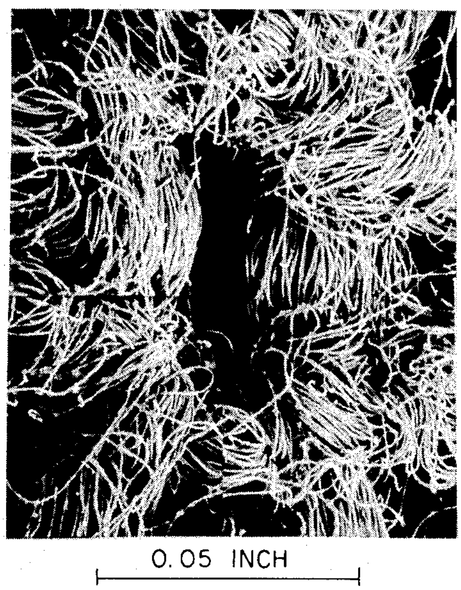

FIG. 17

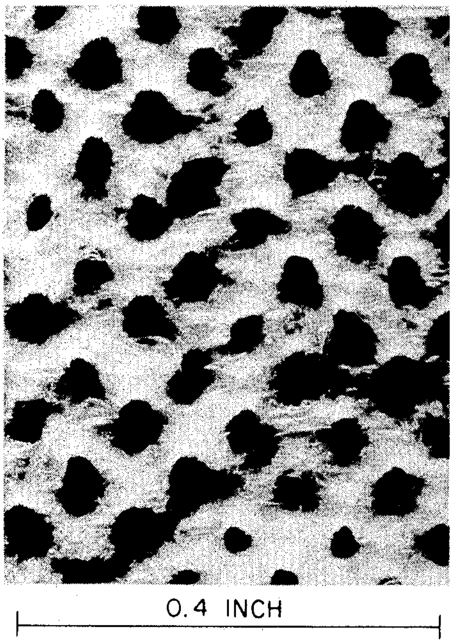

FIG. 17a

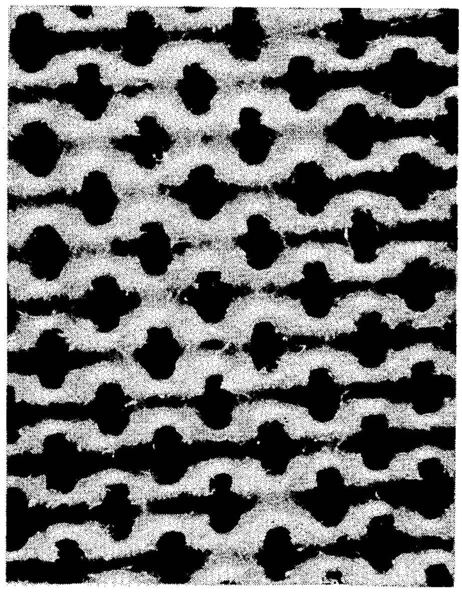

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FIG. 20

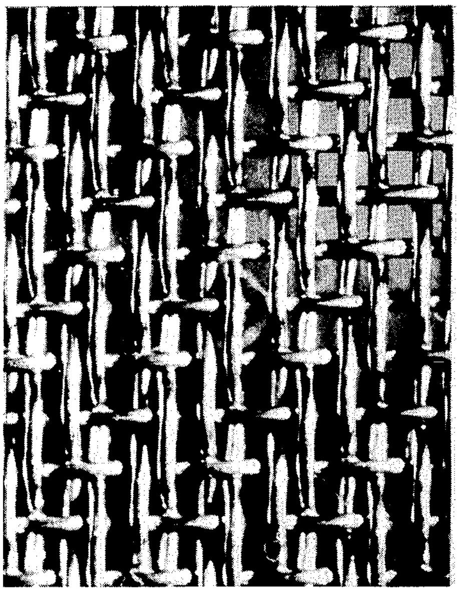

FIG. 21

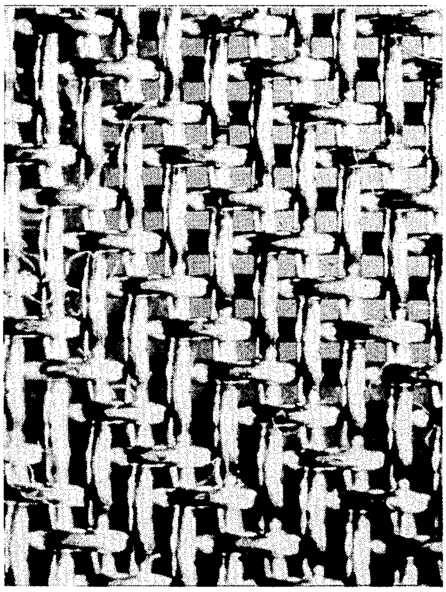

FIG. 22

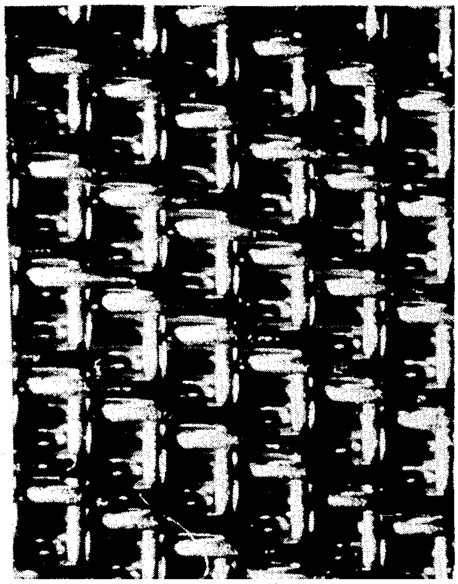

FIG. 23

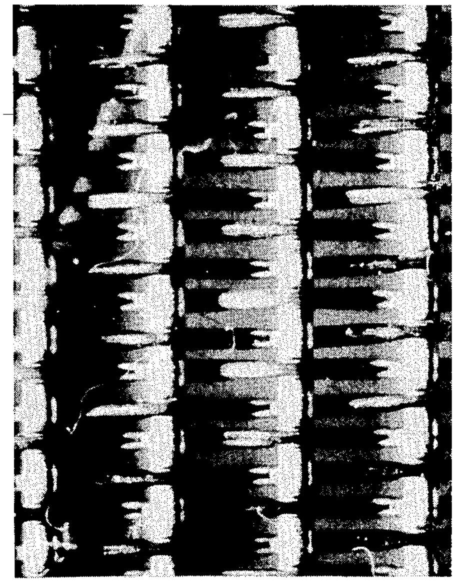

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FIG. 24

FIG. 24a

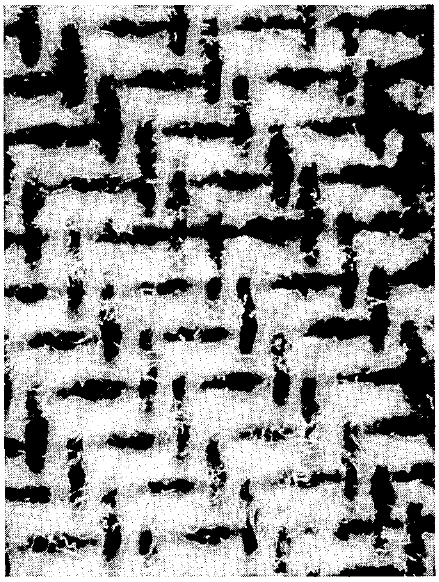

FIG. 25

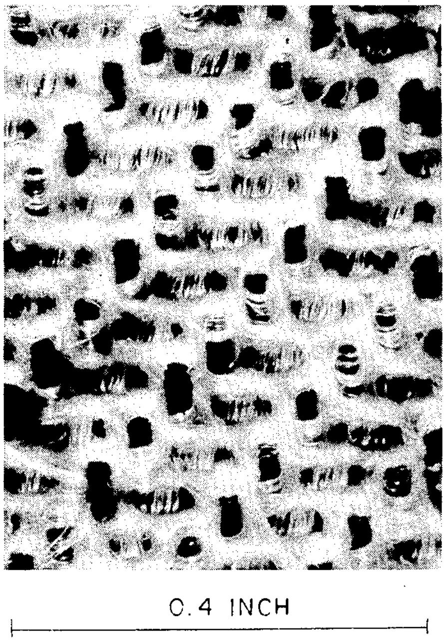

FIG. 25a

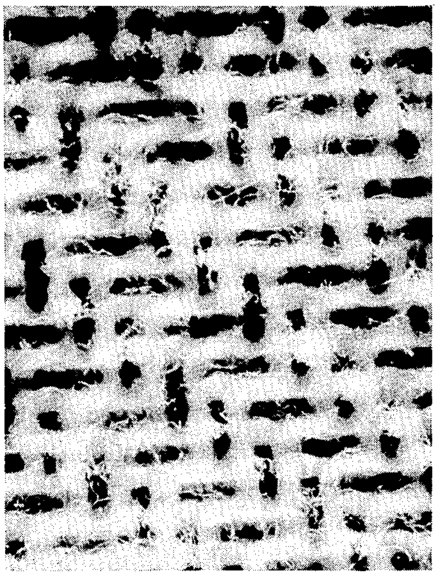

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FIG. 26

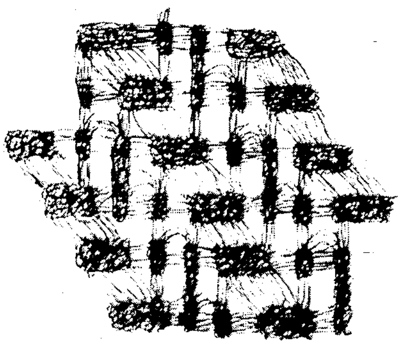

FIG. 27

FIG. 28

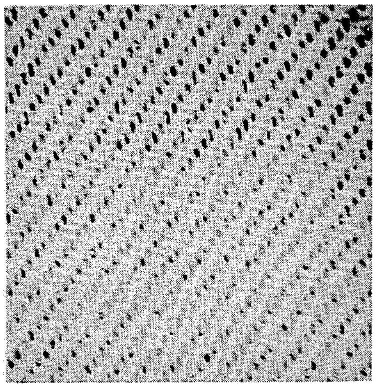

FIG. 28a

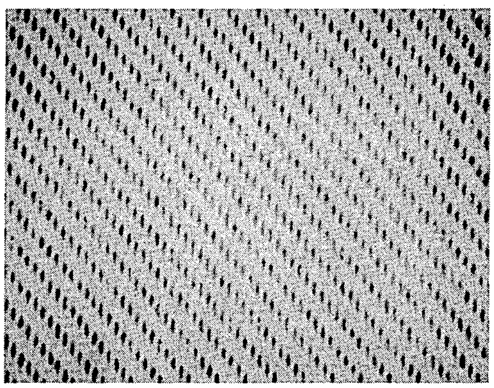

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FIG. 29

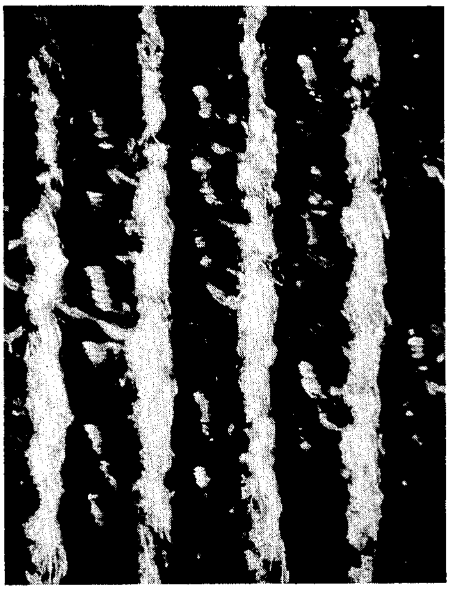

FIG. 29a

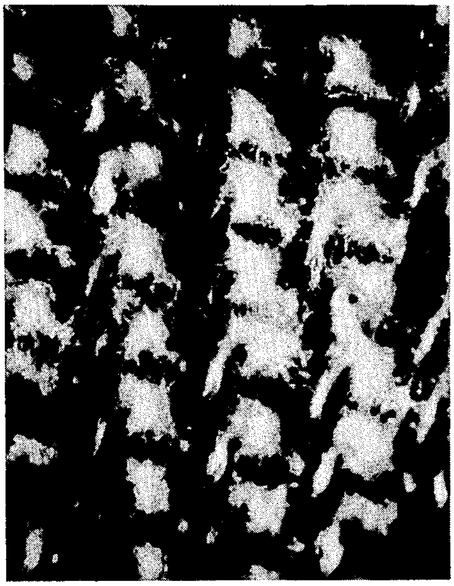

FIG. 30

FIG. 30a

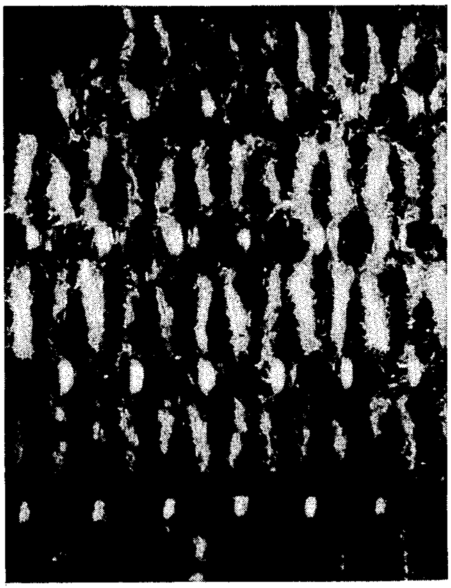

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FIG. 31

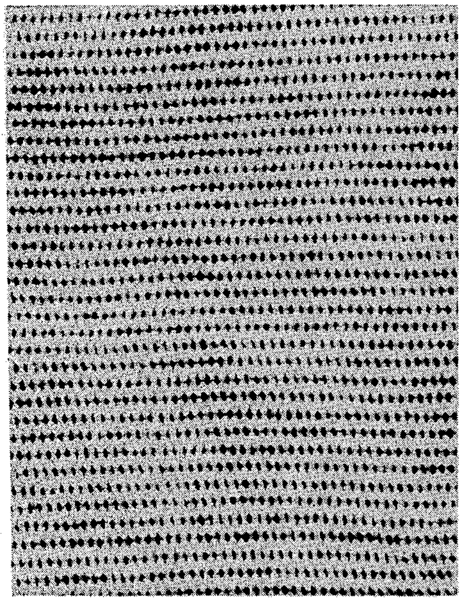

FIG. 31a

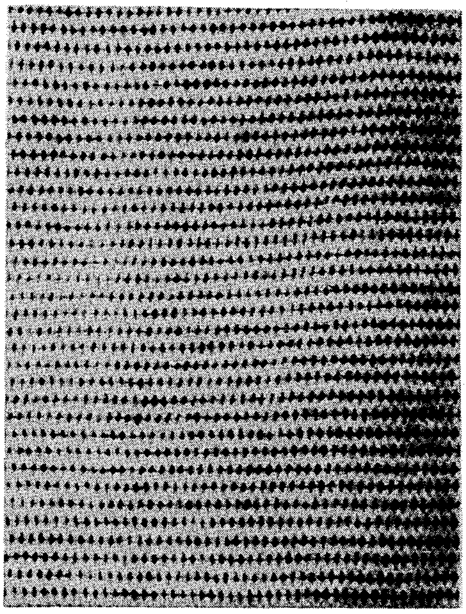

FIG. 32

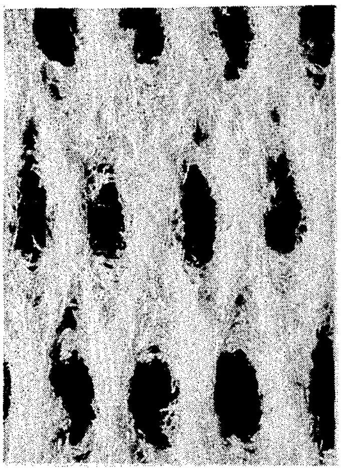

FIG. 33

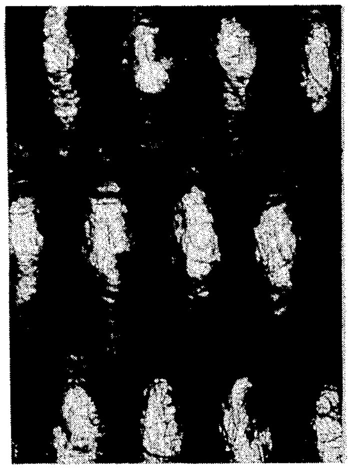

FIG. 34

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FIG. 35

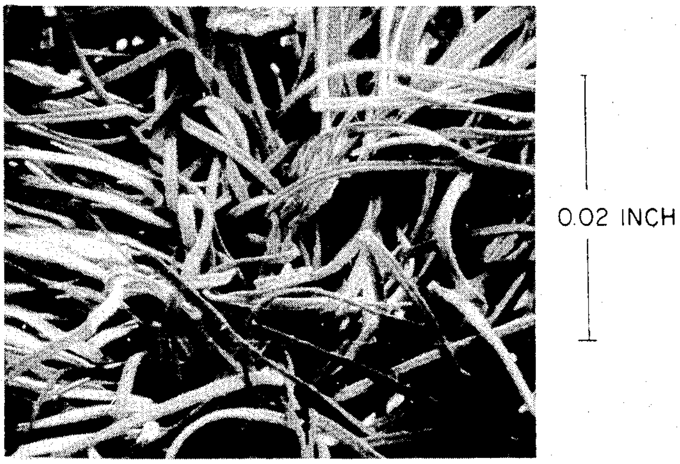


FIG. 36

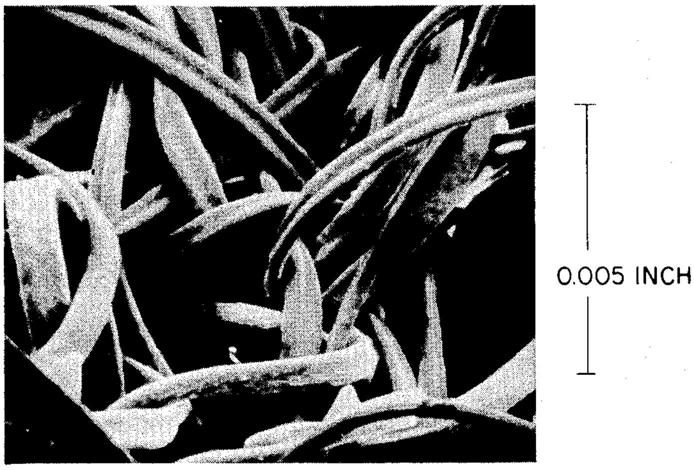
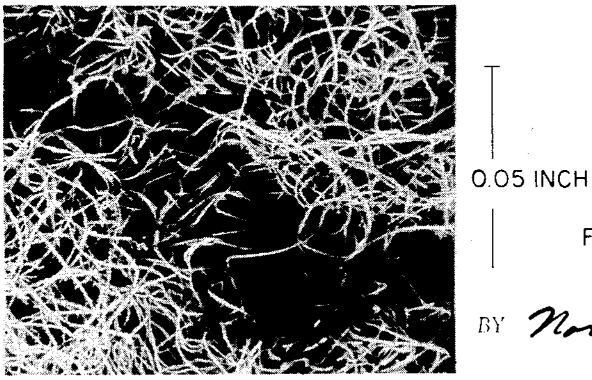


FIG. 37



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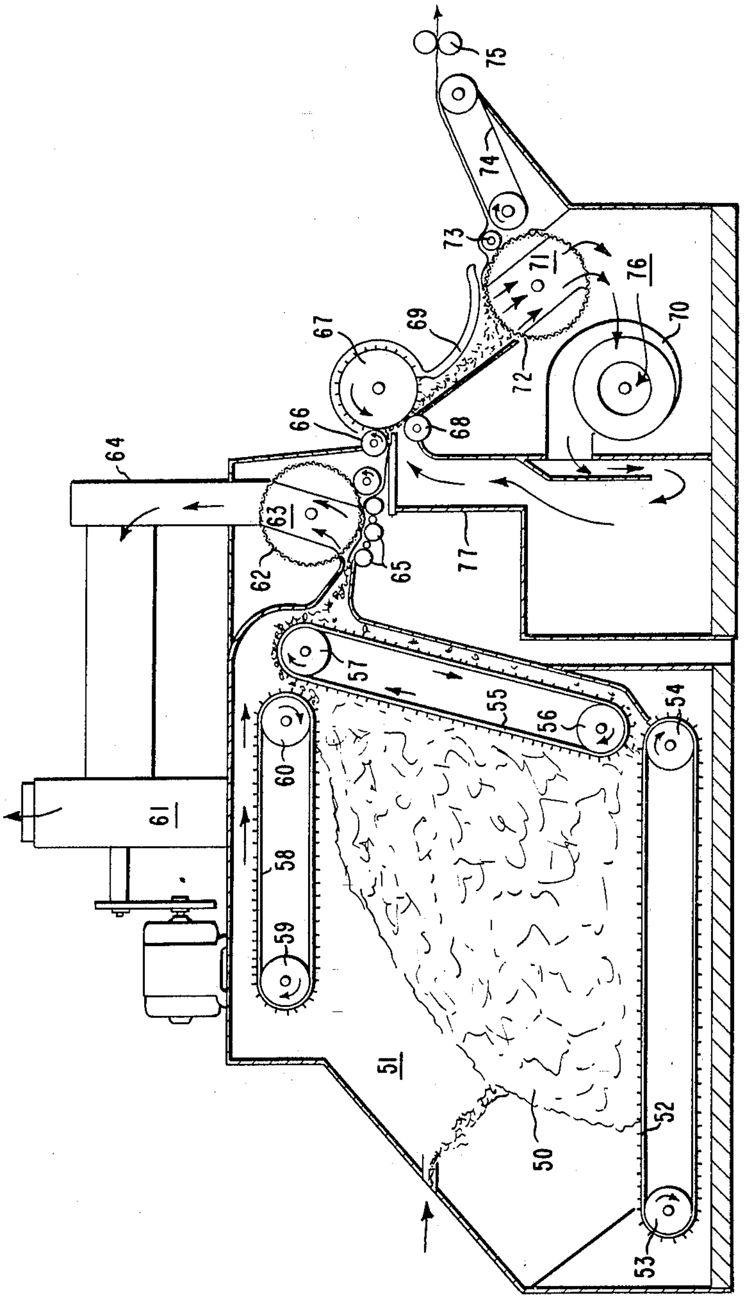

FIG. 38

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Dec. 23, 1969 F. J. EVANS **3,485,706**

TEXTILE-LIKE PATTERNED NONWOVEN FABRICS AND THEIR PRODUCTION

Filed Jan. 18, 1968 17 Sheets-Sheet 16

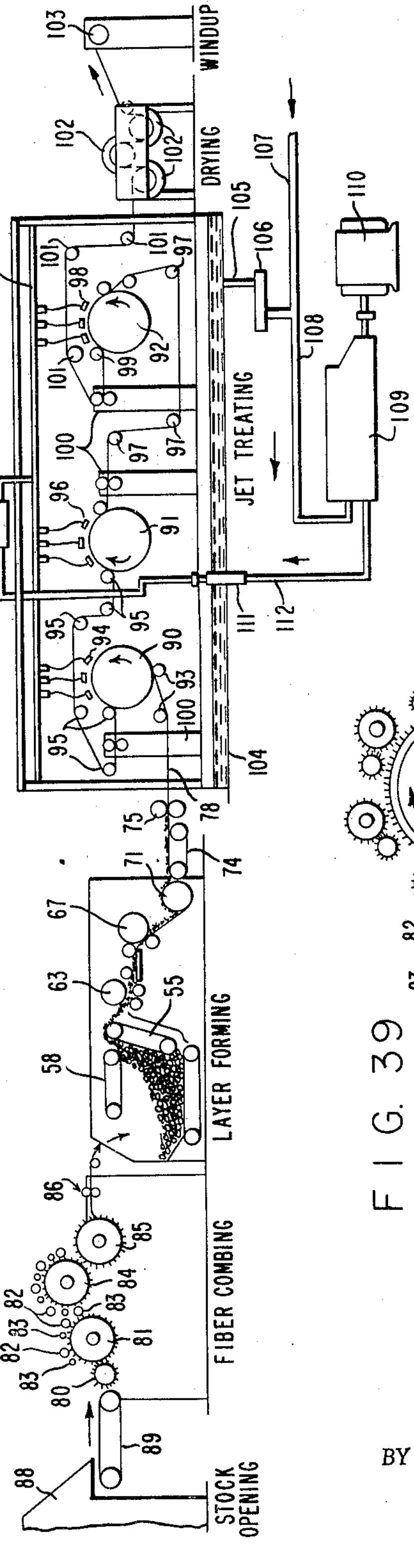

FIG. 40

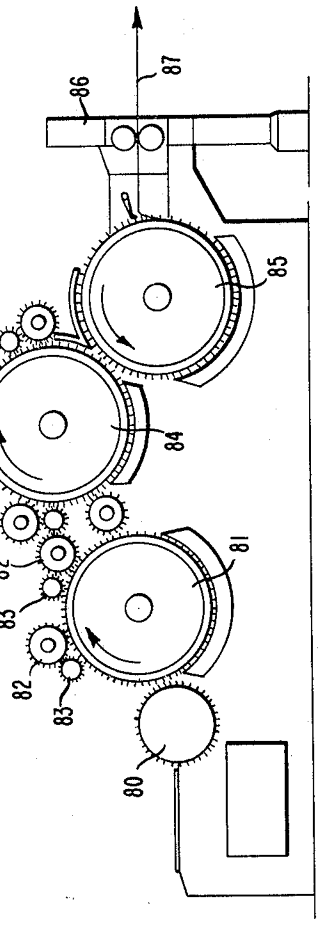

FIG. 39

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TEXTILE-LIKE PATTERNED NONWOVEN FABRICS AND THEIR PRODUCTION

Filed Jan. 18, 1968

17 Sheets-Sheet 17

FIG. 41

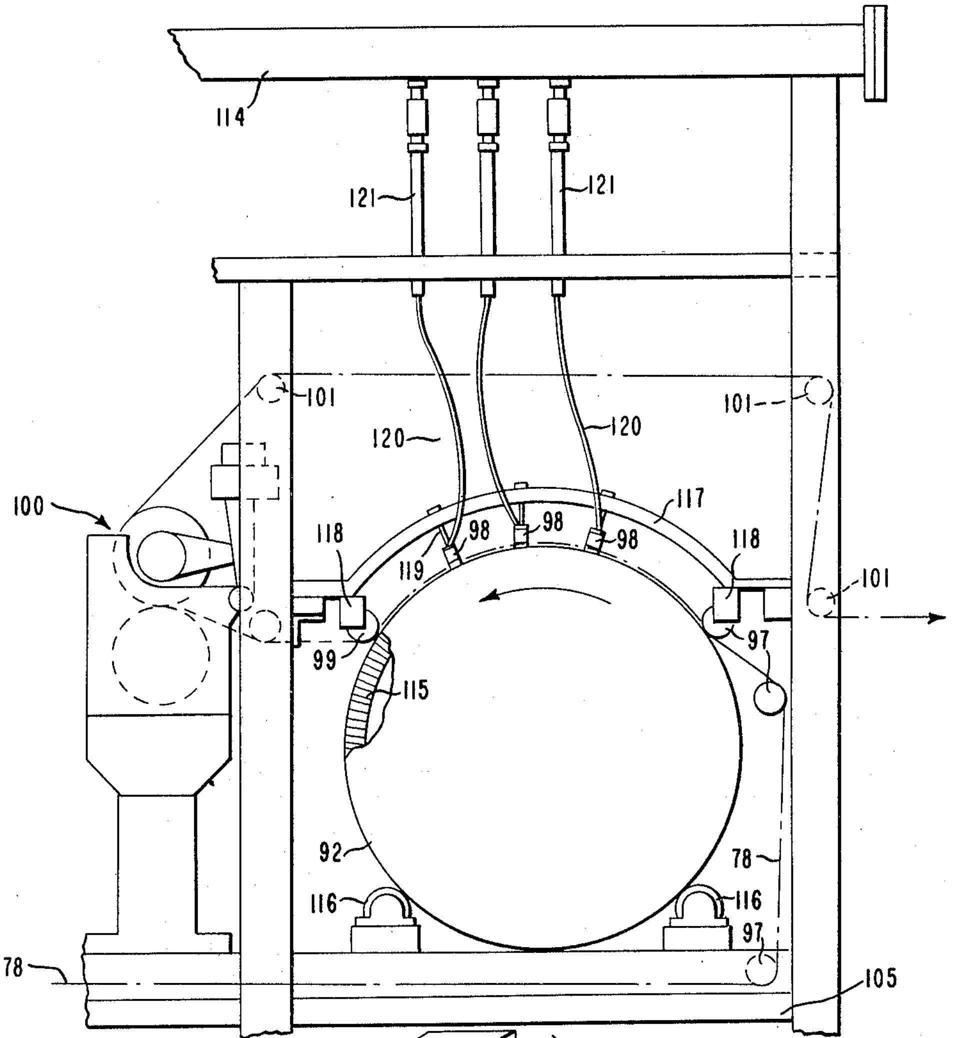
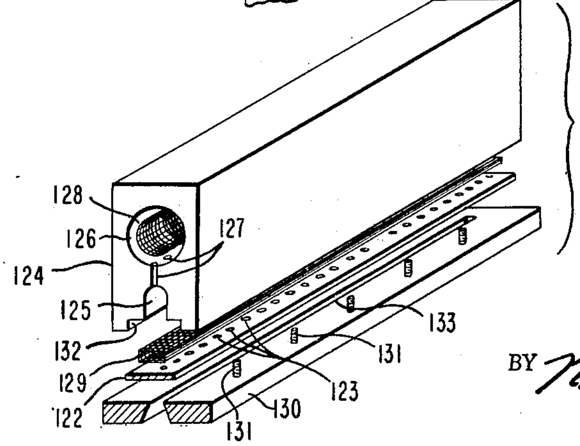


FIG. 42



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BY

ATTORNEY

United States Patent Office **3,485,706** **Patented Dec. 23, 1969**

3,485,706

TEXTILE-LIKE PATTERNED NONWOVEN FABRICS AND THEIR PRODUCTION

Franklin James Evans, Wilmington, Del., assignor to E. I. du Pont de Nemours and Company, Wilmington, Del., a corporation of Delaware

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. 462,170, June 8, 1965, Ser. No. 462,183, June 8, 1965, Ser. No. 550,209, May 16, 1966, Ser. No. 607,748, Jan. 6, 1967, and Ser. No. 607,749, Jan. 6, 1967. This application Jan. 18, 1968, Ser. No. 698,802

Int. Cl. D04h *3/08;* **D06c** *1/06*

U.S. Cl. 161—72 **75 Claims**

ABSTRACT OF THE DISCLOSURE

A wide variety of textile-like nonwoven fabrics is produced by traversing fibrous material with high energy liquid streams while supported on an apertured member, such as a perforated plate or woven wire screen, to consolidate the material in a repeating pattern of entangled fiber regions and interconnecting fibers. Fibers are randomly entangled in a manner which holds the fibers of the fabric in place without the need for bonding agents. Processes and apparatus are illustrated for preparing a loose layer of fibers and treating the layer with liquid jetted at a pressure of at least 200 p.s.i.g. from a row of small orifices to convert the layer directly into coherent, highly stable, strong nonwoven fabrics which resemble many textile fabrics prepared by conventional process steps such as mechanical spinning and weaving.

CROSS-REFERENCES TO RELATED APPLICATIONS

This is a continuation-in-part of my applications Ser. No. 299,805 filed Aug. 5, 1963, Ser. 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. 462,170 filed June 8, 1965, Ser. No. 462,183 filed June 8, 1965, Ser. No. 550,209 filed May 16, 1966, Ser. No. 607,749 filed Jan. 6, 1967, all now abandoned, and Ser. No. 607,748 filed Jan. 6, 1967.

BACKGROUND OF THE INVENTION

This invention relates to a new jet process and apparatus for producing nonwoven fabrics, and to the novel fibrous products which are obtained. More particularly, it relates to patterned nonwoven structures and to process and apparatus for producing them by subjecting bulk fibrous materials to the action of high-energy-flux liquid streams.

Foraminous nonwoven webs have been made in the past by a variety of processes. For example, staple or papermaking fibers have been deposited from a slurry or from an air stream onto slotted forming screens or molds or onto screens having spaced protuberances in order to form webs, in which the fibers are arranged in groups in accordance with the pattern of the forming screen. Apertured webs have also been made by subjecting staple fiber webs to a localized mechanical working, for example, by perforating an unwoven sheet at spaced intervals with pins or by passing a wetted web between meshing toothed cylinders and using vibration to forcibly move segments of fibers apart to form holes in the web. Localized streams of gas or liquid have also been used to blow the fibers out of discrete areas of a web to thereby create a plurality of holes in the web. Foraminous nonwoven webs have also been produced by using dispersed low impact-pressure sprays of water to exert a washing action on the fibers of a staple fiber web, as the web is held sandwiched between an apertured plate and a fine mesh screen.

Of the above, those processes which require the use of vibrating needles, blowing and the like, in general, provide foraminous webs having a poorly ordered pattern and apertures which are irregular in size and shape. Formainous webs having a predetermined pattern and more uniform apertures may be achieved by the use of the air or slurry-deposition processes or by the spray-washing process described above. However, all of the above prior art procedures yield foraminous webs which have little or no integral strength. This lack of strength and coherence is due to the fact that the individual fibers within the web are not permanently associated with one another, with the result that the web can be readily pulled apart when subjected to stress. Some degree of strength and coherency may be imparted to such webs by the use of an adhesive or binder to bond the individual fibers together. The strength which can be achieved by such methods and the utility of the webs obtained are limited by the bonding power of the adhesive employed and its ability to retain its bonding power after repeated use and/or laundering of the web. Moreover, in many applications, the persence of any adhesive substance is undesirable, particularly when used in the amount required to develop some degree of strength, because of the deleterious effect of the adhesive on dyeability, drapability, hand and other properties important for textile uses. Finally, the additional cost of the binder and of its application to the web add to the overall cost of the product.

SUMMARY OF THE INVENTION

The present invention provides for the production of textile-like nonwoven fabrics of fibers randomly entangled with each other in a repeating pattern of localized entangled regions interconnected by fibers extending between adjacent entangled regions. This invention also provides a process for consolidating fibers or filaments into strong patterned structures without using the conventional process steps previously required for producing strong, nonbonded, patterned fabrics, such as weaving, knitting, netting or the like, and without the need for binder or other supplementary treatment. The present invention further provides apparatus for the direct conversion of bulk fibrous materials into such patterned nonwoven fabrics. The present invention also provides for such production of textile-like nonwoven fabrics from a wide variety of types and lengths of fibers, starting with various forms of bulk fibrous materials, an important improvement over conventional weaving or knitting with yarns of staple fibers which are formed into yarn by drafting and twisting operations and must be of suitable length. The present invention also provides a multitude of new and useful patterned nonwoven fabric products. These and other advantages of this invention will become apparent in the course of the following specification and claims.

The novel products of the present invention are textile-like nonwoven fabrics comprising fibers locked into place by fiber interaction to provide a strong cohesive structure without the need for binder or filament fusing. The products have a repeating pattern of entangled fiber regions, of higher area density (weight per unit area) than the average area density of the fabric, and interconnecting fibers which extend between the dense entangled regions and are randomly entangled with each other in the dense entangled regions. Many different patterns can be provided as disclosed subsequently. Localized entangled regions may be interconnected by fibers extending between adjacent entangled regions to define regions of lower area density than that of tthe adjacent fabric. A pattern of apertures substantially free from fibers may be defined by the dense entangled regions and interconnecting fibers. In preferred products the dense entangled regions are arranged in a regular pattern and joined by ordered groups of fibers to provide a fabric having an appearance similar to that of a conventional woven fabric, but in which the fibers proceed randomly through the fabric from entangled region to entangled region. The fibers of an ordered group may be either substantially parallel or randomly disposed relative to one another. Embodiments include fabrics having complex fiber structures with entangled fiber regions interconnected by ordered fiber groups located in different thickness zones of the fabric, which are particularly suitable for apparel, including dress goods and suiting materials.

As stated, fibers are locked into place in the fabric by fiber interaction. By "locked into place" is meant that individual fibers of the structure not only have no tendency to move from their respective positions in the patterned structure but are actually physically restrained from such movement by interaction with themselves and/or with other fibers of the fabric. Fibers are locked into place in the entangled fiber regions of higher area density than the average area density of the fabric, and such fiber interaction may also occur elsewhere.

By "interaction" is meant that the fibers turn, wind, twist back-and-forth, and pass about one another in all directions of the structure in such an intricate entanglement that they interlock with one another when the fabric is subjected to stress. This can be measured by the fiber-interlock test described near the end of the specification. The fabrics of this invention have a fiber-interlock value due to fiber entanglement of at least 7. Fabric bonded with binder will give higher values than the same fabric before bonding. Since the value determined in the absence of binder is at least 7 for the products of this invention, it is desirable to test samples before bonding or after substantial removal of any binder present, if this is possible. For nonbonded fabrics, the proportion of fibers which have interlocking entanglement can be evaluated by the evaluated by the entanglement completeness test described near the end of the specification, and the average intensity of fiber entanglement along the fibers can be estimated by the entanglement frequency test. In preferred products, the fiber entanglement frequency for nonbonded fabric is at least 20 per inch with a fiber entanglement completeness of at least 0.5. Fabrics having entanglement frequencies of at least 40 per inch are also provided for uses requiring outstanding surface stability.

The three-dimensional character of the fiber entanglement described above is readily seen when fabric cross-sections through entangled regions are observed at high magnification with a microscope having sufficient depth of focus, and can be evaluated in various ways, e.g., by the relatively simple "internal-bond" test described at the end of the specification. Included within the scope of the invention are textile-like nonwoven fabrics of fibers locked into place in a structure characterized by an internal-bond value of at least 0.2 foot-pound.

The entangled fiber structure is preferably characterized by random fiber segments that penetrate entangled fiber regions of the fabric and have a re-entrant loop configuration in the fiber segment which binds other fibers in place in the fabric. This is illustrated in FIGURE 36. By "re-entrant loop configuration which binds other fibers in place" is meant the configuration of fiber segments (portions of a fiber) in the entangled region which emerge into view from random locations within the body of the fabric, are bent around and pass over other fibers, and then re-enter the body of the fabric. A considerable fraction (generally a large fraction for fabrics having relatively large entangled areas) of these fiber segments normally emerge from and re-enter the same entangled region at a substantial angle to the fabric plane. The configuration of the re-entrant segment may resemble a hairpin or reflex loop (in the case where the emerging and re-entering legs are close together) and cause fibers to be bound in place in an analogous manner. The legs of such a reflex loop often penetrate entirely through the fabric to emerge from the opposite side of the fabric as either fiber ends or closed loops and, in some cases, may re-enter the fabric as second loops.

Fiber segments that penetrate entangled regions, and bind other fibers in place by a re-entrant loop configuration, are to a considerable degree responsible for the high level of fiber-interlock value characteristic of many products of this invention, since this structural feature distributed on the surface and through the volume of the fabric serves to generate an arrangement of fibers in the entangled regions with the latent ability to inter-lock, ensnarl, and tighten up when the fabric is deformed. This feature is in large part also responsible for the integrity leading to surface durability, wash resistance and coherence of these fabrics.

The re-entrant loop configuration of fibers as described above is most readily observed by coating the fibers on the faces of a fabric specimen with metal by a vacuum vaporization technique and photographing at high magnification with a microscope having a great depth of focus, preferably a scanning electrode microscope.

The entangled fiber regions of higher area density than the average area density of the fabric can be of any shape or size. An entangled fiber region can be quite long in one direction, or can have a compact shape for which the diameter of the inscribed circle is at least 50% of the diameter of a circle circumscribed about the perimeter of the region. Regions of fiber entanglement can extend substantially continuously along straight or sinuous paths, or can be distinct entangled fiber masses of essentially circular, square or oblong appearance. They may be interconnected by ordered fiber groups to define a pattern of apertures. By "aperture" is meant a hole in the fabric which may be completely free of fibers or contain relatively few stray fibers. The ordered fiber groups may hold the dense entangled fiber regions so closely together that apertures are not visible unless the fabric is stretched and/or observed with magnification. The term "ordered" applies to the gross appearance of fiber groups. The groups may be bundles or bands of yarn-like or ribbon-like appearance. The individual fibers may be substantially parallel, or become so when the fabric is stressed, or the fibers may be randomly entangled or otherwise disposed in arrangements capable of acting in concert to distribute fabric stress.

The repeating pattern of fiber arrangements can be regular, i.e., substantially identical arrangements are repeated periodically in one or more directions in the plane of the fabric, or the repeating pattern can be irregular. Most of the examples of this application are concerned with regular repeating patterns, but irregular or random patterns can be made as discussed subsequently. Depending on the fineness of the pattern produced on the patterning member, or following such after-treatments as shrinkage, development of fiber crimp or the like, the fiber arrangements forming the pattern may or may not be readily apparent upon visual inspection with the naked eye. However, they will be readily discernible with magnification. When viewed with transmitted light, the high density entangled regions will be revealed as dark areas in the fabric. With shrunk or crimped fibers, placing a slight strain on the fabric will help to distinguish between dense entangled regions and ordered fiber groups.

The process of the present invention involves supporting a layer of fibrous material on an apertured patterning member for treatment, jetting liquid supplied at pressures of at least 200 pounds per square inch gage (p.s.i.g.) to form streams having over 23,000 energy flux in foot-poundals/inch^2 second at the treatment distance, and traversing the supported layer of fibrous material with the streams to entangle fibers in a pattern determined by the supporting member, using a sufficient amount of treatment to produce a uniformly patterned fabric. The terms "apertured patterning member," "energy flux" and "amount of treatment," and preferred apparatus for the treatment, will be explained in detail hereinafter.

As illustrated subsequently, the process can be used to produce a large number of different products by varying the initial material and/or the patterning member used. The initial material may consist of any web, mat, batt or the like of loose fibers disposed in random relationship with one another or in any degree of alignment. The term "fiber" as employed herein is meant to include all types of fibrous materials, whether naturally or synthetically produced, comprises fibrids, paper fibers, textile staple fibers and continuous filaments. Improved properties can be obtained by suitable combinations of short and long fibers. Reinforced fabrics are provided by combinations of staple length fibers with substantially continuous fibrous strands, where the term "strands" includes continuous filaments and various forms of conventional yarns. 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 inital material. Particularly desirable patterned, nonwoven fabrics are prepared by using an initial material comprising fibers having a latent ability to elongate, crimp, shrink, or otherwise change in length, and subsequently treating the patterned, nonwoven structure to develop the latent properties of the fibers so as to alter the free-length of the fibers. The initial material may contain different types of fibers, e.g., shrinkable and nonshrinkable fibers, to obtain special effects upon activation of the latent properties of one type of fiber.

The term "apertured patterning member" includes any screen, perforated or grooved plate, or the like, on which the inital material is supported during processing and which by reason of its apertures and/or surface contours influences the movement of the fibers into a pattern in response to jets of high-energy-flux liquid streams. The patterning member may have a planar or nonplanar surface or a combination of planar and nonplanar areas.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying photographs illustrate some of the many varieties of patterned, nonwoven fabric structures which may be made, their pattern depending on the selection of the apertured patterning member.

In accompanying illustrations of the invention,

FIGURE 1 shows a schematic view of one type of apparatus for carrying out the process of this invention.

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

FIGURE 3 is a photomicrograph in plan view of a portion of a patterned, nonwoven fabric prepared from filaments which have been highly crimped following production of the fabric, as described in Example 16. Magnification is the same as in FIGURE 4.

FIGURE 4 is a corresponding photomicrograph of the fabric of FIGURE 3 held under a multiaxial stress sufficient to elongate the fabric 15%. Magnification is indicated by the scale below the figure.

FIGURE 5 is an enlarged plan view of a portion of a patterning plate, showing the staggered arrangement of apertures used when the triangular-mesh, tanglelaced fabric of FIGURE 3 is prepared.

FIGURE 6 is a photomicrograph in plan view of a portion of the triangular-mesh sample of Example 17. Magnification is indicated by the scale at the side of the figure.

FIGURE 7 is a photograph of the fabric of FIGURE 6 after being subjected to the grab tensile test.

FIGURE 8 is like FIGURE 6 but illustrates the better appearance obtained in Example 30. Magnification is indicated by the scale beneath the figure.

FIGURE 9 is a photomicrograph of the square-mesh sample of Example 17 (at the magnification indicated by the scale beneath the figure).

FIGURE 10 is a photomicrograph showing the oblong-shaped entangled regions in the product of Example 59.

FIGURE 11 is a photomicrograph in plan view of the square-mesh, nonwoven fabric of Example 10. Magnification is indicated by the scale beneath the figure.

FIGURE 12 is a similarly enlarged plan view of a portion of the plain weave patterning screen used to prepare the square mesh fabric shown in FIGURE 11.

FIGURE 13 is a photomicrograph of a different type of square-mesh, nonwoven fabrics, like the product of Example 42D but of lighter weight. Magnification is inlicated by the scale beneath the figure.

FIGURE 14 is a photomicrograph showing, with a product in the position formed, the type of patterning screen used to prepare the product of FIGURE 13.

FIGURES 15 and 15*a* are photomicrographs of the upstream and downstream (screen) faces of the product of Example 40C; FIGURES 16 and 16*a* are of the product of Example 40E; and FIGURES 17 and 17*a* are of the product of Example 40L. The products are shown as removed from the screens without further treatment, at the magnification indicated by the scales.

FIGURE 18 illustrates the general appearance of products of the above type when viewed without magnification.

FIGURE 19 shows details of the structural pattern in fabric prepared as described in Example 63(a). Magnification is indicated by the scale.

FIGURES 20–23 are enlarged views of patterning screens dscribed in Examples 45 and 47.

FIGURES 24 and 25 show upstream faces of products prepared as described in Example 45, and FIGURES 24*a* and 25*a* show the corresponding downstream faces. Magnification is shown by the scale beneath FIGURE 25.

FIGURES 26 and 27 are schematic illustrations of the structural pattern found in products of the above type.

FIGURES 28 and 28*a* are of the upstream and downstream faces of a product prepared as described in Example 45, showing the appearance when viewed without magnification.

FIGURES 29 and 30 show upstream faces of products prepared as described in Example 47, and FIGURES 29*a* and 30*a* show the corresponding downstream faces. Magnification is shown by the scale.

FIGURES 31 and 31*a* show the normal appearance of the two faces of fabric produced as described in Example 47(E), and FIGURES 32–34 show the structural pattern at the magnification indicated by the scale; in FIGURE 32 (upstream face) and FIGURE 34 (downstream face) the fabric is viewed with direct illumination, and in FIGURE 33 the view is with light transmitted through the fabrics.

FIGURES 35 and 36 are greatly enlarged views of fiber entanglement in a fabric prepared as described in Example 63(B). Magnifications are indicated by the scales.

FIGURE 37 is a view of fiber entanglement in a fabric prepared as described in Example 29. Magnification is indicated by the scale beside the figure.

FIGURE 38 is a side-sectional view of a machine for air-laydown of fibers to form a random web suitable for treatment to form nonwoven fabrics.

FIGURE 39 is a side-sectional view of a card machine suitable for preliminary processing of fibers for preparing a web.

FIGURE 40 is a schematic side view of apparatus for continuously feeding and opening staple fibers, forming a web and jet treating the web to form patterned nonwoven fabrics.

FIGURE 41 is an enlarged side-sectional view of one of the jet-treating machines indicated in FIGURE 40; and

FIGURE 42 is an exploded isometric view of one of the jet manifolds of FIGURE 41.

One class of products which includes the embodiments illustrated in FIGURES 3, 4, 6, 8, 9, 10 and 11 are strong, textile-like, patterned nonwoven fabrics comprising fibers which are entangled with each other at intervals along their lengths in a repeating pattern of compact masses bound to adjacent masses by linking fibers to provide a strong unitary fabric having the aesthetics of a woven or knitted fabric. The linking fibers are locked into place in the compact masses by three-dimensional fiber interaction. When the linking fibers are arranged in ordered groups or bundles there is a random distribution of fibers among the linking groups projecting from the masses, with the fibers lying in a variety of different paths through said repeating pattern.

When linking bundles are spaced 90° apart around the compact masses of entangled fibers, as illustrated in FIGURE 11, they define a square-mesh pattern simulating the pattern of a woven fabric. However, the linking bundles of the patterned nonwoven fabrics of the present invention merge with one another in the compact masses and do not cross one another in an over-lapping relationship as do the yarns of a woven fabric. The product may also have small linking bundles extending at 45° angles to the main bundles, as illustrated in FIGURE 9, which provide enhanced properties. When the linking bundles are spaced 60° apart around the compact masses of entangled fibers, as illustrated in FIGURES 4 and 6, they define a triangular-mesh pattern.

The fibers are interentangled in the compact masses in an exceedingly complex manner, as can be seen from the accompanying photographs. The convolutions of the individual fibers have been studied by observing successive cross-sections through entangled fiber regions. It will be convenient to use the term "segment" with reference to a particular portion of a fiber. The fibers are interentangled in three-dimensional rather than planar convolutions, each fiber having random convolutions which are also random relative to those of the other fibers, so that the segments of the fibers visible in a cross-section proceed in random directions at varying angles, both in the plane of the fabric and out of the plane.

Products of the types discussed above can be prepared from initial fibrous material by sufficient treatment of a layer of the material with fine, columnar streams of liquid jetted at high orifice pressure, while the material is supported on an apertured patterning member whose surface is planar or substantially planar, such as the perforated plate or the fine-wire screen shown in enlarged views in FIGURES 5 and 12, respectively. During treatment, some fibers and/or segments of fibers are moved by the streams into interentangled relationship in the areas overlying the apertures of the patterning member, while other fibers and/or segments form groups or bundles which serve to link or interconnect the entangled fiber areas or masses. The fiber segments in the linking bundles may be more or less parallelized depending upon the nature of the fibers, the patterning member and/or the processing conditions. By choice of the proper conditions, as illustrated in the examples, the entangled fiber areas or masses can be closely adjacent one another, i.e., placed so close to one another that they are interconnected by individual very short fiber segments spaced fairly uniformly about the entangled fiber mass or area, the interconnecting segments being discernible only upon close inspection.

FIGURES 15–19 and 24–36 are illustrative of a variety of types of products obtained when using an apertured patterning member which differs, from the planar-surfaced ones mentioned above, in having a pattern of raised portions defining intersecting channels, in addition to the pattern of apertures. As disclosed in greater detail in the examples, they are prepared by traversing a layer of fibrous material with fine, columnar streams of liquid jetted at high orifice pressure while the material is supported on an apertured patterning member having a contoured surface of channels or grooves arranged to provide the desired pattern of entangled fiber regions.

FIGURE 14 shows a suitable heavy wire screen which differs from the screen of FIGURE 12 in having substantially straight wires in one direction and highly crimped wires in the other direction. The projections formed by the crimped vertical wires of FIGURE 14 cause fibers to align in a modified square-mesh pattern as shown. Products having a variety of patterns are produced by using heavy-wire screens of other weaves, as illustrated in FIGURES 20 to 23, or by using other types of apertured members whose surfaces are characterized by the presence of channels or grooves. For example, the appearance of a woven fabric can be reproduced by using a patterning member which is a negative replica of the woven fabric, so that the surface of the member has raised portions corresponding to holes between woven yarns, and has elongated apertures or depressions corresponding to cross yarns.

During the treatment, fibers and/or segments of fibers are realigned to follow the contours of the member and are also arranged in groups located in different zones throughout the thickness of the structure, the groups being interconnected with one another by areas of interentangled fibers, forming a multilevel structure. Thus, if an apertured patterning member has a surface characterized by channels or grooves running along and across the member at different depths, the fibers and/or segments of fibers will be realigned into groups which proceed along and across the structure at different levels, and which are integrally interconnected with one another by localized interentanglement of fibers in the areas overlying the apertures or deepest recesses of the patterning member during processing. The fiber groups can be caused to follow either a sinuous or a straight path. Thus, if the patterning member has channels which follow a curved path, such as the sinusoidal path seen in FIGURE 14, the fiber groups will also follow such a path and the entangled areas will cause the groups to remain permanently in that configuration in the final structure. In general, fiber groups will take the form of ridge-like protrusions on at least one face of the structure, generally the downstream face, which is the face adjacent to the patterning member during processing. The remaining face of the structure may be similarly characterized or may comprise randomly-disposed fibers arranged in ordered groups which outline the apertures of the structure.

By use of an apertured patterning member having both planar and nonplanar areas, other patterned nonwoven structures can be obtained. Thus, in accordance with still another embodiment of the present invention, nonwoven structures are provided which comprise a sketetal continuum of closely-associated fibers defining a number of apertures in an ordered geometric pattern, said skeletal continuum comprising (1) localized areas of interentangled fiber and (2) ordered groups of randomly-disposed fibers, said ordered groups being interconnected with one another at said localized areas to form a pattern when said structure is viewed in plan. In such a structure, the interentangled areas and the random areas cooperate to define apertures in the structure. Products of the latter type may be prepared as illustrated in Example 58.

By use of a patterning member having apertures of random location, size and/or shape, special artistic nonwoven fabrics are produced which do not have a regular pattern. Such patterning members may be prepared by bonding together grains of sand, of various sizes and shapes, so as to leave apertures between the grains. Another way is to treat a screen with resin to provide an arrangement of raised lines, filled holes or partially-filled holes, which may be non-repeating for a considerable distance or completely random. Thus epoxy resin can be applied in curved and crossing lines and allowed to cure on the screen. Raised designs of various thickness and relief, which enclose islands of untreated screen between and among lines of resin, may be formed. Fabric formed on such screens will have islands of fibers interentangled in a regular pattern, characteristic of the screen, interconnected by randomly entangled fibers. Artistic lace-like fabrics are produced in this manner.

FIGURES 15–34 illustrate several types of products having ridge-like protrusions on at least one surface of the fabric. Many of them have ordered fiber groups located in different thickness zones of the fabric and interconnected with one another at entangled fiber regions to define an ordered geometric pattern of apertures. All of the products have a repeating pattern of entangled fiber regions which have a higher area density than the average area density of the fabric, and are characterized by random fiber segments that penetrate entangled fiber areas at substantial angles to the plane of the fabric and have a re-entrant loop configuration which binds other fibers in place in the fabric. This type of entanglement is illustrated at high magnification in FIGURE 36. When prepared on patterning screens having almost straight wires in one direction and heavily crimped wires in the other direction, such as the screens shown in FIGURES 14 and 20–23, the products have a regular pattern of ridges separated by grooves lying along parallel straight lines, the ridge fiber groups being interconnected by fibers which bridge under the ridge-separating grooves, are generally parallel, and are locked into place in entangled fiber regions of the ridges.

The fabrics may have a pattern of ridges and grooves on both faces, with ridge-interconnecting fibers in an intermediate layer as illustrated in many of the figures, or there may be a layer of random fibers on one face as illustrated in FIGURE 17. The ridges may extend in substantially continuous lines in the same general direction of the fabric, as illustrated in FIGURES 15–17, or the ridges may have other forms, e.g., as in FIGURES 24 and 25. The ridges may be substantially straight and evenly spaced as in FIGURE 29. The ridge-interconnecting fibers may form a substantially continuous array beneath the grooves, but fabrics wherein the ridges and interconnecting fibers define a repeating pattern of apertures more closely resemble conventional woven fabrics in appearance.

Fabrics prepared on screens on the type shown in FIGURE 14 are illustrated in FIGURES 15–19. They are characterized by a repeating pattern of ridges separated by grooves lying along parallel straight lines on at least one fabric face and by a repeating pattern of apertures spaced along the grooves; the fabric structure comprising entangled fiber regions located in areas between adjoining grooves and interconnected into substantially continuous ridges following paths passing between the grooves adjacent to portions of the apertures, and bands of fibers interconnecting entangled fiber regions beneath the grooves and extending along sides of apertures. In these figures the ridges follow sinusoidal paths which are substantially 180° out of phase with respect to adjacent sinusoidal ridge paths, but other configurations are produced on different types of patterning screens. The ridges may have entangled fiber regions alternating with interconnecting parallelized fiber groups, as illustrated in FIGURE 19, or the entangled fiber regions may extend substantially continuously along the ridges. More detailed description of particular fabric structures are given in the examples.

Fabrics prepared on patterning screens of types shown in FIGURES 20 and 21 are illustrated in FIGURES 24–28*a*. They have the appearance of a twill-weave textile fabric. Typical patterns are shown schematically in FIGURES 26 and 27. The repeating pattern is characterized by a fabric face layer of protruding ribs arranged in rows in a twill pattern and by fibers extending from entangled fiber areas in the ribs in parallelized fiber groups interconnecting entangled fiber areas in a principal fabric direction, parallelized fiber groups interconnecting entangled fiber areas transversely to said principal fabric direction, and bands of parallelized fibers interconnecting entangled fiber areas of ribs in a bias direction of the fabric. As illustrated in FIGURES 24*a* and 25*a* there is a fabric face layer of protruding ribs separated by grooves lying along parallel straight lines and arranged in rows in a twill pattern, the ribs being interconnected by groups of parallelized fibers which extend from entangled fiber regions of the ribs in principal fabric directions and by bands of parallelized fibers which extend under said grooves to interconnect ribs in a bias direction of the fabric. The bands of parallelized fibers may be arched and form protrusions on the fabric face opposite to the ridge-separating grooves, or they may form an intermediate layer which is overlaid with random fibers on the face opposite to the ribbed face. In heavy fabric weights there may be a substantially continuous array of ridge-interconnecting fibers. Both faces may be ribbed and almost identical in appearance, as in FIGURES 28 and 28*a*. In this type of fabric the entangled fiber regions may be so extensive as to substantially or completely eliminate the short parallelized fiber groups indicated in FIGURES 26 and 27.

FIGURES 29–34 illustrate types of fabric which can be prepared on patterning supports having slot-shaped openings aligned along parallel straight lines. Thus FIGURE 23 shows a suitable oblong screen, of plain weave but having many more wires per inch in one direction than in the other screen direction. The fabric shown in FIGURE 30*a* has ridges which are substantially straight, with the fibers interentangled except where they wind around the protruding wire crimps of the screen. The ridges are separated by parallel straight grooves and are interconnected under the grooves by bands of parallel fibers, seen in FIGURE 30. Adjacent ridges and interconnecting bands define apertures at positions corresponding to the protruding crimps of the widely-spaced wires of FIGURE 23.

These apertures can be spaced as far apart along the ridges as desired by increasing the wire spacing, or can be eliminated entirely by modifying the screen construction. Thus a patterning screen can be used which consists of straight wires welded together, instead of woven, to have the wires of one screen direction entirely on one face and the crossing wires entirely on the opposite face. Fabric prepared on such screens has straight parallel ridges of entangled fibers, uniformly separated by grooves and interconnected across the grooves by a continuous array of substantially parallel fibers locked into place by the entanglement.

FIGURES 29 and 29*a* illustrate a type of fabric which can be made on the Dutch twill screen of FIGURE 22. This wire weaves over two and under two, as in the above twill weave screen, but the wires are pushed closely together in one screen direction. The fabric differs from those considered previously in appearance but has the structural characteristic of a regular pattern of ridges separated by grooves lying along parallel straight lines and interconnected by bands of generally parallel fibers locked into place by entanglement. The bridging bands of generally parallel fibers seen in FIGURE 29 correspond to the positions of the twill lines of protruding wire crimps seen in FIGURE 22. Since each protrusion is formed by two wires, side-by-side, there is a relatively wide separation between ridges. There is no well-defined pattern of apertures, but small triangular-shaped apertures are visible at positions corresponding to the vertical wires in FIGURE 22. At somewhat heavier fabric weights apertures are no longer visible, there being a substantially continuous array of ridge-interconnecting fibers. FIGURE 29 shows ridges lying along parallel straight lines in which entangled fiber regions alternate with relatively short interconnecting groups of generally parallel fibers. The ridges are not as clearly defined on the screen face of FIGURE 29*a*. In heavier fabrics, or in fabrics containing less pliable fibers, the ridges may have substantially uniform and similar appearance on both faces of the fabric. The ridge entanglement can also be extended to substantially or completely eliminate the short parallelized groups seen in FIGURE 29, i.e., in such embodiments the ridges are continuous entangled fiber groups which protrude on both faces of the fabric.

Any of the products discussed previously can be composed of textile staple fibers of any length, continuous filaments or very short fibers such as paper fibers. Various combinations can be used effectively. By combining short fibers with fibers at least twice as long, fabric having exceptionally good surface durability can be obtained. The short fibers become concentrated to a greater extent in the entangled fiber regions, wrapping around the longer fibers and being highly entangled to bind the longer fibers securely into the body of the fabric. Staple fibers and paper fibers of shorter length are effective for this purpose. Combinations on continuous filaments and fibers of less than one inch in length can be used. Preferred combinations include 90% to 25% of continuous filaments with 10% to 75% paper fibers, and 90% to 40% of staple fibers at least about 1.5 inches in length with 10% to 60% of short staple fibers of about ¼ inch to ¾ inch in length.

Fabric of staple length textile fibers can be reinforced with 3% to 90% of substantially continuous fibrous strands for improved properties. When the fibrous strands are textile yarns they preferably constitute 10% to 70% of the weight of the fabric. The fibrous strands may be composed of continuous filaments or may be spun yarns of staple fibers. Textured bulk yarns are particularly useful because the fibers entangle more readily to become locked into place. Crimped stretch yarns provide desirable textile-like properties.

PROCESSING CONDITIONS

Patterned, nonwoven fabrics are produced in accordance with this invention by a process in which nonwoven fibers or filaments are consolidated with streams of liquid to form a fabric on an apertured patterning member, such as a screen or plate having small openings and/or recesses arranged in a pattern corresponding to the location of entangled fiber regions desired in the fabric, and of a size which provides a total open area in said pattern of 10% to 98% (preferably 35% to 65% when using a perforated plate). A nonwoven batt or other initial fibrous layer is supported on the patterning member and is traversed with fine, high-energy-flux streams of liquid, such as water, until the fibers are rearranged into groups extending between and intersecting at the apertures of the patterning member, in an ordered pattern, and are interentangled to lock the fibers into position in this pattern. In order to interentangle the fibers adequately, the streams impinged on the fibrous layer must have an energy flux of at least 23,000 foot-poundals per square inch per second and, in order to avoid excessive treatment times, the streams should be formed by jetting liquid from orifices at high pressure. For example, a practical minimum is treatment equivalent to that provided at a 3-inch distance by essentially columnar streams from orifices 0.005 inch in diameter when supplied with water at a pressure of at least 200 pounds per square inch above atmospheric pressure (hereinafter abbreviated p.s.i.g.). Preferably, water pressures of 500 to 5000 p.s.i.g. (35.2 to 352 kg./cm.^{2}) are used for orifices 0.003 to 0.010 inch (0.0076 to 0.0254 cm.) in diameter with orifice-to-fiber spacings ranging from substantially 0 to 4 inches (0 to 10.2 cm.), although greater pressures and spacings can be used. Lower water pressures can be used at closer spacings. Water at about 1°–99° C. is suitable.

The initial layer may consist of any web, mat, 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, cross-lapped carded webs. The initial layer may include scrim, woven cloth, bonded nonwoven fabrics, 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 processability of stiff fibers can be improved by plasticization with solvent or heat, e.g., by use of hot water.

The apertured backing member may consist of a perforated plate, sheet, woven screen, honeycomb or the like, made of any suitable material which is not susceptible to attack by the fluid used in the process. Suitably, a stainless-steel screen or perforated plate is used. This will usually be flat, but may be shaped in a three-dimensional contour when direct formation of shaped garments is desired. The apertures in the backing member may be of any desired shape and/or size and may be arranged in any regular pattern, such as in parallel or staggered rows, providing that the open area of the apertured backing member and the size and spacing of the apertures are properly chosen so as to permit the fibers of the web being treated to move into an entangled fiber pattern. It is to be understood that these conditions may vary depending on the particular web to be treated. However, in general, the ease with which a given web can be formed into a patterned nonwoven fabric on a planar patterning member under a given set of process conditions is diminished as the percent open area of the backing member is decreased. Processibility is improved with the use of nonplanar patterning members and with such members it improves with increasing depth or height of the recesses or protrusions, respectively. Obviously, the apertures may not be so large nor spread so far apart as to preclude the formation of any pattern. As illustrative of suitable apertured backing members are coarse, regular or fine-wire plain weave screen ranging from 3 mesh to 80 mesh (wires per inch) (1.18 to 31.4 wires/cm.) having wire diameters ranging from 0.005 inch to 0.105 inch (0.0127 to 0.267 cm.), and having from about 10% to about 98% open area. Other examples are perforated metal plates having circular holes, ranging from 0.01 to 0.25 inch (0.025 to 0.635 cm.) in diameter, arranged in parallel or staggered rows and having from about 10% to 98% open area. Perforated plates having slots, triangles, and/or apertures of other geometrical shapes are also suitable. Moreover it is not necessary that all of the apertures in a given plate be of the same diameter or shape. Furthermore, an aperture can vary in cross-sectional area throughout the thickness of the plate, e.g., apertures may be of conical or other cross-section. Finally, they need not even extend completely through the thickness of the plate; thus, for example, patterned structures can be produced using a cross-grooved plate or a plate having pyramidal or other depressions and/or protrusions.

Solid (i.e. non-foraminous) patterning plates having ridges on the face supporting the fibrous material can be used to produce nonwoven fabrics with a corduroy appearance. Suitable ridged surfaces can be made by sealing the openings of a grating, for example, one having 8 to 20 parallel rods per inch of circular or other cross section, so that the rods produce ridges of about 30 to 100 mils in height above the plate. Such surfaces can also be made by cutting grooves in a solid, flat plate. The ridges may be non-parallel if a different pattern is desired. A 14 x 14 mesh screen (17% open area) can be filled to half of its thickness to provide a useful solid patterning plate. Other useful solid patterning plates contain protrusions such as pegs, wires (as from a coated strip of fillet card clothing), or metal strips with teeth (i.e. metallic cloth). In order to expedite removal of the water it is advantageous to have the web in contact with a solid patterning member only while being impinged by the water jets as, for example, with a patterning member on the face of a small roll or an endless belt that rotates in the direction of travel of the web.

In operating the process as illustrated subsequently, water or other suitable liquid is forced under high pressure through small diameter orifices so as to emerge continuously or intermittently in the form of fine, essentially columnar, high-energy-flux streams. The web or other fibrous layer is placed on the selected apertured backing member, and the assembly is moved, layer side up, into the path of the high-energy-flux streams. Either the web or the streams, or both, are moved to traverse the web. When using a planar or substantially planar apertured patterning member, the high-energy-flux streams impinge upon and physically cause the individual fibres to move in the general direction of the nearest aperture while simultaneously forcing segments of the individual fibers to move into and about other fibers and about themselves as they bridge the gap of the aperture, until a highly entangled, dense, fibrous mass is produced within the aperture. During this impingement, segments of a given fiber may be caused to move toward one aperture while other segments of the same fiber are caused to move to one or more different apertures. As the impingement continues, that portion of the fiber which extends between adjacent apertures is reduced in length as the segments within the apertures are driven into tighter and tighter entanglement with themselves and other fibers. Thus, the fibers of the web are simultaneously realigned, entangled, and locked into place in a pattern corresponding to the arrangement of holes in the apertured backing member. The resulting structure comprises fibers arranged in an ordered geometric pattern of intersecting bundles locked together at their intersections solely by fiber interaction. The ordered groups of fibers locked together in series in any given line form the structural elements of the patterned, nonwoven fabric and are capable of withstanding stress as are the yarns of a conventional woven fabric. Unlike a conventional woven fabric, however, the structural elements of the patterned, nonwoven fabric do not merely overlap one another but are locked with one another at each intersection, and the individual fibers migrate randomly from bundle to bundle via intersections.

When using a nonplanar apertured patterning member, such as a screen woven of heavy wire and having a relatively coarse mesh or any other patterning member whose surface is characterized by the presence of channels or grooves, the high-energy-flux streams force the fibers generally away from any protrusions and into and along the channels of the supporting surface of the patterning member. Preferably, the nonplanar patterning member is a woven wire screen having a low open area (approximately 50% or less) and a relatively coarse mesh (60 mesh or coarser). Such screens are characterized by wires having a moderate degree of crimp amplitude in one axis and a greater degree of crimp amplitude in the transverse axis. Accordingly, the surface of the screen is characterized by a series of slight protrusions, corresponding to the crimped portions of the wire, along one axis and a series of high protrusions along the transverse axis. The difference of the crimp amplitude in the two axes of the screen and the interweaving of the wires thereof impart to the screen a contoured surface characterized by the presence of regularly spaced channels or grooves which may run along the screen at different levels and are separated from one another by the high points or protruding portions of the wire, in addition to the actual drainage apertures defined between adjacent wires. When a fibrous initial material is placed on such a screen and treated with high-energy-flux liquid streams, the individual fibers and/or segments thereof are caused to move into the channels and to be consolidated with one another along the channels. In general, some fibers tend to move toward the lowest portion of the screen, i.e., into the deepest channels. As these channels become filled, fibers are caused to move into other channels of lesser original depth. Accordingly, the ultimate fiber structure is of a layered or multilevel configuration. During their movement into the various levels of the screen, the fibers at certain localized regions are caused by the high-energy-flux streams to entangle with one another.

In contrast to the nonplanar screens described above, screens of very high open area, or screens of low open area and very fine mesh, are relatively flat and lack a channeled surface because the good conformability of the wires results in little difference in the crimp amplitude of the two axes. Thus, instead of multilevel structures, such screens yield products more closely resembling those produced with a perforated plate having apertures arranged in parallel in a square pattern.

The patterned nonwoven fabrics prepared in accordance with the present invention may be dried while still on the apertured backing member or after removal from it. They 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. They may be stretched in one or more directions, as illustrated in Example 53. This post-stretching treatment improves the yield resistance of the fabric. Desirably it involves stretching beyond that which merely causes a pantograph collapse of the fabric pattern. In some cases, the fibers of the fabric may also be stretched during this post-stretching of the fabric. By post-stretching two patterned, nonwoven fabrics, cross-lapping them and repeating the treatment with high-energy-flux streams of water one obtains an integral fabric having a stress-strain behavior similar to that of a woven print cloth.

In order to obtain the high-strength patterned, nonwoven products of the present invention, it is essential that the initial material be subjected to the action of streams of a noncompressible fluid at sufficiently high energy flux and for a sufficient amount of treatment. 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. If the jet initially forms a "solid" stream, i.e., an unbroken, homogeneous liquid stream, the initial energy flux, in foot-poundals/inch^2 second, is readily calculated by the formula,

$$EF_1=77PG/a$$

where:

P=the liquid pressure in p.s.i.

G=the volumetric flow of the stream in cu. ft./minute, and

a=the initial cross-sectional area of the stream in square inches.

The value 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), 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 will usually decrease rapidly as the stream travels away from the orifice, even when using carefully drilled orifices. The stream diverges to an area (A) just 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

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

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, as illustrated in Example 62. 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 straight cylindrical hole, drilled-tube orifice manifolds, of types used in the examples unless a different type is described, are given in Table 1.

TABLE 1.—ENERGY FLUX VALUES FOR DRILLED TUBE ORIFICES

	Distance Below Orifice		
	⅛ inch	¾ inch	1.5 inch
For 3 Mil Orifice Diameter:			
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:			
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:			
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)	0.236	0.079	0.0196
Energy flux	2,910,000	972,000	242,000
1,500 p.s.i.:			
Stream density (*a*/A)	0.236	0.0645	0.0125
Energy flux	5,350,000	1,460,000	283,000

The high strength, nonwoven, 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 inch^2 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, nonwoven, 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 of high energy flux provides improved product uniformity by minimizing air turbulence at the surface of the web during processing.

As the divergence angle of a stream is reduced from a given value (e.g. 5°) to 0°, the character of the stream changes from a mixture of liquid droplets and ligaments with entrained air to a perfectly columnar solid liquid stream which generally increases the efficiency of the stream (as measured by the extent of entanglement for a given energy input) when all other conditions are kept constant. In some cases the use of a slightly divergent stream may be preferred over a perfectly columnar stream even at the cost of process efficiency as, for example, when patterning a low basis-weight web.

The process of the present invention may be used to produce patterned, nonwoven fabrics from any type of loose fibrous web, batt or sheet. The ease with which a given web can be patterned and entangled 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 case 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 varying the size of the orifices from which the streams emerge, the pressure at which the noncompressible fluid is delivered, 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 entanglement, 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.

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 (E) 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.

Patterned, highly entangled nonwoven fabrics can be prepared from an easily entangled fiber such as rayon at an energy flux of about 23,000 ft.-poundals/in.^{2} sec. with an expenditure of total energy of about 0.2 HP-hr./lb. of fabric (as shown in Example 62A). Under more vigorous conditions of pressure and energy flux the energy can be reduced to as low as 0.1 HP-hr./lb. of fabric. At any given set of processing conditions it is generally observed that as the energy (E) of treatment is increased the tensile strength of the product increases rapidly until it reaches a substantially constant level. The surface stability of the nonwoven fabrics (i.e., the resistance of the fabric to surface pilling and fuzzing) also increases as the energy of treatment is increased, but treatment with 2 to 8 or more times as much total energy may be required to reach maximum surface stability as to reach maximum tensile strength. This is illustrated by Example 62 (items B–E) where a product of good strength is made at an energy (E) of 0.34 HP-hr./lb. The tensile strength is only increased about 47% as the treatment is increased by a factor of 29 but the entanglement frequency (which is a measure of surface stability) increases over 3 times.

It must be understood that the energy requirements to make a given quality product vary widely with the nature of the starting web. With all other conditions being equal, the energy needed to make well-entangled products is greater for 66-nylon than for cotton, rayon or polyester fibers, and is less for 66-nylon than for acrylic fibers and polypropylene fibers. Using the same fiber composition and length, fibers of small denier are more readily entangled than higher denier fibers. Using the same fiber composition and denier, shorter fibers are more readily entangled than longer fibers. Using the same fiber composition, denier and length, fibers having greater crimp frequency and amplitude of crimp are entangled more readily than less crimped fibers.

In addition to these differences, it is to be understood that, with a given web, the energy requirements to obtain a desired level of entanglement will depend upon the nature of the patterning plate or other support.

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.

The examples will show that webs ranging from 0.5 oz./yd.^{2} or less to about 10 oz./yd.^{2} or more and composed of natural, cellulosic, and/or wholly synthetic fibers, can be readily converted into patterned nonwoven fabrics having strip tensile strengths of at least 1 lb./in. per oz./yd.^{2} through the use of water as the fluid and process conditions within the following ranges:

Orifice size	inch	0.003 to 0.030
Orifice spacing	do	0.01 to 0.1
Water pressure	p.s.i.	200 to 5000
Web to orifice separation	inches	0 to 6
Number of passes		1 to100

The effect of the above process variables on the production of patterned, nonwoven fabrics in accordance with the present invention will be illustrated in more detail in the examples.

The geometric pattern of the entangled structures produced in accordance with the present invention is dependent upon the arrangement of holes and/or the contour of the apertured backing member. As illustrated in the examples, in planar patterning members the holes are usually arranged in a uniform pattern of about 25 to 4000 holes per square inch (3.8 to 620 holes/square cm.) of backing member. Webs of the type described above may be successfully processed into patterned, nonwoven fabrics on apertured backing members having the following characteristics:

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

When a planar backing member has apertures aligned in parallel rows, the nonwoven fabric will have a square-mesh pattern, simulating that of a plain weave fabric. If the apertures are arranged in staggered rows, the nonwoven fabric will have a triangular-mesh pattern. Fancy patterns, such as a simulated herringbone weave of the like, may also be produced in nonwoven fabrics by proper choice of the backing member. If desired, one or more patterns may be superimposed by treating the web first on one backing member and then on another. Designs and/or lettering may also be produced by blocking out selected portions of the backing member used in the production of the nonwoven fabric. Different effects can be achieved by the use of multicolored fibers and/or webs. For example, striped, nonwoven fabrics may be made by the use of a starting web comprising parallel strips of fibers of different colors. Plaid, tanglelaced fabrics may be made by using two such webs, cross-laid with respect to one another, as the initial layer.

In the specific embodiments of the present invention wherein a patterned, nonwoven fabric is produced and subsequently treated so as to crimp, elongate, shrink or otherwise change the dimensional properties of the individual fibers, it is to be understood that the gross pattern may be completely or partially obscured in the final product and/or it may be drastically reduced in size.

In general, such fabrics, on being stretched or pulled taut, will again reveal the gross pattern. Nonwoven fabrics wherein the gross pattern has been thus obscured 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 the like.

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 entangled at high energy flux. 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 nonwoven 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 energy flux 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, nonwoven 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 energy flux.

Apparatus suitable for use in the continuous production of entangled, patterned fabrics in accordance with the present invention is shown schematically in FIGURE 2. A pump **25**, which may be one of the types used for supplying water to high pressure steam boilers, is used to provide liquid at the required pressure. A pulsation dampener **27** is used to provide uniform pressure. A fibrous layer **29**, prepared by conventional means such as a card machine or random air-laydown equipment, is supplied continuously to a moving carrier belt **31** of flexible foraminous material, such as a screen. The carrier belt may also be the patterning member or, as illustrated, an apertured patterning member **30** may be supplied with the fibrous layer so that changes can readily be made in the pattern. The carrier belt is supported on two or more rolls **32** and **33** provide 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 from the pump **25** to the orifice manifolds through pipe **18**. 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 and jet orifices 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 energy flux during travel under the liquid streams **34**. However, the conditions are readily adjusted to provide the desired patterning and entangling treatment of different initial fibrous layers. Suction boxes **48** be used to help remove liquid during high-speed treatment.

FIGURE 38 illustrates one type of suitable appartus for assembling staple fibers into a continuous layer in preparation for conversion to nonwoven fabric with the above jet-treatment apparatus. A loosely opened mass of staple fibers **50** is introduced into a receiving chamber **51**. The fibers are supported on creeping delivery apron **52** which travels around supporting rolls **53** and **54**. The fibers are advanced into contact with elevating apron **55** which travels around supporting rolls **56** and **57**. The elevating apron carries the fibers to the top of the chamber where they pass through a narrow opening between this apron and stripper apron **58**. The stripper apron travels about supporting rolls **59** and **60** in a direction counter to the elevating apron. The aprons are provided with suitable wire teeth for engaging the fibers so that a layer of fiber tufts is formed at the top of the elevating apron, of a thickness determined by the stripper apron. A fiber-conveying fan **61** sucks a stream of air past the elevating apron, where the apron travels over the upper supporting roll **57**. The air stream blows fibers from the apron and carries them to the screen surface **62** of condenser roll **63**. The air stream passes through the roll and ductwork **64** to the fan, leaving a layer of fibers on the screen. The fiber layer is conveyed away from the air stream, between the screen **62** and a roller conveyor **65**, and is then guided to a feed roll **66**. A lickerin **67**, of a type similar to that used in a card machine, receives the fibers from the feed roll.

The lickerin rotates close to saber tube **68** to feed separated fibers into venturi duct **69**. A web-forming fan **70** sucks a stream of air through the duct. The air stream carries the fibers through the duct to condenser roll **71** and deposits the fibers uniformly in random arrangement on the screen surface **72** of the condenser roll. The resulting loose layer of fibers is removed from the screen surface by separator roll **73**. The layer is forwarded on conveyor belt **74** to calender **75**, which compacts the layer sufficiently to be self-supporting. The air stream passes through the condenser roll into compartment **76** and is recirculated to the lickerin by the fan **70**, through ductwork **77**.

Staple stock is usually shipped in highly compressed bales. These must be opened to form a loose mass of fibers before the staple is introduced into the layer-forming apparatus. Conventional cotton openers or pickers can be used for initial opening of staple stock. However, fiber-opening should be completed by combining to separate and parallelize the fibers so that a loose mass is obtained which is free from clumps, neps, caterpillars or other fiber entanglements. FIGURE 39 shows a conventional roller-type card machine, which is one form of apparatus suitable for the purpose. At the feed end of the machine, a lickerin **80** conveys fibers onto card cylinder **81**. The cylinder is rotated and carries the fibers under worker rolls **82** which comb the fibers. Stripper rolls **83** feed the fibers to the worker rolls and transfer the fibers to a second card cylinder **84** for a repetition of the treatment on the first cylinder. The carded fibers are removed from cylinder **84** by doffer roll **85**, which is rotated at a suitable speed to form a thin layer of fibers. The carded layer of fibers is stripped and passed through a calender **86** to form a loosely coherent layer **87** of generally parallel fibers. It is preferable to feed the carded fibers to an apparatus of the type shown in FIGURE 38 to form a random fiber web, as discussed above, which is then converted into nonwoven fabrics. However, several layers can be combined to form a carded web, as by cross-lapping, and treated directly with liquid streams to form nonwoven fabrics. Cross-lapped carded webs can also be fed directly to feed roll **66** of the layer-forming apparatus shown in FIGURE 38.

FIGURE 40 illustrates a combined apparatus for continuous processing of staple fiber stock, as received from the supplier, to convert the material into nonwoven fabric. The stock is fed through a conventional opener or picker **88** and the opened stock is carried on conveyor belt **89** to a card machine of the type described above. The fibers are combed on card cylinders **81** and **84**, the fibers are collected on doffer **85**, the fibers are taken off through calender **86** and are introduced into a layer-forming apparatus of the type described above. The fibers are carried on elevating apron **55** until removed by stripper apron **58** and are collected on condenser roll **63** to form a preliminary layer. The lickerin **67** separates the fibers and the fibers are deposited on condenser roll **71** to form a uniform layer of randomly arranged fibers. The layer is supported on conveyor belt **74** until it passes through calender **75** to be made sufficiently self-supporting for subsequent treatment. The resulting layer **78** passes to the jet-treating apparatus, described below, for conversion to a nonwoven fabric. Apparatus for continuous drying and windup of the fabric is also indicated.

The layer-forming apparatus processes a given weight of material at a relatively slow rate, whereas the jet-treating apparatus is capable of high speed operation. Increasing the speed of the layer-forming apparatus will result in a lighter weight layer. Therefore, it may be desirable to provide more than one layer-forming apparatus, combine the layers, and feed the combination of layers to the jet-treating apparatus. When the layers are of the same material, the treatment will produce a homogeneous product with no evidence of lamination. However, different types of layers can be combined for special purposes and they will be securely entangled together by the jet treatment.

The jet-treating apparatus shown has three treatment drums **90**, **91** and **92**. With this arrangement, the fabric formed on the first drum can be treated from the reverse face on the second drum and, if desired, given an additional treatment on the third drum, all in a continuous, uninterrupted operation. However, one or two of the drums can be by-passed when treatment thereon is not desired. As shown in FIGURE 40, the layer **78** travels continuously from the layer-forming apparatus to the first treatment drum **90**. In addition to the guide rolls **93** shown, a conveyor for supporting weak webs and means for prewetting the layer may be provided in order to feed the layer smoothly onto the cylindrical surface of the drum. The drum rotates counter-clockwise and carries the layer beneath a plurality of jet-treatment manifolds **94**. The fabric produced then passes through wringer **100** and travels over a series of guide rolls **95** to the second treatment drum **91**. This drum rotates clockwise and the fabric is fed onto it so that the previously treated face is next to the cylindrical surface of the drum. The fabric is carried beneath a plurality of jet-treatment manifolds **96** to treat from the face of the fabric opposite to that previously treated. From the second drum the fabric is guided by a series of rolls **97** to the third treatment drum **92**. This drum rotates counter-clockwise to carry the fabric beneath a plurality of jet-treatment manifolds **98**. This completes the treatment with liquid jets and the fabric leaves the drum at guide roll **99**.

The jet-treated fabric passes to a wringer **100** to partially remove the treating liquid. The fabric is guided by a series of rolls **101** to conventional drying cans or drums **102**, which are heated to dry the fabric. The dry fabric proceeds to a conventional type of fabric windup **103**.

The used treating liquid is collected in tank **104** and is recovered, except for a small amount carried in the fabric to the drying apparatus. The liquid is withdrawn from the tank through drain **105**, is passed through a filter **106** to remove any fibers or foreign matter, and make-up liquid is added through pipe **107**. The liquid may be stored in a tank (not shown) located so as to provide the proper head pressure for feeding pump **109**. The tank may include means for heating or cooling the liquid. Pipe **108** conducts the liquid to the pump. A multiple-piston, positive-displacement pump powered by an electric motor **110** is preferable. A multiple-stage centrifugal pump can be used, but is less efficient for pumping large volumes of liquid at high pressure. Since a piston pump causes pulsation surges, even when there are five or more pistons, a pulsation dampener **111** is provided in high pressure pump line **112**. A conventional fluid-filled, in-line pulsation dampener is preferable in large scale operation, instead of the gas-dampener shown in FIGURE 1, because of the simplicity and greater safety provided when high pressure liquid is supplied at a substantial rate. The treating liquid flows from dampener **111** to a second filter **113** designed to remove any remaining particles of material large enough to plug the jet orifices. A pleated woven screen which will remove any particles of larger than 25 microns in size is preferred. The filtered liquid then flows into a feed manifold **114** which supplies the jet manifolds **94**, **96** and **98**. Conventional pressure-control and high-pressure-relief valves (not shown) should be provided to supply the liquid at the desired pressure with safety.

Further details of the jet treating apparatus are shown in FIGURE 41. The single treatment drum illustrated is similar to the third drum of FIGURE 40 and the elements are correspondingly numbered. The fibrous material for treatment may come directly from the layer-forming apparatus, without previous jet treatment. Layer **78** is guided by rolls **97** onto the cylindrical surface of the treatment drum **92**, is carried under jet manifolds **98**, leaves the drum at guide roll **99**, passes through wringer **100**, and is guided by rolls **101** to drying apparatus.

The treatment drum is constructed so that the cylindrical surface contacting the fiber layer is one of the types of patterning members discussed previously. A patterning member which does not have sufficient rigidity, such as a woven wire screen, must be supported. Perforated plates or very heavy screens can be used to support a fine wire screen, but have been found to produce a secondary pattern which shows through on the processed fabric. A honeycomb support **115**, made of thin sheet metal with about ⅛-inch cells oriented radially and at least 1 inch in thickness, is preferred. The circular ends of the treatment drum rest on rollers **116**.

The jet manifolds **98** are mounted on frame **117** which is supported on bearing blocks **118** at four corners of the frame. Drive means can be connected to the frame by means of an eccentric to impart a circular oscillation to the frame and the jet manifolds mounted thereon. Oscillation in a horizontal circle of ¼-inch diameter at 400 cycles per minute can be used to eliminate noticeable jet tracks on the treated fabric. However, this is not necessary when the jet orifices are close together along the jet manifolds, particularly when they are spaced to coincide with the wire spacing of a patterning screen. The jet manifolds are mounted on the frame by adjustable means **119** and are supplied with high pressure liquid through flexible hoses **120**, which are connected to high pressure manifold **114** by suitable fittings **121**.

FIGURE 42 is an isometric view of a portion of jet manifold **98**, shown at a larger scale and with the parts separated for clarity. Along the central axis of flat metal strip **122** are equally-spaced jet orifices **123**. Above this is the manifold body **124**, which has a lower chamber **125** connected to an upper chamber **126** by a multitude of distribution holes **127**. High pressure liquid is supplied to the upper chamber for distribution to the lower chamber. Uniformity of flow can also be improved by filter tube **128**, extending over the full length of the upper chamber, into which the liquid is introduced from one or both ends. An arrangement of fine mesh screens **129** can be provided in the lower chamber to reduce turbulence of flow. A heavy retainer plate **130** is secured to the manifold body by bolts **131** to hold jet strip **122** in place in undercut portion **132** of the manifold with a liquid-tight seal. A slit **133** extends along the central axis of the retainer plate to expose the jet orifices **123**.

The invention will be better understood from the examples of specific embodiments of nonwoven, patterned products and processes for producing them. The examples illustrate a wide variety of new and useful products, which are provided in accordance with this invention, but are not intended to be limitative.

Example 1

This example illustrates the production of a triangular-mesh pattern, textile-like, nonwoven fabric from a blend of rayon staple fibers. It further demonstrates the production of light-weight, strong, nonwoven fabric.

A carded batt composed of 75% of 1.5 denier per filament (0.17 tex), approximately 1.6-inches rayon staple and 25% 1.5 denier per filament (0.17 tex), 0.5-inch rayon staple is used as the initial web.

The web is placed on an apertured stainless-steel plate having 0.063-inch diameter holes arranged on 0.094-inch staggered centers. The plate has 132 holes/sq. in. and 41% open area. Using apparatus of the type shown in FIGURE 1, the web while supported by the plate is treated with fine, essentially columnar streams of water issuing under controlled pressure from 0.003-inch diameter orifices on 0.025-inch centers. In operation the web is first wetted down with water to hold it in place. The pressure of the water delivered to the orifices is then successively increased to the following levels: 50, 100, 300, 500, 800 and 1,000 p.s.i. At each level of pressure, the web and plate assembly is passed into the path of the streams twice, so that the streams traverse the web in one direction and then in the direction transverse thereto, the web and plate assembly being spaced about 3 inches from the orifice during all phases of the treatment. At the final pressure, the web is subjected to an additional two passes under the streams so that the total number of passes is 14. The fabric is then blotted with paper towels to remove excess moisture, removed from the backing screen and dried at room temperature. The resulting product is a triangular-mesh pattern, nonwoven fabric of a very lightweight, drapable type. The properties of the fabric are given below. The fibers are observed to be locked into place in a pattern of compact masses of entangled fibers interconnected by ordered fiber groups. The extent of this interentanglement is evident from the high strip tensile strength.

Sample weight (oz./yd.^{2})	0.62
Thickness (inch)	0.01
Strip tensile strength (lbs./in.//oz./yd.^{2})	3.54
Elongation (percent)	33
Initial modulus (lbs./in.//oz./yd.^{2})	4.60
Fiber interlock value	9.7

Similar experiments are conducted using as the initial layer a batt of 100% rayon staple (approximately 1.6 inches in length), a batt of 100% cotton, a batt of 75% of the above rayon staple and 25% cotton, and a batt of 50% cotton and 50% of ½-inch rayon staple. In all cases, the use of a fine, essentially columnar stream of water having high energy flux yields a strong, nonwoven fabric of fibers locked into place in a stable pattern.

Example 2

The example illustrates the effect of the water pressure and amount of treatment on the properties of a nonwoven product when using a staggered-hole patterning plate.

A jet-treating apparatus similar to that shown in FIGURE 2 having one stationary (non-oscillating) row of orifices located 1 inch above the web is used. The orifices are funnel shaped with an upper cylindrical diameter of 0.005 inch and are spaced 40 per inch. The patterning plate has a staggered arrangement of 0.075-inch diameter holes to give 112 holes per square inch (50% open area).

The starting layer is a random web of 2 oz./yd.^{2} weight containing equal weights of 1.5-inches and 0.25-inch rayon fibers of 1.5 denier.

Nonwoven fabrics are made by passing a web at 5.9 y.p.m. under the water jets at 100 p.s.i. for a preliminary wetting and then passing the web at the same speed under the jets at a given pressure for the number of treatments needed to give the treatment energy desired.

The variable operating conditions and the properties of the products are shown in Table 2. The number of treatments (passes) vary from 1 at 1000 p.s.i. for Item A to 88 at 200 p.s.i. for Item J.

The energy flux of the water streams varies from 1,100,000 to 12,400,000 fot-poundals/second-inch^2 for 200 and 1000 p.s.i., respectively.

The products are characterized in terms of entanglement completeness ($\bar{c}$), entanglement frequency ($\bar{f}$) and the average (of HD and CD) strip tensile strength (T) in (lbs./in.) per (oz./yd.^{2}). The products all have elongations at the break ranging from 40% to 60% and secant modulus values at 5% elongation ranging from 1.6 to 4.0 (lbs./in.) per (oz./yd.^{2}). The weights of the final products range from 1.9 to 2.3 oz./yd.^{2}.

All products have a repeating pattern of compact masses of entangled fibers which are bound to adjacent masses by linking fibers. The separation of the linking fibers into distinct fiber bundles spaced 60° apart around the nubs (similar to FIGURE 8) is much more distinct in the products prepared at energy levels of 1.0 or more HP-hrs./lb.

TABLE 2

	Total treatment energy HP-hrs./lb.				
	0.25	0.5	1.0	1.7	2.1
	Item				
	A	B	C	D	------
Pressure:					
1,000 p.s.i.:					
$\bar{c}$	.42	.56	.65	.75	------
$\bar{f}$	21	35	43	68	------
T	2.2	2.5	2.8	3.2	------
Fiber interlock value	12	11	11	11	------
	Item				
	E	F	------	------	------
400 p.s.i.:					
$\bar{c}$		.49	------	------	------
$\bar{f}$		27	------	------	------
T		2.8	------	------	------
Fiber interlock value	11	13	------	------	------
	Item				
	G	H	I	------	J
200 p.s.i.:					
$\bar{c}$		.37	.54	------	.72
$\bar{f}$		18	22	------	26
T		2.7	2.80	------	3.8
Fiber interlock value	9.7	9.2	14	------	14

$\bar{c}$=Entanglement completeness.
$\bar{f}$=Entanglement frequency.
T=Strip tensile, average MD and CD directions.

Example 3

This example illustrates the preparation of triangular-mesh-pattern nonwoven fabrics from polyester staple fibers.

The initial fibrous layer for each of these fabrics is prepared by cross-lapping (90°) two carded batts of 1.5 denier per filament (0.17 tex), 1.5-inch polyethylene terephthalate staple fibers. A series of samples is prepared by subjecting each cross-lapped web, while supported on a patterning plate having 0.063-inch diameter holes on 0.094-inch staggered centers (132 holes/sq. in., 41% open area), to the action of essentially columnar streams issuing from 0.005-inch orifices (on 0.025-inch centers) at high energy flux. The webs are turned 90° after each pass under the streams so as to be treated in two directions.

Using the above streams and spacing the web 3 inches from the orifices, a fabric having a tensile strength of about 1 to 1.5 lbs./in//oz./yd.^{2} is obtained by subjecting the web to 16 passes under the streams at a pressure of 200 p.s.i. (Sample A). The same number of passes at 300 p.s.i. produces a fabric with a strength of 3 to 3.5 lbs./in.//oz./yd.^{2} (Sample B) This latter strength or a greater strength is achieved with a lesser number of passes if the pressure is increased from 300 to 500 or 1000 p.s.i. (Samples C through E). When it is desired to pass a previously untreated web directly into the path of the 500 and 1000 p.s.i. streams at 3 inches from the orifices, a coarse-mesh screen can be placed on top of the web to help hold the fibrous material in place while it is consolidated. In this example, a 20-mesh screen is used for samples C through E during a first few passes. After the web is sufficiently wetted down and consolidated, treatment is continued without the screen for the remaining passes to complete entanglement of the fiber. The above results are summarized in Table 3 below as samples A through E.

If desired, instead of maintaining a constant pressure for all passes, a given web may be subjected to the action of the essentially columnar streams at pressures which are increased incrementally. In Table 3 are listed the properties of nonwoven fabrics (Samples F through H) prepared incrementally increased pressures using the previously described orifices, patterning plate, and separation from the orifices. As can be seen from the table, fabric strength is dependent on the maximum pressure to which a given web is subjected, all other process conditions being the same. Thus, after 8 passes, the last six of which are at 300 p.s.i., Sample F has a strength of 2 to 2.7 lbs./in.//oz./yd.^{2}. This strength is approximately doubled when the web is subjected to 8 passes at incrementally increased pressures, the last two passes being at 1000 p.s.i. (Sample H).

In still another series, nonwoven fabrics are made by altering the above process conditions by passing the web and plate assembly into contact with the streams so that the web just contacts the orifices. In this manner, webs can be processed directly even at 1000 p.s.i. without being blown apart. Sample I in Table 3 shows the properties of a fabric obtained in this fashion.

Finally, webs which have been treated under any set of conditions can be subjected to final passes at a still higher pressure with the web in contact with the orifices to further entangle the fiber and hence increase the strength of the nonwoven fabric. This may be observed by a comparison of Samples E and J of Table 3.

TABLE 3

Sample	Passes [1]	Water Pressure (p.s.i.)	Test Direction	Sample Weight (oz./yd.^{2})	Strip Tensile Strength (lbs./in.// oz./yd.^{2})	Elongation (percent)	Modulus 5% Secant (lbs./in.// oz./yd.^{2})	Thickness (inches)	Bending Length (cm.)	Tongue Tear Strength (lbs./ oz./yd.^{2})
A	16	200	MD XD	1.11 1.20	1.4 1.1	89 81	0.4 0.4	0.023	2.3 2.3	0.7
B	16	300	MD XD	1.32 1.34	3.6 2.9	76 70	0.8 0.5	0.025	2.4 2.2	1.8 2.8
C	*4 8	500 500	MD XD	1.61 1.44	2.5 4.1	69 79	1.0 0.7	0.024	2.4 2.4	3.0 2.6
D	*6 4	1,000 1,000	MD XD	1.71 1.80	3.3 4.8	86 96	0.8 0.6	0.029	2.3 2.3	3.1 2.5
E	*6 8	1,000 1,000	MD XD	1.69 1.70	5.1 6.5	61 84	1.4 0.8	0.031	2.2 2.5	2.6 2.3
F	2 6	100 300	MD XD	1.46 1.48	2.0 2.7	97 91	0.5 0.7	0.023	2.9 2.5	0.8 1.3
G	2 2 4	100 300 500	MD XD	1.42 1.53	3.0 3.2	76 85	0.8 0.6	0.023	2.2 2.4	1.8 2.2
H	2 2 2 2	100 300 500 1,000	MD XD	1.46 1.58	4.2 4.5	74 90	0.8 0.6	0.026	2.4 2.0	2.9 2.2
I	**8	1,000	MD XD	1.43 1.42	5.4 5.7	86 99	1.1 1.0	0.022	2.6 2.1	2.0
J	*6 8 **2	1,000 1,000 1,000	MD XD	1.53 1.48	7.6 7.7	79 72	1.1 1.3	0.024	2.2 2.5	2.4 2.8

[1] 3 inches from orifice unless otherwise specified.

*With 20-mesh screen on top of web.

**In contact with orifices.

Example 4

This example illustrates the preparation of triangular-mesh-pattern, nonwoven fabrics from isotactic polypropylene and from spontaneously elongatable polyethylene terephthalate continuous filament webs. It also illustrates the effect of filament denier on the ultimate properties of the fabric.

For each fabric, an initial layer of about the same basis weight, consisting of randomly-disposed continuous filaments, is used. Samples A through C consist of polypropylene filaments, each sample having filaments of a different denier. A similar series (Samples D through G) is prepared for the polyethylene terephthalate filaments.

Using the apparatus of FIGURE 1, each web is subjected to action of high energy flux, essentially columnar streams emerging from 0.005-inch diameter orifices on 0.025-inch centers, while the web is supported on an apertured patterning plate. Samples A–C are treated on a patterning plate having 0.156-inch diameter holes arranged on 0.219-inch staggered centers, the plate having an open area of about 46%. The web is treated at a distance of approximately 3 inches below the orifices using a water pressure which is incrementally increased to a maximum of about 1,000 p.s.i., the treatment being continued until a clear and distinct pattern is visually observed in the web. During treatment the web is rotated so that streams pass over it first in one direction, then in a direction transverse thereto, and finally once in each diagonal direction. Samples D–G are made in the same manner using an apertured patterning plate having 0.075-inch diameter holes arranged on 0.10-inch staggered centers.

After the treatment, the webs are blotted to remove excess moisture, removed from the patterning plate, dried at room temperature, and then tested. Properties are listed in Table 4 below. As can be seen from the table, the lower denier fibers, because they are capable of being moved more readily and hence entangle more thoroughly, yield patterned nonwoven fabrics having higher tensile strengths.

Thus, under these process conditions, for any type of fiber, the smaller the denier the higher will be the tensile strength obtainable under a given set of process conditions. Of course, process conditions can be varied to produce fabrics of the same strength from different denier fibers, if desired.

TABLE 4

Sample	Filament denier	Sample weight (oz./yd.^{2})	Strip tensile strength (lb./in.// oz./yd.^{2})	Fiber interlock value
A	1.5	2.2	14.1	
B	2.0	3.0	11.0	64
C	2.7	2.0	10.3	74
D	1.7	2.4	11.0	
E	1.8	2.5	10.0	42
F	2.5	2.3	6.8	31
G	3.6	2.6	3.9	

Example 5

This example illustrates the preparation of a triangular-mesh-pattern, nonwoven fabric from spontaneously elongatable polyethylene terephthalate continuous filaments, and demonstrates the effect which spacing of the web from the orifices during treatment has on the properties obtained.

As the initial fibrous layer, there is used a 2.5 oz./yd.^{2} web of randomly-disposed continuous filaments having a denier per filament of 1.69 (0.19 tex), a tensile strength of 2.93 g.p.d., an elongation of 118%, and an initial modulus of 29.4 g.p.d. In each instance, the initial web is placed on an apertured patterning plate having 0.077-inch diameter holes arranged in a staggered pattern, the distance between centers being 0.109 inch and the total number of holes being 96 per sq. inch., resulting in an open area of approximately 45%.

Using apparatus of the type shown in FIGURE 1, the web while supported on the patterning plate is passed under 0.005-inch orifices on 0.025-inch centers for a total of 8 passes, all of which are made in one direction.

Samples A through D are prepared using a constant water pressure of 800 p.s.i., each sample being processed at a different distance from the orifices. A similar series of samples (E through H) is prepared under the same conditions with the exception that a constant pressure of 400 p.s.i. is maintained. Each of the prepared samples is blotted dry, removed from the patterning plate, dried at room temperature and tested. As can be seen from Table 5 wherein the physical properties are reported, tensile strength decreases as the web is processed further from the orifices. This is due to the fact that the area of the fluid stream increases with increasing distance from the orifice with the result that the stream strikes the web at a progressively lower energy flux as the distance from the orifice increases.

TABLE 5

Sample	Water pressure (p.s.i.)	Distance from orifice (inches)	Strip Tensile strength (lbs./in.// oz./yd.^{2})	Fiber interlock value
A	800	1	9.3	37
B	800	2	8.3	
C	800	3	7.2	24
D	800	4	4.1	
E	400	1	9.1	32
F	400	2	6.3	28
G	400	3	5.3	16
H	400	4	2.9	

Example 6

This example illustrates the use of a continuous process. Webs are made from acrylic and rayon staple fibers using the random web-forming section of FIGURE 40.

A single jet-treating apparatus similar to that shown in FIGURE 41, having 4 stationary (non-oscillating) rows of orifices spaced 0.25 inch above the drum, is used. The orifices of a row have an upper cylindrical section of either 0.005 or 0.007-inch diameter, with a lower frustoconical section as an exit, and are arranged along the manifold at a spacing of 40 per inch for the 0.005-inch orifices and 20 per inch for the 0.007-inch orifices.

A mixture of 50% acrylic fibers (containing 2.4% TiO_2 and 750 parts per million of a commercial optical brightener) of 1.5 d.p.f. and 0.75 inch long and 50% of 1.5 d.p.f. rayon fibers of 0.25 inch length is used to make a web with a nominal weight of 2.7 oz./yd.^{2}. The web is processed on a screen surface under the 4 rows of water streams and wound up. The wet, semi-finished product is turned over and given a second treatment with the jet-treating apparatus on a different screen. Process conditions are given in Table 6. The minimum energy flux of the streams used is greater than 1,000,000 ft.-poundals per inch^2 second, and the total treatment energy is 5.0 HP-hrs./lb. of product.

The well-patterned, apertured product has the following properties:

Weight, oz./yd.^{2}	2.9
Strip tensile MD×CD (lb./in.)/(oz./yd.^{2})	4.0×3.6
Entanglement completeness	0.85
Entanglement frequency	63
Fiber interlock value	9.7

The product is a strong, surface-stable textile-like fabric that preserves its good appearance and integrity after 15 or more laundry cycles and is well adapted for such uses as a reusable diaper.

TABLE 6

Pass	Web Speed, y.p.m.	Pressure (p.s.i.g.) in rows— 1	2	3	4	Orifice diameters, inches	Screen
1st	3.5	500	1,000	1,500	1,500	0.005 for all rows	30 × 30 mesh (49% open area).
2nd	1.7	500	1,000	1,500	0	0.005 for rows 1 and 2, 0.007 for row 3.	20 × 20 mesh (36% open area).

Example 7

This example illustrates a product made by a continuous process from rayon fibers.

A random web having a nominal weight of 1.0 oz./yd.^{2} and consisting of 0.75-inch long rayon fibers of 1.5 d.p.f. is prepared and treated with apparatus of the type illustrated in FIGURES 40 and 41. Four rows of orifices are used for a single treatment. The orifices of each row are at a spacing of 40 per inch, have an upper cylindrical section of 0.005-inch diameter and a lower frusto-conical section as an exit. The minimum energy flux of the stream used is greater than 1,000,000 ft.-poundals per inch^2 second, and a treatment of 1.0 HP-hr./lb. of product is applied. The web is supported on a 24 x 24 mesh screen (16% open area) and passed at 5.0 y.p.m. under the four rows of orifices supplied with water at 150, 400, 800 and 800 p.s.i.g., respectively. The well-patterned, apertured product has the following properties:

Weight, oz./yd.^{2}	1.0
Strip tensile, MD×CD (lb./in.)/(oz./yd.^{2})	4.4×3.2
Entanglement completeness	0.59
Entanglement frequency	34
Fiber interlock value	16

Example 8

This example illustrates the preparation of a triangular-mesh-pattern, polypropylene nonwoven fabric of particular suitability for very high strength uses.

A loose web having a weight of 1.6 oz./yd.^{2} and consisting of randomly-disposed isotactic polypropylene continuous filaments, having a denier per filament of 1 and a drawn filament tenacity of 6.4 g.p.d. (57.6 g./tex), is used as the initial layer. The web is placed on an apertured stainless-steel plate containing 0.156-inch diameter holes arranged on 0.219-inch staggered centers, the plate having 46% open area. Using apparatus of the type shown in FIGURE 1, the web is treated on the plate with high energy flux streams of water issuing from 0.005-inch diameter orifices on 0.025-inch centers. The procedure used is as follows: A dilute, aqueous solution of wetting agent (fatty alcohol sulfate) is first applied to the web to wet it. The web is then passed under the jet at a distance of about 3 inches from the orifices and treated with streams of water, using a pressure of about 10–20 p.s.i. and passing the streams across the fabric once in one direction, then once in a direction transverse thereto, and finally once in each diagonal direction. The above procedure is then repeated using a pressure of 500 p.s.i. and finally using a pressure of 1000 p.s.i. The temperature of the water in all cases is 50° C. A visual pattern is observed to take place at about 1000 p.s.i. The treated web is then blotted between paper towels to remove excess moisture, removed from the apertured plate, and allowed to dry at room temperature.

The resulting structure is a nonwoven fabric having a triangular-mesh pattern. During the treatment the fibers are physically driven by the high energy flux, essentially columnar streams and caused to realign into the pattern while at the same time becoming so entangled with one another that they form a strong, durable, stable, nonwoven fabric. Properties of the fabric are as follows:

Strip tensile strength (lbs./in.//oz./yd.^{2})	22.4
Elongation (percent)	41.0
Tongue tear strength (lbs./oz./yd.^{2})	3.5
Fiber interlock value	65

The remarkable tensile strength of this fabric is achieved without the use of any binder and is solely the result of fiber entanglement. The nonwoven, patterned fabric so produced is coherent and stable because the individual fibers are locked into position in the pattern. Because of its exceptionally high strength, this nonwoven fabric is particularly useful for many industrial applications.

Example 9

This example illustrates the production of a wool-like, triangular-mesh-pattern, nonwoven fabric from fibers of polypivalolactone.

A carded web is prepared from staple fiber (about 1.5 inches long) from polypivalolactone. The fibers have a denier per filament of 3.2 (0.36 tex) and a tensile strength of 2.36 g.p.d. (21.2 g./tex). The web is placed on a patterning plate having 0.156-inch diameter holes arranged on 0.219-inch staggered centers (46% open area). Using the apparatus of FIGURE 1, the web and plate assembly is passed under streams issuing from 0.007-inch orifices arranged on 0.050-inch centers. The water temperature is 25° C. and the water pressure is raised incrementally to a maximum of 1500 p.s.i. and the web is passed repeatedly under the streams at a distance of about 2 to 3 inches from the orifices until a clear visual pattern is observed. The web is then blotted to remove excess moisture, removed from the plate, dried at room temperature and tested. The triangular-mesh-pattern, nonwoven fabric so obtained has aesthetic properties similar to those of a woven wool or wool blend suitable for use in suitings, skirts, blankets, overcoats and the like. Properties of the fabric are as follows:

Fabric weight (oz./yd.^{2})	2.8
Strip tensile strength (lb./in./oz./yd.^{2})	3.6
Elongation (percent)	62.3
Tongue tear strength (lb./oz./yd.^{2})	1.41
Fiber interlock value	9.7

Example 10

This example illustrates the preparation of a square-mesh-pattern, nonwoven fabric from polyethylene terephthalate continuous filaments.

A loose web consisting of randomly-disposed continuous filaments of polyethylene terephthalate is placed on a 10-mesh woven screen having a 56.3% open area and a wire diameter of 0.025 inch. Using apparatus of the type shown in FIGURE 1, the web while supported by the screen is treated with high energy flux, essentially columnar streams of water issuing from 0.007-inch diameter orifices on 0.050-inch centers supplied with water at 1000 p.s.i.g. pressure. The web is subjected to two passes across the web and two passes transverse thereto, while being held substantially in contact with the jet face.

As a result of the treatment, the random web of fibers is converted into a patterned sheet on which intersecting filament bundles are aligned in a uniform pattern, the intersections being square-shaped areas of fibers entangled with one another to form a stable, coherent and durable fabric. The web is allowed to dry on the screen, after which it is removed from the screen, examined and tested. Properties of the fabric are listed below:

Fabric weight (oz./yd.^{2})	2.90
Strip tensile strength (lbs./in.//oz./yd.^{2})	1.57
Elongation (percent)	147.00
Initial modulus (lb./in.//oz./yd.^{2})	0.70
Bending length (cm.)	3.80

The entangled areas of the fabric are in a square-mesh-pattern corresponding to the square openings in the patterning screen, and the sides of the squares are connected by substantially parallel bands of fibers which define openings corresponding to the locations where wires cross in the screen. Especially desirable fabrics are obtained when highly crimped filaments are used in the initial web. FIGURE 11 shows a typical portion of such a square-mesh-pattern, nonwoven fabric after magnification, and FIGURE 12 is a drawing of a similarly enlarged portion of the patterning screen used in this example.

Example 11

This example illustrates the preparation of a highly drapable, triangular-mesh-pattern, nonwoven fabric from polyethylene terephthalate continuous filaments.

A web of randomly-disposed, shrinkable, continuous filaments of polyethylene terephthalate is used as the starting material. The web has a weight of about 1.2 oz./yd.^{2} and the filaments have the following properties:

Denier per filament	1.6
Tensile strength (g.p.d.)	2.9
Elongation (percent)	129
Initial modulus (g.p.d.)	24.7

The wetb is placed on an apertured plate having 0.075-inch diameter holes on 0.1-inch staggered centers, there being 112 holes/in.^{2}, resulting in an open area of about 50%. Using the apparatus of FIGURE 1, the web and plate assembly is passed under high energy flux streams of water issuing from 0.005-inch orifices on 0.025-inch centers. The web is passed under the orifices for a total of 8 times in each of two perpendicular directions. During the treatment, the water pressure is adjusted to 1000 p.s.i., the water temperature is 50° C., and the web is spaced 2 to 3 inches from the orifices. A strong, triangular-mesh-pattern, nonwoven fabric having a 5% secant modulus of about 5 to 6 lbs./in.//oz./yd.^{2} is obtained.

This fabric is placed in a chamber containing water at 85° C. for about 2 to 3 minutes. As a control, filaments of the same type as used in the fabric, when subjected to the same hot-water treatment, have the following properties:

Tensile strength (g.p.d.)	2.67
Elongation (percent)	163
Initial modulus (g.p.d.)	21

The hot water causes the fibers to undergo a linear shrinkage of about 30%, whereupon the fabric area shrinks about 50%. When removed from the water, the fabric is observed to be bulkier and to have a smaller size pattern than before.

After drying, the fabric is placed between two 200-mesh screens to restrain the fibers and the assembly is heated in an air oven at approximately 180°–200° C. for 1 minute. The fabric now has the following properties:

Fabric weight (oz./yd.^{2})	1.82
Strip tensile strength (lbs./in.//oz./yd.^{2})	8.2
Elongation (percent)	160
5% secant modulus (lbs./in.//oz./yd.^{2})	0.70
Bending length (cm.)	1.75
Fiber interlock value	33

The fabric is observed to be soft, strong, stretchy, dimensionally stable, coherent, launderable and highly drapable. It is suitable for use in apparel and home furnishing areas, such as upholstery, draperies, bedspreads, shirts, underwear, socks and the like.

Example 12

This example illustrates the preparation of a highly drapable, triangular-mesh-pattern, nonwoven fabric from spontaneously elongatable fibers.

A web of randomly-disposed, spontaneously elongatable polyethylene terephthalate continuous filaments is used as the initial fibrous layer. The filaments are prepared in accordance with the teachings of U.S. Patent No. 2,952,879 and have a spontaneous elongation of about 15%. Other properties of the fialments are as follows:

Tensile strength (g.p.d.)	1.9
Elongation (percent)	238.0
Initial modulus (g.p.d.)	13.3
Denier per filament (0.4 tex)	3.64

The starting web is placed on an apertured plate having 0.077-inch diameter holes arranged on 0.109-inch staggered centers, the plate having 96 holes/sq. in. and an open area of approximately 45%. Using the apparatus of FIGURE 1, the web and plate assembly is passed under streams issuing from 0.005-inch orifices on 0.025-inch centers at a water pressure of 1300 lbs./sq. in. The web is treated in four directions, spaced 45° apart, until a well-defined pattern is obtained. The web is then removed from the plate, placed between 200-mesh screens and exposed to heat at 200° C. in an air oven. The heat serves to develop the spontaneous elongation of the fibers. The resulting fabric is highly drapable and is soft, strong and well suited for apparel, home furnishings, and other conventional fabric uses. Properties of the fabric are listed below:

Fabric weight (oz./yd.^{2})	2.73
Strip tensile strength (lbs./in.//oz./yd.^{2})	6.12
Elongation (percent)	171
5% secant modulus (lbs./in.//oz./yd.^{2})	0.51
Bending length (cm.)	1.25
Fiber interlock value	31

Example 13

This example illustrates the production of a highly drapable, strong, triangular-mesh-pattern, nonwoven fabric from two-component, post-crimpable filaments. It also illustrates the production of a flannel-like fabric.

A web of randomly-disposed, trilobal cross-section, two-component filaments prepared from polyhexamethylene adipamide and polycaproamide (50/50 weight ratio) is used as the initial fibrous layer. The web has a weight of about 2.1 oz./yd.^{2} and is placed on a patterning plate having 0.063-inch diameter holes arranged on 0.094-inch staggered centers (132 holes per sq. in., 41% open area). The web and plate assembly is passed repeatedly back and forth under essentially columnar streams of water issuing from 0.005-inch diameter orifices linearly disposed on 0.025-inch centers, using the apparatus of FIGURE 1. During the treatment, the water pressure is increased incrementally through the following steps: 25, 100, 300, 600 and 800 p.s.i., and the water temperature is 60° C. The treatment is continued until a nonwoven fabric having a triangular-mesh pattern is obtained. The fabric is then boiled-off for five minutes during which it undergoes an area shrinkage of 12%.

One portion of the fabric, after drying, is consolidated by pressing at 192° C. between smooth platens for 5 seconds at approximately 300 p.s.i. pressure. Properties of both fabrics are as follows:

Properties	After Boil-off	After Boil-off and Consolidation
Fabric Weight (oz./yd.^{2})	2.01	2.25
Strip Tensile Strength (lb./in.//oz./yd.^{2})	4.30	4.53
Elongation (percent)	115	153
Initial Modulus (lb./in.//oz./yd.^{2})	1.05	0.67
Bending Length (cm.)	1.19	1.55

Both of the triangular-mesh pattern, nonwoven fabrics so obtained are highly drapable and are suitable for typical fabric uses, such as apparel and the like.

A flannel-like fabric with a warm, soft hand is then prepared by sanding each side of the above-described, consolidated fabric with a 240-grit emery paper to break long loops of fibers, shearing the resulting nap of surface fibers with barber clippers (000 cutting head), and consolidating the sheared structure at 192° C. between smooth press platens for 5 seconds at approximately 300 p.s.i. pressure.

Example 14

This example illustrates the production of a highly drapable, triangular-mesh-pattern, nonwoven fabric from two-component, highly crimped fibers.

Filaments having a ribbon-shaped cross-section are prepared by spinning polyethylene terephthalate and polyhexamethylene adipamide (50/50 weight ratio) in side-by-side relationship through a spinning slot (0.003 inch by 0.060 inch), the components being spun at opposite ends of the slot. The filaments are then subjected to a high temperature treatment which shrinks the polyethylene terephthalate component to produce filaments having about 150 crimps/in. The filaments are then collected in the form of a web of randomly-disposed, continuous, crimped filaments, the web having a weight of approximately 1.6 oz./yd.^{2}.

Two of the above webs (placed one on top of the other) are laid on a patterning plate having 0.063-inch diameter holes arranged on 0.094-inch staggered centers (132 holes per sq. in., 41% open area). The web and plate assembly is passed repeatedly back and forth under essentially columnar streams of water issuing from 0.005-inch diameter holes linearly disposed on 0.025-inch centers, using the apparatus of FIGURE 1. During the treatment, water pressure to the orifices is raised from 25 to 100 and finally to 1000 p.s.i. pressure. The treatment is continued until a nonwoven fabric having a clear, distinct triangular-mesh pattern is obtained. The fabric is removed from the patterning plate, boiled-off, and then dried.

One-half of the fabric thus obtained is then placed between 30-mesh screens under a pressure of about 20 p.s.i. for approximately 30 seconds at 185° C., which serves to heat-set the fibers and also causes the polyethylene terephthalate component to elongate.

Both of the resulting fabrics are highly drapable and flexible, and are suitable for conventional fabric uses, particularly apparel uses. Properties of the fabrics are as follows:

Properties	After Boil-Off	After Boil-Off and Heat-setting
Fabric Weight (oz./yd.^{2})	3.28	3.24
Strip Tensile Strength (lb./in.//oz./yd.^{2})	3.4	3.4
Elongation (percent)	209	190
Initial Modulus (lb./in.//oz./yd.^{2})	0.8	0.36
Bending Length (cm.)	1.38	1.23

Certain bicomponent fibers, such as the crimped side-by-side, fibers from polyhexamethylene adipamide and polyethylene terephthalate split during treatment with the high pressure streams of water, resulting in fine denier fibers which yield more highly entangled products. This contributes to the good properties shown above.

Example 15

This example illustrates desirable modifications of the processsing conditions employed when treating webs of different weights in the production of nonwoven, triangular-mesh-pattern fabrics.

The initial starting layers are random webs of different weights in three series, with a different fiber in each series. The fibers include 1.5 d.p.f. (0.17 tex), 1.5-inch long polyacrylic staple (Series A), 1.5 d.p.f. (0.17 tex), 1.5-inch polyethylene terephthalate staple (Series B), and cotton fibers having a staple length of approximately 1 inch (Series C). Each nonwoven fabric is prepared by placing the initial web on a patterning plate having 0.063-inch diameter holes on 0.094-inch staggered centers, the plate having 132 holes per sq. in. and 41% open area. The web and plate assembly is passed under 0.005-inch orifices arranged on 0.025-inch centers, and supplied with water under pressure, initially at 100 p.s.i., for the number of passes at each pressure indicated in Table 7. The web is initially at a distance of approximately 5 inches from the orifices, and the distance is decreased progressively to approximately 1 inch from the orifices at the highest pressures. The treatment is continued at incrementally increased pressures until a clear and distinct triangular-mesh pattern is obtained.

Properties of the various fabrics are given in Table 7 below. It will be observed that the processing conditions used for heavier web weights are made more severe by increasing the number of passes to which the web is subjected and/or by increasing the maximum pressure of the water to provide higher energy-flux streams.

TABLE 7

Fiber Interlock Value	Fiber Series	Web Weight (oz./yd.^{2})	Strip Tensile Strength (lb./in.// oz./yd.^{2})	Processing Conditions (Heading: Water Pressure in p.s.i. Body: No. of Passes)									Total No. of Passes
				100	200	300	400	500	800	900	1,000	1,200	
—	A	0.74	6.8	2	1			2	1		1		7
—	A	1.54	7.1	1	2			2	1			4	10
—	A	1.90	8.8	1				2	2			6	11
20	B	1.09	7.25	2		2		3	1		2		10
24	B	1.82	11.8	1		2		2			2	4	11
—	B	2.07	14.9	1			2		2			5	10
—	B	2.56	13.9	1			2		2			6	11
9.4	C	0.55	1.18	2	2			2	3				9
9.4	C	0.96	3.74	1		2			2			5	10
—	C	1.75	6.81	1		2			2			6	11
—	C	2.12	7.15	1			2			2		4	9

Example 16

This example illustrates the preparation of a triangular-mesh-pattern, nonwoven fabric from two-component, continuous filaments followed by treatment of the web to close up the pattern and increase the cover of the fabric.

A web of randomly-disposed, continuous filaments having a denier per filament of 3 (0.33 tex) is used as the initial fibrous layer. The web is prepared from two-component, post-crimpable filaments having polyhexamethylene adipamide as one component, and a copolyamide of hexamethylene adipamide and hexamethylene sebacamide units as the other component. The web is placed on a patterning plate having 0.063-inch diameter holes on 0.094-inch staggered centers (132 holes per sq. in. and 41% open area) and is passed under essentially columnar streams issuing from 0.005-inch orifices on 0.025-inch centers at pressures up to 500 p.s.i. maximum. The web is passed under the streams until a clear, distinct, nonwoven pattern is formed. The fabric is then immersed in hot water until a crimp is developed in the fibers and there is a 25% reduction in the area of the fabric. The appearance of a typical portion of the fabric is shown in FIGURE 3 at 40× magnification. The extent to which crimping closes up the pattern is apparent when the fabric is pulled taut to straighten the fibers, as shown in FIGURE 4 with magnification. The fabric is strong and coherent.

Another triangular-mesh-pattern, nonwoven fabric is produced in the same manner. Prior to crimping the opacity is measured and found to be 31%. The fabric is then immersed in boiling water to develop a high crimp in the fibers, resulting in a 50% area reduction of the fabric. The fabric is then padded in a water dispersion of an acrylic resin (10% pickup by weight) and pressed at 90 tons/ft.^{2} at 80° C. The opacity of the final structure is 76% and the fabric thus obtained has a weight of 2 oz./yd.^{2}. The fabric is highly drapable, has good cover and is well suited for conventional fabric uses such as apparel. The appearance of the fabric after magnification is similar to that illustrated in FIGURE 3. The fiber interlock value is 11.5.

Example 17

This example illustrates the preparation of both triangular-mesh-pattern and square-mesh-pattern nonwoven fabric from two-component continuous filaments.

A web of randomly-disposed continuous filaments, having a denier per filament of 3 (0.33 tex) and over 60 crimps per inch, is used as the initial web. The filaments are two-component filaments prepared from polyhexamethylene adipamide and polyethylene terephthalate.

The web is placed on an apertured plate having 0.063-inch diameter holes on 0.094-inch staggered centers (132 holes per sq. in., 41% open area) and is treated with essentially columnar water streams issuing through 0.003-inch diameter orifices on 0.025-inch centers, using the apparatus of FIGURE 1. During the treatment the pressure is slowly raised from zero to a maximum of 1900 p.s.i. The web is passed under the streams until a clear, distinct pattern is formed and the filaments are firmly entangled. A typical portion of the resulting fabric is shown in FIGURE 6 at low magnification. Properties are as follows:

Property	Initial Web	Product
Sample Weight (oz./yd.^{2})	1.9	2.0
Strip Tensile Strength (lb./in.//oz./yd.^{2})		2.7
Grab Tensile Strength (lbs.)	5.7	12.9
Grab Elongation (percent)	470	64
Fiber Interlock Value		16

Examination of the product reveals that it is a strong, coherent, triangular-mesh-pattern fabric, fibers of which are so highly entangled that the structure cannot be pulled apart without rupturing fibers. The extent to which the fibers have interlocked is evident from the properties of the fabric. It is noted that when the fabric is subjected to the grab tensile test it ruptures by breakage of the filaments, the break being abrupt and the web retaining its triangular-mesh-pattern structure under stress. FIGURE 7 shows the appearance of the fabric after rupture in the grab tensile test.

The above observations also apply to fabric produced on other types of apertured plates. When the example is repeated, but using an apertured plate having 0.079-inch holes aligned on 0.125-inch centers in straight rows and columns, instead of staggered holes, a corresponding superiority results from following the previous procedure. The appearance of the fabric obtained in this way is shown in FIGURE 9 at moderate magnification. The compact masses of entangled fibers are centered on the corners of squares and are interconnected by heavy fiber bundles aligned with the sides of the squares, giving a square-mesh pattern. Smaller interconnecting fiber bundles extend across the diagonals of the squares to provide strength in all fabric directions and a pleasing appearance.

Example 18

This example illustrates the preparation of triangular-mesh-pattern, nonwoven fabrics from steel wool for use as scouring pads and the like.

Two commercially produced, Number 000 grade steel wool batts are cross-lapped and placed on a patterning plate having 0.156-inch diameter holes arranged on 0.188-inch staggered centers (63% open area). The batt and plate assembly is passed under essentially columnar streams of water issuing from 0.007-inch orifices on 0.050-inch centers, using the apparatus of FIGURE 1. The pressure is increased to a maximum of 1500 p.s.i. and the treatment is continued until a clear, distinct pattern is obtained. The product is then removed from the patterning plate and is found to be a coherent, strong, triangular-mesh nonwoven fabric of steel wool. These properties make it superior for use as a scouring pad or other uses of conventional steel wool.

In a similar manner, a fiber-surfaced steel-wool fabric is obtained by placing a web of randomly-disposed continuous filaments of polyethylene terephthalate, the web having a weight of about 2 oz./yd.^{2}, above or below the steel wool layer and subjecting the composite to the action of essentially columnar fluid streams as described above. In the triangular-mesh fabrics thus obtained, the steel wool and the polyethylene terephthalate filaments are thoroughly interentangled with one another to form a coherent, stable, unitary product.

Example 19

This example illustrates the preparation of a film-laminated, triangular-mesh-pattern, nonwoven fabric suitable for use as apparel-type fabric.

Two triangular-mesh-pattern fabrics are prepared from webs of randomly-disposed, two-component, continuous filaments composed of equal weights of polyhexamethylene adipamide and a copolyamide of hexamethylene adipamide and hexamethylene sebacamide units (50/50). In each instance, the initial layer has a web weight of about 0.5 oz./yd.^{2} and is placed on a patterning plate having 0.0625-inch diameter holes on 0.094-inch staggered centers (132 holes per sq. in. and 41% open area). Using the apparatus of FIGURE 1, the web and plate assembly is treated with essentially columnar streams of water issuing from 0.005-inch orifices on 0.025-inch centers at a distance of 3 to 4 inches from the orifices. A low water pressure is used to wet down the web, after which the water pressure is increased incrementally to a maximum of about 1000 p.s.i. Treatment is continued until a clear, distinct nonwoven pattern is obtained.

A piece of 0.004-inch polyethylene film is sandwiched between the two triangular-mesh-pattern, nonwoven fabrics so obtained. The composite is pressed at 130° C. for two minutes at 300 p.s.i. to fuse the polyethylene and laminate the sheets together. The laminate is then subjected to mechanical working by hand. The resulting structure is a triangular-mesh-pattern, nonwoven fabric which is highly drapable and fabric-like. The polyethylene enhances the surface stability of the fabric. The product has a fiber interlock value of 17.

Example 20

This example illustrates the production of a more drapable, triangular-mesh-pattern, nonwoven fabric by using an aqueous detergent as the fluid.

A web of randomly-disposed, two-component continuous filaments, composed of equal weights of polyhexamethylene adipamide and a copolyamide of hexamethylene adipamide and hexamethylene sebbacamide units (50/50), is used as the initial layer. The filaments have a denier per filament of 3 (0.33 tex) and the web has a weight of about 3 oz./yd.^{2}. The web is placed on a patterning plate having 0.063-inch holes on 0.094-inch staggered centers (132 holes per sq. in. and 41% open area). Using the apparatus of FIGURE 1, the web is treated with essentially columnar streams from 0.005-inch orifices (0.025-inch centers) at 3 to 4 inches from the orifices. The web is wet down at low pressure; then the pressure is increased incrementally to 1200 p.s.i. The web is subjected to a total of 10 passes under the streams, the passes being in two perpendicular directions. One fabric is prepared using water as the liquid; another is prepared using a 0.1% solution of a commercial liquid laundry detergent.

The as-prepared fabrics are rinsed, boiled-off for 5 minutes, dried and tested. Properties are given below. Both nonwoven, patterned fabrics have approximately the same tensile strength but the fabric prepared by using the detergent is more drapable and has a higher tear strength.

	Water	Detergent
Fabric Weight (oz./yd.^{2})	3.4	3.4
Strip Tensile Strength (lbs./in.//oz./yd.^{2})	3.36	3.29
Elongation (percent)	108	133
5% Secant Modulus (lbs./in.//oz./yd.^{2})	0.31	0.17
Tongue Tear Strength (lbs./oz./yd.^{2})	0.60	1.04
Bending Length (cm.)	1.40	1.36
Fiber Interlock Value	10.8	11.2

Example 21

This example illustrates the use of short cellulosic fibers in combination with staple fibers to produce special effects in triangular-mesh-pattern, nonwoven fabrics.

Nonwoven fabrics are prepared from three different initial webs using the apparatus of FIGURE 1 and the following processing conditions:

Orifice size—0.005 inch (0.025-inch centers)
Spacing of web from orifice—3 to 4 inches
Patterning plate—0.156-inch diameter holes, 0.188-inch staggered centers, 63% open area
Water pressure—0 to 1200 p.s.i., increased incrementally
Passes—5 in one direction and 5 perpendicular thereto for a total of 10.

For Sample A the initial web is a carded batt (about 2 oz./yd.^{2}) of 1.5 denier per filament (0.17 tex) polyethylene terephthalate staple fiber (1.5 inch).

For Sample B, a commercially available facial tissue is laid on a similar staple batt and the composite is passed under the streams.

For Sample C a commercially available paper towel is laid on a similar staple batt and the composite is passed under the streams.

Triangular-mesh-pattern, nonwoven fabrics of good properties are obtained in each instance. In the preparation of these fabrics, the short paper fibers used in the overlays of Samples B and C appear to assist in pattern formation and definition. They are observed to be interentangled with the staple fibers in the compact masses or nubs of entangled fibers formed over holes of the patterning plate. Unexpectedly, the shorter fibers increase the over-all strength of the web as can be seen from the properties tabulated below. When the fabrics are subjected to 5 washings in a household washing machine, of the agitator type, there is no loss of the short fibers (as evidenced by the fact that no weight loss occurs).

Sample	A	B	C
Overlay of paper fibers	None	Tissue	Towel
Fabric Weight (oz./yd.^{2})	1.44	1.73	2.87
Strip Tensile Strength (lbs./in.//oz./yd.^{2})	4.45	5.93	6.85
Elongation (percent)	70	65	68
Initial Modulus (lbs./in.//oz./yd.^{2})	2.0	4.4	6.4
Bending Length (cm.)	2.10	2.15	2.20
Fiber Interlock Value	29	31	24

If desired, various designs can be achieved by working the overlay fibers into the pattern in certain areas only, or into certain nubs only, or into the bundles between nubs to produce special effects. Blends of different types of fibers, e.g., absorbent and nonabsorbent fibers, provide products having advantages of both. Other specialty fabrics can be obtained by converting the short fiber webs into patterned fabrics and then attaching these by entanglement to random, nonpatterned webs.

Example 22

This example illustrates the preparation of a triangular-mesh-pattern, nonwoven fabric combining continuous filaments with short fibers from a synthetic fiber paper.

A nonwoven fabric is prepared from a web (about 2 oz./yd.^{2}) of randomly-disposed, spontaneously elongatable, polyethylene terephthalate continuous filaments having a denier per filament of about 4 (0.44 tex). The filaments are prepared in accordance with the teaching of U.S. Patent No. 2,952,879 and have a spontaneous elongation of about 20%. The fabric (Sample A) is prepared using the apparatus of FIGURE 1 and the following processing conditions:

Orifice diameter—0.005 inch (0.025-inch centers)
Spacing of web from orifice—3 to 4 inches
Patterning plate—0.063-inch diameter holes, 0.094-inch staggered centers, 132 holes per sq. in. and 41% open area
Water pressure—0 to 1000 p.s.i., raised incrementally
Passes—5 in one direction and 5 perpendicular thereto for a total of 10 passes.

Using the same processing conditions, a nonwoven fabric (Sample B) is then prepared from a composite consisting of a synthetic-fiber paper overlay on a web as described above, the composite being placed on the patterning plate with the web adjacent the plate. The paper sheet comprises 80% by weight of 0.25-inch polyethylene terephthalate staple fibers and 20% of fibrids of a copolyester of 80% ethylene terephthalate and 20% ethylene isophthalate. The preparation of papers from fibrids and staple fibers is described in U.S. Patent No. 2,999,788. During the treatment, the original continuity of the paper is destroyed and the components of the paper are caused to entangle with and realign with the filaments of the web thereby forming a triangular-mesh-pattern, nonwoven fabric. It is observed that the shorter fibrous components are predominantly concentrated in the compact masses of the fabric.

Samples A ad B are then pressed between a rubber sheet and a 40-mesh screen at 170° C. for one minute, the temperature being sufficient to cause the spontaneously elongatable fibers to elongate but insufficient to fuse the fibrids of Sample B. Both triangular-mesh-pattern, nonwoven products are soft, strong and drapable and well suited for conventional fabric uses. Properties are given below.

Sample	A	B
Fabric Weight (oz./yd.^{2})	1.90	2.17
Strip Tensile Strength (lbs./in.//oz./yd.^{2})	1.18	3.68
Elongation (percent)	99	158
5% Secant Modulus (lbs./in.//oz./yd.^{2})	0.42	1.11
Bending Length (cm.)	1.84	1.72
Tongue Tear Strength (lbs./oz./yd.^{2})	3.83	4.23
Thickness (inch)	0.026	0.019

Example 23

This example illustrates the use of short fibers from a synthetic fiber paper in combination with continuous filaments to produce triangular-mesh-pattern, nonwoven fabric having special properties.

Using the apparatus of FIGURE 1, a nonwoven fabric (Sample A) is prepared from a web of randomly-disposed, postcrimpable, two-component continuous filaments of 50% polyhexamethylene adipamide and 50% of a copolyamide of hexamethylene adipamide and hexamethylene sebacamide units (50/50 weight percent). The filaments have a denier per filament of about 3 (0.33 tex) and the web has a weight of about 2 oz./yd.^{2}. Processing conditions are as follows:

Orifice diameter—0.005 inch (0.025-inch centers)
Spacing of web from orifices—3 inches
Patterning plate—0.156-inch diameter hole, 0.188-inch staggered centers, 63% open area
Water pressure—0 to 1000 p.s.i., increased incrementally
Passes—5 in one direction and 5 perpendicular thereto for a total of 10.

Using the same process conditions, two additional nonwoven fabrics (Samples B and C) are prepared. Sample B is prepared from a composite consisting of a similar continuous filament web as base layer (adjacent to the patterning plate) and a paper overlay (approximately 0.5 oz./yd.^{2}) prepared from polyhexamethylene adipamide staple fibers (65%) and fibrids (35%) of a copolyamide of 20% hexamethylene adipamide and 80% caprolactam units. Sample C is made from a similar composite having 2 layers of paper instead of one. Preparation of papers from fibrids is described in U.S. Patent No. 2,999,788. During the treatment the paper is separated into its fibrous components, which are realigned with and entangled with the continuous filaments of the web. It is noted that the fibrous components of the paper tend to concentrate in the compact masses.

Samples A, B and C are then immersed in boiling water for five minutes, during which the fibers crimp and close up the pattern thereby densifying the fabric. All of the fabrics are soft, strong and drapable and are suitable for conventional fabric uses, particularly apparel uses. Samples B and C fabrics, while having approximately the same level of drape as Sample A, exhibit a lesser tendency to stretch and thus more nearly resemble a woven fabric, whereas Sample A more nearly resembles a knitted fabric. Properties of the fabrics are given below.

Sample	A	B	C
Overlay	None	1 layer	2 layers
Fabric Weight (oz./yd.^{2})	1.85	2.45	3.06
Strip Tensile Strength (lbs./in.//oz./yd.^{2})	5.75	5.38	5.06
Elongation (percent)	132	135	118
Thickness (inch)	0.024	0.029	0.034
Bending Length (cm.)	1.0	1.1	1.3
5% Secant Modulus (lbs./in.//oz./yd.^{2})	0.07	0.13	0.46
20% Secant Modulus (lbs./in.//oz./yd.^{2})	0.44	1.52	3.42
Fiber Interlock Value	21	24	19

Example 24

This example illustrates the production of nonwoven fabric having one pattern superimposed on another.

A web of randomly-disposed continuous filaments is converted to a triangular-mesh-pattern, nonwoven fabric using the apparatus of FIGURE 1 and the following conditions:

Orifice diameter—0.005 inch (0.025-inch centers)
Spacing of web from orifices—3 to 4 inches
Patterning plate—0.063-inch diameter hole, 0.094-inch staggered centers, 132 holes per sq. in., and 41% open area
Water pressure—0 to 1000 p.s.i., increased incrementally.

The treatment is continued until a clear distinct triangular-mesh pattern is obtained. The fabric is then removed from the above described plate, transferred to a 5 mesh screen, and treated again with high-energy-flux streams in the same fashion. The fabric is then blotted to remove excess moisture, removed from the screen and dried. The nonwoven fabric now exhibits a pattern of repeating triangles (approximately 0.094 inch on a side), onto which is superimposed a pattern of repeating squares (approximately 0.25 inch on a side). The fiber interlock value is 15.

A product wherein two patterns can be observed can also be prepared by treating a web on a patterning screen which has one pattern superimposed on another. For example, a 40 x 40 mesh (wires/inch) patterning screen is embossed by pressing the screen between a wood block and an 8 x 8 mesh screen. The 40 mesh screen thus has superimposed on it a number of dents (8 per inch in each direction) corresponding to the knuckles of the 8 x 8 screen. When a 2.5 oz./yd.^{2} web of acrylic fibers (1.5 inches) and rayon fibers (0.25 inch) is placed on the modified screen and treated with columnar jets of liquid at high pressure, a patterned nonwoven fabric having a pattern of thick entangled fiber areas, at a spacing of 8 per inch corresponding to the dents, is obtained. In the thinner remainder of the fabric, between these thick entangled areas, the pattern of the 40 mesh screen is seen. A similar product is made if the web weight is increased to 3.5 oz./yd.^{2} and this product has greater covering power than the 2.5 oz./yd.^{2} product.

A product having a thick/thin pattern is obtained by using high pressure, columnar streams of water to treat a 3 oz./yd.^{2} web of acrylic/rayon (50/50) fibers supported on a modified screen. In this instance, the screen is a 100 x 100 mesh screen which has been embossed by being pressed against a plate having 11 grooves per inch in one direction and 5.5 grooves per inch in the direction perpendicular to the first direction, the plate surface having elongated wedge-shaped projections having 0.020 inch x 0.110 inch "lands". The embossed screen has dents which are 0.027 inch deep and correspond to the projections of the plate. The nonwoven product has a pattern of interconnected entangled fiber areas corresponding to the embossed dents; no pattern corresponding to the 100 x 100 mesh screen surface is visible.

Example 25

This example illustrates the production of a triangular-mesh-pattern, nonwoven fabric of acrylic fibers. It also demonstrates the effect of water temperature on processing acrylic fiber webs.

Two carded batts of commercial acrylic staple fibers having a length of 1.5 inch and a denier per filament of 1.5 (0.17 tex) are converted to nonwoven fabrics using the apparatus of FIGURE 1 and the following conditions:

Orifice diameter—0.005 inch (0.025-inch centers)
Spacing of web from orifices—3 to 4 inches
Patterning plate—0.156-inch diameter holes, 0.188-inch staggered centers, 63% open area

Water pressure—0 to 1000 p.s.i., increased incrementally
Passes—5 in one direction and 5 perpendicular thereto, for a total of 10.

Each carded batt has a weight of about 2 oz./yd.^{2}. Batt A is processed using water at a temperature of 20° C., and batt B is processed using water at a temperature of 50° C. In both instances a strong, triangular-mesh-pattern, nonwoven fabric is obtained. It is noted that with the use of hot water, which apparently exerts a plasticizing action on the fibers, thereby increasing their mobility, a clearer and more distinct pattern and a higher tensile strength are achieved. Properties of the fabrics are given below.

	A	B
Fabric weight (oz./yd.^{2})	2.30	2.88
Strip Tensile Strength (lbs./in.//oz./yd.^{2})	3.88	4.77
Elongation (Percent)	45	50
5% Secant Modulus (lbs./in.//oz./yd.^{2})	0.96	1.19
Fiber Interlock Value	18	16

The beneficial effect which the use of hot water has, on the ease of production of patterned, nonwoven fabric from acrylic fibers, increases as the pattern size decreases. Thus the use of hot water makes it possible to produce strong acrylic fiber fabrics on finer-mesh screens and/or patterning plates than would otherwise be possible.

Example 26

This example illustrates the production of an exceptionally drapable triangular-mesh-pattern, nonwoven fabric from relatively straight acrylic fibers.

A batt (approximately 2 oz./yd.^{2}) of commercially available 1.5-inch acrylic fiber staple having a denier per filament of 1.5 (0.17 tex) is placed on a patterning plate having 0.075-inch diameter holes arranged on 0.1-inch staggered centers (112 holes per sq. in., and 50% open area). Using the apparatus of FIGURE 1, the web is subjected to essentially columnar streams of water (50° C.) from 0.005-inch orifices (0.025-inch centers) for a total of 10 passes (5 in each of two perpendicular directions). During the treatment, the water pressure is raised incrementally from 0 to 1000 p.s.i. and the web is processed at a distance of 3 to 4 inches from the orifices. The resulting triangular-mesh-pattern, nonwoven fabric is immersed in boiling water for about five minutes, dried and tested. It is a strong fabric which is exceptionally drapable and thus particularly suitable for apparel uses. Properties are given below:

Fabric weight (oz./yd.^{2})	2.20
Strip tensile strength (lbs./in.//oz./yd.^{2})	4.35
Elongation (percent)	61
5% secant modulus (lbs./in.//oz./yd.^{2})	0.31
Bending length (cm.)	1.53
Fiber interlock value	19

Example 27

Uncrimped rayon fibers of 1.56 inch (3.94 cm.) length and 1.5 d.p.f. are made into a web [weight of 1.2 oz./yd.^{2} (41 g./m.^{2})] of randomly oriented fibers by an air deposition process using a random-laydown machine.

The above web is placed on a 20 x 20 mesh per inch (per 2.54 cm.) plain woven screen (36% open area) and passed under a row of substantially cylindrical, unbroken vertical jet streams of water. The streams are produced by a row of funnel-shaped orifices spaced 40 per inch (per 2.54 cm.) located in a manifold. The water enters the cylindrical portion of the orifice 5 mils (0.13 mm.) in diameter and about 1 mil (0.025 mm.) long and exits as a stream from the frusto-conical portion which is about 11 mils (0.28 mm.) long and has a diameter of about 15 mils (0.38 mm.) at the exit edge of the cone.

Items *a* to *f* are made using 1 pass each at 400 and 500 p.s.i.g. (28 and 35 kg./cm.^{2}) at the speed given below. Items *e* and *f* have minor differences in the fiber denier as noted.

Sample *a* is prepared with the orifices 0.75 inch (1.9 cm.) above the fiber layer, Samples *b–f* are made in the same manner as Sample *a*, but with the orifices located 3 inches (7.6 cm.) above the web. It is observed that the jets are much more efficient at this greater distance and it is reasoned that the chance relation between streams and wires is emphasized at the closer orifice-web distances where the streams are more columnar. Properties of the resulting patterned nonwoven fabrics are given below:

Item	a	b	c	d	e	f
Fiber (d.p.f.)	1.5	1.5	1.5	1.5	0.75	3.0
Web speed (y.p.m.)	1.5	7.4	3.0	1.5	1.5	1.5
Treatment Energy (HP-hrs./lb.)	1.0	0.2	0.5	1.0	1.0	1.0
Entanglement completeness	0.21	0.21	0.40	0.54	0.82	0.41
Entanglement frequency	12	14	18	15	26	24
Strip tensile strength	1.3	1.1	1.9	2.3	3	1.3
Fiber interlock value	7.0	7.9	11	12	13	8.5

Washing tests are carried out on samples measuring approximately 8 inches x 10 inches (20 x 25 cm.) by immersing them in water, removing the excess water by wringing by hand and then vigorously wiping a smooth surface approximately a yard square, such as a blackboard or mirror. The samples are then rinsed in water, wrung out by hand and hung up to air dry. Samples are judged not to be useful if they leave clumps of fibers on the wiped surface, or if large masses of loose fibers are apparent on the surface of the fabric after drying. If the latter occurs, it is also noted that the pattern has almost completely disintegrated.

All of the above products are judged to be useful when evaluated in this manner. Other fabrics made in a similar manner but under milder conditions so that they have fiber interlock values of less than 6.5 have been found unsatisfactory in this washing test.

Example 28

This example shows a modification of the process wherein a fiber web is passed on a drum covered with the wire screen of Example 27 under 2 to 4 banks of orifices. The orifices in rows 1 and 2 are identical to those of Example 27 and at the same spacing. Rows 3 and 4 contain funnel-shaped orifices with a 7 mil (0.18 mm.) diameter cylindrical portion and are spaced 40/inch also.

Each sample is made by forwarding the web on the drum beneath orifices [spaced 0.25 inch (6.3 mm.) above the web] at the speed given in Table 8. All webs have the same weight and use the 1.5 d.p.f. rayon of Example 27. Different fiber lengths are used. Results are given in Table 8.

All items (*a–e*) are well patterned, aperture products which pass the washing test of Example 27.

TABLE 8

Item	Fiber Length, inches	Web Speed, y.p.m.	Pressure (p.s.i.) in rows— 1	2	3	4	Treatment Energy, HP-hrs./lb.	(c)	(f)	Tensile	Fiber Interlock Value
a	1.56	3	200	300	400	400	1.04	0.66	22	3.0	15
b	1.56	3	400	500	0	0	0.50	0.62	19	2.5	12
c	0.75	3	400	500	0	0	0.50	0.47	19	1.5	11
d	0.75/0.25	4	500	600	0	0	0.50	0.33	25	1.15	8.8
e	1.56/0.25	4	300	400	500	0	0.47	0.41	21	1.38	8.0

Example 29

This example illustrates the continuous production of a triangular-mesh-pattern, nonwoven fabric involving unidirectional treatment.

A web of randomly-disposed, continuous filaments of polyethylene terephthalate is used as the initial web. The web is wrapped around a hollow drum having a diameter of 12 inches and an apertured face which is 6 inches wide and contains 0.063-inch diameter holes arranged on 0.094-inch staggered centers (132 holes per sq. in., and 41% open area). Using the apparatus of FIGURE 1, the drum is axially aligned with the manifold and is positioned for rotation beneath the manifold orifices with the drum face spaced about 2 inches from the orifices. The manifold is 2 inches long and contains 0.005-inch orifices spaced on 0.025-inch centers along its length. The drum is rotated while essentially columnar streams issuing from the orifices impinge on a 2-inch section of web at one end of the drum, the water pressure being incrementally increased to a maximum of 1000 p.s.i. as the drum is rotated. After each successive rotation, the drum is moved horizontally approximately 2 inches and the treatment is continued until the entire web is processed under the streams. A nonwoven fabric is obtained which has a triangular-mesh pattern and is strong, stable and coherent. The fiber interlock value is 21.

Example 30

This example illustrates the production of an acrylic fiber, triangular-mesh-pattern, nonwoven fabric having a very high degree of surface stability.

A carded batt (2 oz./yd.^{2}) of commercially available acrylic fiber staple (1.5 inch) having a denier per filament of 1.5 (0.17 tex), as the initial fibrous layer, is converted to a triangular-mesh-pattern fabric using the apparatus of FIGURE 1 and the following processing conditions:

Orifice diameter—0.005 inch (0.025-inch centers)
Water pressure—0 to 1200 p.s.i., increased incrementally
Passes—5 in one direction and 5 perpendicular thereto for a total of 10
Patterning plate—0.075-inch diameter holes, 0.1-inch staggered centers, 112 holes per sq. in., and 50% open area.

During the treatment the layer of fibers on the patterning plate is gradually moved closer to the orifices, the spacing of the fiber batt from the orifices being about 3 inches at the beginning of the process and the surface of the layer being substantially in contact with the orifices at the final pass.

The resulting triangular-mesh-pattern, nonwoven fabric is removed from the patterning plate, turned over, replaced on the plate, and subjected to 8 passes under the above described streams at 1200 p.s.i. on the reverse side. The final product is a strong coherent fabric, the appearance being as illustrated in FIGURE 8 on both sides. The fabric has a fiber interlock value of 21. The fabric is subjected to a 20-minute cycle wash in a commercially available, household washing machine of the agitator type, using hot water (about 50° C.) and laundry detergent. Eight conventional-woven hand towels (total weight of 1 lb.) are added to the wash to more nearly simulate normal washing conditions and to provide a source of lint. After washing, the fabric is dried in a hot-air tumble drier for 15 minutes. This procedure is repeated for a total of 15 washings and 15 dryings. There is no evidence of surface pilling or pattern destruction, demonstrating the excellent surface stability of the fabric.

Nonwoven fabrics having a high resistance to pilling and fuzzing can also be obtained by incorporating brittle fibers (staple or continuous filament) at the surface(s) of the fabric prior to treatment with the liquid jets. By "brittle" is meant low molecular weight synthetic fibers such as polyethylene terephthalate or other fibers such as cotton which fibrillate under the high velocity liquid entangling conditions. Suitable are the fibers of polyethylene terephthalate of relative viscosity ranging from 13.5 to 16.5 described in Christens et al., U.S. Patent No. 3,104,450. Fibers of polymers of relative viscosity below that range, e.g., about 11, or above it can also be used. Surfacing with cellulosic fibers (rayon, cotton or acetate), and their blends with low relative viscosity polyethylene terephthalate staple, also improves the surface stability of base webs, for example, of continuous polypropylene or polyethylene terephthalate filaments. Particularly attractive fabrics are obtained by placing a 0.3 oz./yd.^{2} overlay of randomly disposed, 1.5 d.p.f., low relative viscosity (12.5) polyethylene terephthalate staple on each side of a web of randomly disposed, spontaneously elongatable, continuous filaments of polyethylene terephthalate, then hydraulically patterning and entangling the composite, and finally heat setting at 200° C. between screens to elongate the filaments about 10%.

Triangular-mesh-pattern, nonwoven fabrics having exceptional surface stability are also prepared by the above procedure, but without treating the reverse side of the fabric when the initial fibrous layer includes very short fibers which are interentangled with the longer fibers. Thus, fabrics prepared from composites obtained by overlaying ordinary commercial facial tissue on the initial staple fiber batt show no evidence of pilling after 15 washings and 15 dryings as described above.

Example 31

This example illustrates the preparation of a nonwoven fabric having annular masses of entangled fibers arranged in a regular pattern and interconnected by linking bundles spaced 60° apart around the annular fiber masses.

A web of randomly-disposed, two-component, continuous filaments is used as the initial fibrous layer. The filaments have polyhexamethylene adipamide as one component and a copolyamide of hexamethylene adipamide and hexamethylene sebacamide units as the other component. The filaments have a denier per filament of 3 (0.33 tex).

The patterning plate has 0.172-inch diameter holes arranged on 0.188-inch staggered centers. A second plate, having 0.125-inch diameter cylindrical projecting members arranged on staggered centers such that they register with the holes of the patterning plate, is placed under the patterning plate such that the projections are centered within the holes of the patterning plate and protrude 0.125 inch above the top surface of the patterning plate. The resulting patterning-plate assembly is thus provided with annular openings (0.125-inch inside diameter and 0.172-inch outside diameter).

The web is placed on this assembly and, using the apparatus of FIGURE 1, is exposed to high-energy-flux water streams issuing from 0.005-inch orifices on 0.025-inch centers. During the treatment, water pressure is increased from 0 to 1000 p.s.i.g. and the web and plate assembly is passed under the streams at distances ranging from 4 inches to 0.5 inch from the orifices. Treatment is continued until a distinct pattern is obtained. The resulting fabric is removed from the plate, dried and tested. It is observed that the fabric has annular masses interconnected with one another by linking bundles of fibers, the masses corresponding to the annular openings in the patterning-plate assembly. Properties are as follows:

Weight (oz.yd.^{2})	1.3
Strip tensile strength (lbs./in.//oz./yd.^{2})	5.7
Tongue tear strength (lbs./oz./yd.^{2})	2.7
Bending length (cm.)	1.7
Fiber interlock value	28

Example 32

This example illustrates the use of vacuum to assist in removal of water and to facilitate patterning.

The initial web is composed of two-component, 3 denier per filament (0.33 tex), randomly-disposed continuous filaments. The filaments are composed of polyhexamethylene adipamide as one component and a copolyamide of hexamethylene adipamide and hexamethylene sebacamide units as the other component.

A patterning plate, having 0.156-inch diameter holes on 0.188-inch staggered centers, is affixed to a vacuum box. The web is placed on the plate and wetted down with streams of water. Vacuum equivalent to 22 inches of water is applied on the underside of the plate.

The web and plate assembly is then exposed to 10 passes under high energy flux streams of water issuing from 0.005-inch orifices on 0.025-inch centers, using the apparatus of FIGURE 1. Water pressure is 1500 p.s.i. and the web is treated with the streams in only one direction while being spaced 0.25 inch from the orifices.

The resulting fabric has a weight of 2.7 oz./yd.^{2} and a strip tensile strength of 6.3 lbs./in.//oz./yd.^{2}. The web has a clear distinct, triangular-mesh pattern. The effect of the vacuum in assisting in the development of the pattern can be observed during processing.

In a similar experiment, two webs are converted to triangular-mesh-pattern, nonwoven fabrics under the same conditions except that web A is processed without the use of vacuum and web B is procesesd with the use of vacuum. Properties of both fabrics are given below.

	Fabric A	Fabric B
Weight (oz./yd.^{2})	1.26	1.8
Strip Tensile Strength (lbs./in.//oz./yd.^{2})	4.6	5.4
5% Secant Modulus (lbs./in.//oz./yd.^{2})	1.3	1.9
20% Secant Modulus (lbs./in.//oz./yd.^{2})	2.9	5.7
Tongue Tear Strength (lbs./oz./yd.^{2})	2.0	2.3

Example 33

This example illustrates the production of polyethylene terephthalate fiber, triangular-mesh-pattern, nonwoven fabrics having particularly high surface stability.

A random web of polyethylene terephthalate continuous filaments, which are capable of shrinking 30% in length upon exposure to hot water at 85° C., is used as the initial web. The web has a weight of 1.25 oz./yd.^{2} and is placed between two batts (0.5 oz./yd.^{2} each) of carded staple fibers of polyethylene terephthalate. The assembly is then placed on a paterning plate having 0.077-inch diameter holes on 0.109-inch staggered centers (96 holes per sq. in., and 45% open area).

Using the apparatus of FIGURE 1, the web assembly is then treated with the high-energy-flux streams of water (50° C.) issuing from eighty 0.005-inch orifices on 0.025-inch centers. A water pressure of 1200 p.s.i. is used and processing is continued until a clear, distinct pattern is observed. The patterned, nonwoven fabric thus obtained is removed from the screen, dried, and then immersed in water at 85° C. for a few minutes to cause the continuous filaments to shrink. After removal from the water and air-drying, the resulting fabric is heat-set at 200° C., while held between 200-mesh screens. The final fabric has the following properties:

Weight (oz./yd.^{2})	3.65
Strip tensile strength (lbs./in.//oz./yd.^{2})	5.7
Elongation (percent)	162
5% secand modulus (lbs./in.//oz./yd.^{2})	0.97
Bending length (cm.)	1.3
Thickness (inches)	0.015
Fiber interlock value	29

The fabric is then washed in a commercially available, household washing machine of the agitator type, together with eight woven, cotton hand towels (total weight of 1 lb.) to more nearly simulate normal washing conditions and to provide a source of lint. Hot water (about 50° C.) and a laundry detergent are used and washing is continued for 15 minutes. The fabric is then removed and dried in a hot-air tumble drier (about 15 minutes). After 9 cycles of washing and drying, the nonwoven fabric is removed and examined. It is still a strong, coherent fabric and its surface shows no fuzzing, pilling or other signs of deterioration. The fabric has better resistance to surface fuzzing than similar fabrics prepared without the overlays of staple fibers.

Example 34

This example illustrates the production of a nonwoven fabric having a high nub-frequency and high cover.

Two carded webs of post-shrinkable, polyethylene terephthalate staple fibers, each having a weight of 1.25 oz./yd.^{2}, are cross-lapped and then placed on a patterning plate containing 1045 holes/sq. in. arranged in a staggered pattern so that the plate has an open area of 50%. Each hole has a diameter of 0.024 inch.

Using the apparatus of FIGURE 1, the web assembly is subjected to the high-energy-flux streams of water issuing from eighty 0.005-inch diameter orifices on 0.025-inch centers. Water pressure is 1200 p.s.i. and water temperature is 50° C. After the pattern is observed to be partially developed, the web folded over on itself and the treatment is continued until a nonwoven fabric having a clear, distinct pattern is obtained. The fabric has 1045 nubs per sq. in., the nubs being interconnected in a triangular-mesh pattern. The wet web is then placed in a hot-water bath (85° C.) for a few minutes to cause the fibers to shrink. After removal from the bath and air-drying, the fabric is observed to have undergone an area shrinkage of approximately 50%. Nub frequency is now about 2090 nubs per sq. in. The fabric is then heat-set at 200° C., while held between 200-mesh screens. The resulting fabric has a triangular-mesh pattern which is visible upon close examination. Because of the fineness of the pattern, the fabric has high covering power and a surface which appears uniform and smooth. The fabric has the general appearance texture and hand of cotton broadcloth.

Example 35

This example illustrates the production of a highly-drapable triangular-mesh pattern, nonwoven fabric having high covering power and resembling a knitted fabric.

Filaments having a ribbon-shaped cross-section are prepared by spinning polyethylene terephthalate and polyhexamethylene adipamide (50/50 weight ratio) in side-by-side relationship through a spinning slot (0.003 inch by 0.060 inch), the components being spun at opposite ends of the slot. The filaments are then subjected to a high-temperature treatment which shrinks the polyethylene terephthalate component of the threadline to produce filaments having about 64 crimps/inch. The filaments are then collected in the form of a web of randomly-disposed, crimped, continuous filaments, the web having a weight of approximately 2.6 oz./yd.^{2}.

The web is placed on a patterning plate having 462 conical holes per sq. in. arranged on staggered centers, the holes tapering to a minimum diameter of 0.037 inch in the direction away from the web. Plate thickness is 0.003 inch and percent open area of the plate is 50.

The web, while supported by the plate, is treated with essentially columnar streams of water issuing from 0.005-inch diameter orifices arranged in line at a density of 40 orifices per inch. The web is treated while spaced about 1 inch from the orifices, using 60° C. water and the following conditions: The web is subjected to one pass at a water pressure of 20 p.s.i., then to 3 passes in the same direction at 200 p.s.i. and then to 3 passes at 500 p.s.i. in a direction perpendicular to that used at 200 p.s.i. The web is then removed from the patterning plate, turned over, rotated 90° with respect to the pattern of the plate, replaced on the patterning plate, and then treated as follows: The web is first subjected to 3 passes p.s.i., then to 3 passes at 1000 p.s.i., and finally to 3 passes at 1500 p.s.i. At each pressure, the web is treated in a direction perpendicular to the direction used at the previous pressure.

The resulting fabric is then removed from the plate, dried and heat-set by placing it between two 60-mesh screens and heating at 200° C. for 30 seconds at 10 p.s.i. pressure. After heat-setting, the fabric is washed three times (about 15 minutes each) in a commercially available, household washing machine of the agitator type using hot water (about 50° C.) and a laundry detergent. Additional fabrics are added to more nearly simulate normal washing conditions. The nonwoven fabric is then removed and dried in a hot-air tumble drier. The fabric remains stable and coherent and there is no evidence of surface-fuzzing or pilling. Properties of the washed fabric are as follows:

Weight (oz./yd.^{2})	2.5
Strip tensile strength (lbs./in.//oz./yd.^{2})	3.36
Elongation (percent)	147
5% secant modulus (lbs./in.//oz./yd.^{2})	0.164
Bending length (cm.)	0.84
Fiber interlock value	13

The fabric is soft, drapable, and has the general appearance of a cotton knit fabric. Fabrics prepared in the above manner are then converted into T-shirts and tested for launderability. They are found to be satisfactory even after 25 consecutive launderings in the washing machine as previously described.

Example 36

This example illustrates the preparation of a nonwoven fabric resembling a knitted fabric and having a very high nub density.

A web of randomly-disposed, trilobal cross-section, two-component, highly crimped filaments prepared from polyethylene terephthalate and polyhexamethylene adipamide (50/50 weight ration) is used as the initial web. The filaments in the web have about 212 crimps/inch. The web has a weight of 2.5 oz./yd.^{2}.

The web is placed on a patterning plate having 1045 conical holes per sq. in., arranged on staggered centers, and 50% open area. The plate is about 0.002-inch thick and the holes taper to a minimum diameter of 0.024 inch on the side of the plate away from the web.

The web, while on the plate, is subjected to the action of the high-energy-flux streams of water (50° C.) issuing from 0.005-inch diameter orifices arranged in line at a density of 40 orifices per inch. The web is subjected to a number of passes at pressures up to and including 1200 p.s.i. until a clear, distinct pattern is observed.

The resulting fabric is removed from the plate, dried and then heat-set by placing it between 60-mesh screens and heating at 200° C. and 15 p.s.i. for 30 seconds. The fabric is then washed (along with other fabrics to simulate a normal load) for about 15 minutes in a commercially available, agitator-type, household washing machine, using hot water (about 50° C.) and a laundry detergent. The fabric is removed and dried in a hot-air tumble drier. Properties of the laundered fabric are as follows:

	Machine Direction	Transverse Direction
Weight (oz./yd.^{2})	2.74	2.56
Strip Tensile Strength (lbs./in.//oz./yd.^{2})	1.93	1.66
Elongation (Percent)	151	203
5% Secant Modulus (lbs./in.//oz./yd.^{2})	1.0	0.62
Bending Length (cm.)	1.25	1.06
Fiber Interlock Value	9.6	

The fabric is soft, drapable and, in general, resembles a cotton knit fabric in hand and appearance. Because of the fineness of the pattern, the fabric has a high degree of covering power.

Example 37

This example illustrates the production of nonwoven fabrics on patterning supporting members having very small holes, for both low and high percent open area. It further illustrates the preparation of a nonwoven fabric having an exceptionally high nub frequency.

A web of randomly-disposed, two component, trilobal, continuous filaments is used as the initial fibrous layer. The filaments have polyhexamethylene adipamide as one component and polyethylene terephthalate as the other component. Filament denier is 3 (0.33 tex) and the filaments in the initial layer are highly crimped (about 120 crimps/inch).

Three such webs (designated A, B, and C) are converted into nonwoven fabrics as follows: Each web is supported on an apertured patterning support and is subjected to the action of high-energy-flux streams of water issuing from 0.005-inch orifices on 0.025-inch centers. During treatment the web is spaced 3 to 4 inches from the orifices and the water pressure is increased incrementally from 100 to 1500 p.s.i. For webs B and C a single layer of facial tissue is placed over the web during treatment. This facilitates production of the nonwoven fabric. The patterning support used for each web is as follows:

	A	B	C
Hole Shape	Square	Square	Round
Hole Width (inch)	0.030	0.0122	0.0145
Arrangement of Holes	Square	Square	Staggered
Distance between Centers (inch)	0.050	0.025	0.0167
Holes per Square Inch	400	1,600	4,150
Percent Open Area	32.5	22.5	69

Each web is converted to a nonwoven fabric having a clear distinct pattern. Properties of the three fabrics are as follows:

	A	B	C
Weight (oz./yd.^{2})	2.00	2.84	2.42
Strip Tensile Strength (lbs./in.//oz./yd.^{2})	3.83	3.23	2.89
Elongation (percent)	130	177	104
Initial Modulus (lbs./in.//oz./yd.^{2})	2.9	2.7	4.9

In another instance, a 2.5 oz./yd.^{2} web of 1.8 to 2 d.p.f. randomly-disposed, highly drawn, two component, continuous filaments of round cross-section, made from polyhexamethylene adipamide and polyethylene terephthalate (50/50 wt. ratio), is used as the initial material. The web is placed on a patterning plate of the type described as patterning support B above.

The web is passed under a row of 0.005-inch holes, in a manifold 1.75 inches above the web, under the following conditions:

	Speed	Pressure	Top Screen
Passes:			
3	About 6 y.p.m.	1,250	Yes.
1	do	1,500	No.
(Web reversed.)			
1	do	1,000	Yes.
3	do	1,250	Yes.
1	do	1,500	No.
3	do	1,700	No.
24	About 18 y.p.m.	1,700	No.

The web is then removed, blotted to remove excess water, oven dried at 140° C. for five minutes, and heat-set at 200° C. and 10,000 p.s.i. pressure. The product has the appearance of a tightly woven fabric. When it is viewed at 30× magnification, the face adjacent the patterning plate is observed to have a network of squares, the sides of the squares being formed by aligned bundles of fibers and the corners of the squares being entangled masses. Within and throughout each square is a region of randomly arranged fibers which extends through the length and width of the fabric. The random fibers may pass from one square to another without necessarily becoming part of a nub or bundle. The reverse face of the fabric, at 30×, has fibers randomly arranged over the entire surface. The fabric is softened by washing with hot water in a conventional laundry machine and dried in a tumble drier. The fabric obtained has a weight of 2.4 oz./yd.^{2}, a tensile strength of 9.3 lbs./in.//oz./yd.^{2}, an elongation of 70%, a tear strength of 2.8 lbs./oz./yd.^{2}, and a bending length of 1.5 cm.

Example 38

This example illustrates the preparation of a triangular-mesh-pattern, nonwoven fabric wherein nubs protrude from both faces of the fabric.

A nonwoven fabric is prepared as in Example 17 by treatment with streams from 0.005-inch diameter orifices (40/inch) in a manifold spaced 1.5 inches from the web, using 2000 p.s.i. water pressure (4 passes). While the fabric is still in place on the patterning support described in Example 17, the assembly is sandwiched between plates having the same hole-size but half the number of holes. The two outside plates are arranged with the holes in register with each other and in register with half the holes of the patterning support. The ensemble is flipped over and passed 8 times under the essentially columnar streams, using a water pressure of 2000 p.s.i. Nubs protruding through the holes in register are inverted downward by the treatment, whereas the other nubs which are shielded by the plates protrude upward as before.

A product similar to that of Example 17 is obtained. It differs in having protuberant nubs on both faces and in having improved surface stability. The fiber interlock value is 18.

Example 39

This example illustrates the preparation of a nonwoven fabric, using high-energy-flux streams of water issuing from 0.030-inch orifices.

A web of randomly-disposed, two component, highly crimped, continuous filaments is used as the initial fibrous layer. The filaments have polyhexamethylene adipamide as one component and polyethylene terephthalate as the other component. The web is placed on a patterning plate having 0.063-inch diameter holes arranged on 0.094-inch staggered centers. The web is treated with the high-energy-flux streams of water issuing from 0.030-inch orifices arranged in line along a drilled tube at a density of 20 orifices per inch. The web, while supported by the plate, is subjected to one pass under the streams at 100 p.s.i., 2 passes at 500 p.s.i., and 4 passes at 1000 p.s.i., each pass being at about 3 inches from the orifices. The web is then subjected to four passes under the streams at 1000 p.s.i. with about 1.5 inches separation from the orifices.

A triangular-mesh-patterned, nonwoven fabric having the following properties is obtained:

Weight (oz./yd.^{2})	2.35
Strip tensile strength (lbs./in.//oz./yd.^{2})	3.62
Fiber interlock value	17

Example 40

This example illustrates the preparation, from polyester staple fibers, of patterned structures having sinusoidal ridges on their surfaces. Effects of varying the web area weight and the percent open area of the screen are shown.

The initial material is a batt of randomly disposed staple fibers prepared by an air-laying technique. Several such batts having area weights of approximately 2.3 and 4 oz./yd.^{2} are prepared from polyethylene terephthalate staple having a denier per filament of 1.5 (0.17 tex) and a length of 1.5 inches. The fibers have a linear shrinkage capability, when immersed in boiling water, of approximately 40%.

Using apparatus of the type shown in FIGURE 1, patterned structures are prepared as follows. An initial batt is placed on a plain weave, 20 mesh wire screen of the type shown in FIGURE 14, selected from the following:

	Mesh (wires/in.)	Wire diameter (in.)	Open area (percent)
Screen used for product:			
A, E, I	20	.015	49
B, F, J	20	.020	36
C, G, K	20	.025	25
D, H, L	20	.028	19

A 0.002-inch thick, perforated plate having 50% open area, 726 holes/in.^{2}, and 0.029-inch diameter holes is laid on top of the batt. The top plate is merely used to help hold the batt in place during initial processing; it does not influence the patterning of the batt. The assembly is passed under the high-energy-flux streams of water (about 50° C.) issuing from 0.005-inch orifices arranged in line along an 8-inch length of pipe having an outside diameter of 0.25 inch at a density of 40 orifices/inch. Using a water pressure of 1700 p.s.i., the assembly is passed under the streams 20 times. The top plate is then removed and the web is subjected to 80 passes under the streams. During the treatment, the passes are made along each screen axis and the batt is held at approximately one inch from the orifices. The patterned structure thus produced is dried in an air oven at approximately room temperature, while still on the patterning screen. Properties of the structures, before and after development of the latent shrinkage properties of the fiber, are presented in Table 9 below. Shrinkage is accomplished by immersing the structure in boiling water for 15 to 60 seconds, drying, smoothing (low temperature ironing) and heat-setting at 185 to 190° C. for 1 to 5 minutes in a standard sheet drier, in the absence of pressure. This treatment results in an area shrinkage of about 32 to 40%.

The fiber interlock value, measured after the shrinkage treatment, is 22 for Product B and 9.2 for Product C, the latter being an average value for two fabric directions.

TABLE 9

Product Code	Shown in FIGURE No.	Open Area (percent)	Area Weight (oz./yd.^{2})		Tensile Strength (lb./in.//oz./yd.^{2})		Elongation (percent)		5% Secant Modulus (lbs./in.//oz./yd.^{2})		Opacity (percent)	
			Before	After	Before	After	Before	After	Before	After	Before	After
A		49	2.1	2.9	5.5	5.0	94	99	1.5	1.5	47	59
B		36	2.3	3.2	6.2	5.8	85	92	3.3	2.0	47	59
C	15	25	2.2	3.2	5.9	5.9	80	89	2.8	1.9	42	57
D		19	2.1	3.3	6.2	5.9	89	94	1.6	1.2	40	62
E	16	49	3.0	4.6	4.4	3.9	91	125	2.0	0.6	60	72
F		36	3.1	4.4	3.7	3.7	85	118	2.2	0.7	61	73
G		25	3.2	4.7	4.7	4.0	86	96	2.3	0.9	57	70
H		19	2.9	4.5	4.0	3.7	81	99	2.2	1.1	54	68
I		49	3.9	6.1	4.4	3.7	95	112	1.5	0.6	69	81
J		36	3.4	5.1	5.1	4.6	85	102	2.6	1.2	62	76
K		25	3.6	5.2	3.3	2.5	87	88	1.7	0.8	62	75
L	17	19	3.8	6.2	4.0	3.4	85	118	1.8	0.8	61	88

NOTE.—All values are averages of MD and XD values.

The above table illustrates the desirable properties of the structures. In general, they are soft, strong, drapable and fabric-like. Products which have been treated to develop shrinkage are generally characterized by a greater covering power, as illustrated by the opacity measurements, and are more drapable, as illustrated by the secant modulus measurements, than the untreated products.

The appearance and arrangement of the fibers in these structures is shown at moderate magnification in FIGURES 15 through 17 and 15*a* through 17*a*. FIGURES 15 through 17 show the upstream and FIGURES 15*a* through 17*a* the downstream (adjacent the screen) faces of the 2 oz. /yd.^{2} structures prepared on screens of 25, 49 and 19% open area, respectively, prior to any shrinkage treatment. Referring to FIGURES 15*a* through 17*a*, it can be seen that sinusodial ridge-like elements are present on the downstream face of each structure. These sinusodial ridges comprise areas of parallelized fibers alternating with areas of highly entangled fibers. The entangled areas are more pronounced as the percent open area increases, such as at the 49% open-area of FIGURE 16*a*. When viewed from the upstream face, sinusoidal ridges are visible in the lower weight structures, as shown in FIGURE 15. As the weight increases, the upstream face becomes more random in general appearance as shown in FIGURE 17. The periphery of each aperture is characterized by localized areas of many fibers oriented perpendicularly with respect to the surface of the structure. This type of structure is more clearly shown in FIGURE 19 at high magnificaion. Apertures corresponding to the lower wire crimps are partially obscured in lower weight structures, such as shown in FIGURE 15, and eventually are completely lacking in the heavier weight structures, such as shown in FIGURE 17. As the percent open area of the patterning screens increases, such as at 36% and 49% open area, products with smaller apertures and having greater covering power are obtained. Structures with high covering power can also be obtained by using low-open-area (e.g., 16% to 27% open area) patterning screens of finer mesh (e.g., 24 to 40 mesh) and/or by developing latent properties, such as postshrinkability, of the fibers.

Example 41

This example illustrates the use of highly crimped, continuous filaments to prepare patterned structures having sinusoidal ridges on their surfaces. Screens of varying mesh size and the percent open area are used.

The initial material is a web of randomly-disposed continuous filaments, which have a ribbon-shaped cross-section and are prepared by spinning polyethylene terephthalate and polyhexamethylene adipamide (50/50 weight ratio) in side-by-side relationship through a spinning slot (0.003 inch by 0.060 inch), the components being spun at opposite ends of the slot. The filaments, prior to formation of the web, are subjected to a high temperature treatment which shrinks the polyethylene terephthalate component to produce filaments having approximately 120 crimps/inch.

Several of the above webs, having a weight of approximately 2.5 oz./yd.^{2} are prepared and are converted into patterned, multilevel structures using apparatus of the type shown in FIGURE 1. Each web is placed on a plain weave wire screen, of the type shown in FIGURE 14, selected from the following:

	Mesh (wires/in.)	Wire diameter (in.)	Open area (percent)
Screen used for product:			
A	20	.028	19
B	24	.025	16
C	30	.016	27
D	35	.014	26
E	40	.0135	21

A 0.002-inch thick, perforated plate having 50% open area, 726 holes/in.^{2}, and 0.029-inch diameter holes is laid on top of the web. The top plate merely helps to hold the web in place during initial processing; it does not influence the patterning of the web. The assembly is passed under high-energy-flux streams of water (about 50° C.) issuing from 0.005-inch orifices arranged in line along a 2-inch length of pipe having an outside diameter of 0.25 inch at a density of 40 holes per inch. Using a water pressure of 1700 p.s.i., the assembly is passed under the streams 20 times. The top plate is then removed and the web is subjected to 20 passes under the streams at about 1 inch from the orifices and to 10 passes while substantially in contact with the orifices. Half of the passes are made in the direction of one screen axis and half in the direction of the other screen axis. The patterned structure thus produced is dried on a standard sheet drier at about 100°. The products are all strong, nonwoven fabrics with patterns of apertures, having weights of from 2.4 to 2.7 oz./yd.^{2}, average tensile strengths of from 3.0 to 3.4 (lb./in.)/(oz./yd.^{2}), elongations of from 194 to 222% and fiber interlock values of from 14 to 17.

In general these products are soft, strong and very drapable. The products are similar in gross physical appearance to those of comparable weight described in Example 40. They are suitable for conventional fabric enduses.

Example 42

This example illustrates the conversion of polyester staple fiber batts into patterned structures having sinusoidal ridges on their surfaces. Preparation on patterning screens of varying mesh is shown.

The initial material used in each case is a random batt prepared by air deposition. Several such batts are prepared from polyethylene terephthalate staple having a denier per filament of 1.0 (0.17 tex) and a length of 1.5 inches.

Using apparatus of the type shown in FIGURE 1 and screens of the type shown in FIGURE 14, patterned structures are prepared on each of the plain weave, wire screens listed below.

	Mesh (wires/in.)	Wire diameter (in.)	Open area (percent)
Screen used for product:			
A	40	.0135	21
B	30	.016	27
C	20	.028	19
D	14	.041	18
E	9	.063	18
F	6	.080	27
G	3	.162	26

In each case, the initial batt is placed on the selected screen. A 0.002-inch thick, perforated plate having 50% open area, 726 holes/in.^{2}, and 0.029-inch diameter holes is then laid on the batt. The top plate merely helps to hold the batt in place during initial processing; it does not influence the patterning of the batt. The assembly is passed under the high-energy-flux streams of water (approximately 50 to 65° C.) issuing from 0.005-inch orifices arranged in line along a pipe at a density of 40 orifices/inch. After several passes under the streams, the top plate is removed and processing is continued with the batt held at about 1 inch from the orifices. Batts treated on screen B are subjected to 80 passes at 1400 p.s.i.; batts treated on the remaining screens receive 4 passes at 1900 p.s.i. The patterned structures thus produced are dried on a sheet drier at about 100° C. Properties are given in Table 10 below. All of the products are soft, strong, and drapable.

Another fabric is prepared which differs from Fabric D only in being of lighter weight, approximately 1 oz./yd.^{2}. This product is shown in FIGURE 13 at moderate magnification.

TABLE 10

Product Code	Weight (oz./yd.^{2})	Tensile Strength (lb./in.// oz./yd.^{2})	Elongation (percent)	Modulus (lb./in.// oz./yd.^{2})	Fiber Interlock Value
A	1.5	5.6	81	*1.4	24
B	1.7	5.3	93	*1.0	25
C	1.5	6.7	100	**2.3	27
D	1.5	7.0	93	**2.5	27
E	1.5	6.3	93	**2.3	28
F	1.2	4.7	82	**2.5	19
G	4.7	4.1	95	**1.6	----------

*5% Secant modulus.
**Initial modulus.

NOTE.—All properties are averages of MD and XD values.

Example 43

This example illustrates the preparation from acrylic fiber staple of patterned structures having sinusoidal ridges on their surfaces. Preparation on screens of different open area is shown.

The initial material is a batt of randomly-disposed staple fibers prepared by an air-laying technique. Several batts are prepared from acrylic fiber staple having a denier per filament of 1.5 (0.17 tex) and a length of 1.5 inches.

Using apparatus of the type shown in FIGURE 1, each batt is treated while placed on a screen selected from screens A through D previously identified in Example 40. Using a perforated top plate of the same type and for the same reason as described in Example 40, each batt is subjected to 20 passes under the high-energy-flux streams of water (about 50° C.) issuing from 0.005-inch orifices arranged in line in a pipe at a density of 40 orifices/inch at a water pressure of 1400 p.s.i. The top plate is then removed and the treatment is continued for another 80 passes. The passes are made in the directions of each screen axis and the batt is held about 1 inch from the orifices during treatment. The patterned, multilevel product thus produced is dried at about 100° C. in a sheet drier. The products have weights of from 2.1 to 2.4 oz./yd.^{2}, average tensile strengths of from 3.9 to 5.7 (lb./in.)/(oz./yd.^{2}), elongations of from 55 to 68%, capacities of from 53 to 63%, and fiber interlock values of about 17.

The structures thus obtained are similar in gross physical appearance to products of comparable weight described in Example 40 and shown in the figures designated therein. They are soft, strong and drapable and are particularly well suited for use where high absorbency is required, such as in diapers.

Similarly attractive products with greater surface durability and launderability can be prepared by blending in other fibers, such as rayon fibers. Particularly desirable products are obtained by using acrylic and rayon staple fibers of different lengths.

Example 44

This example illustrates the preparation, from high tenacity rayon staple, of patterned structures having sinusoidal ridges on their surfaces. Preparation on screens of different mesh sizes and different percents of open area is shown.

The initial material is a batt of randomly-disposed staple fibers prepared by an air-laying technique. Several such batts are prepared from rayon staple having a denier per filament of 1.5 (0.17 tex) and a length of approximately 1.6 inches.

Using apparatus of the type shown in FIGURE 1, patterned structures are prepared using the same processing conditions described in Example 43 and the following plain weave, wire patterning screens of the type shown in FIGURE 14.

	Mesh (wires/in.)	Wire Diameter (in.)	Open Area (percent)
Screen Used for Product:			
A	20	.015	49
B	20	.020	36
C	20	.025	25
D	20	.028	19
E	30	.012	41
F	30	.016	27
G	35	.014	26
H	40	.008	46
I	40	.0135	21

Soft, strong and drapable structures are obtained. They are similar in gross physical appearance to the structures of comparable weight described in Example 40 and shown in the figures designated therein. Properties of the structures are given in Table 11 below.

TABLE 11

Product Code	Weight (oz./yd.²)	Strip Tensile Strength (lb./in.// oz./yd.²)	Elongation (percent)	5% Secant Modulus (lb./in./ oz./yd.²)	Opacity (percent)	Fiber Interlock Value
A	2.2	5.5	32	12.4	48	
B	2.3	6.5	34	16.0	45	
C	2.0	7.1	36	6.8	42	15
D	2.1	6.8	37	5.1		
E	2.2	5.5	48	4.8	47	16
F	2.2	5.6	57	3.8	47	
G	2.2	5.4	56	2.6	48	
H	1.9	5.3	62	2.4	43	18
I	1.7	4.1	60	2.5	38	14

Example 45

This example illustrates the preparation from polyester staple fiber of patterned structures having short, ridge-like elements proceeding diagonally to impart a twill pattern to the surfaces of the structures. Preparation on several different screens is shown.

The initial material is a batt of randomly-disposed polyester staple fiber weighing about 2.5 oz./yd.² and prepared by an air-laying technique. The fibers have a denier per filament of 1.5 (0.17 tex) and a length of 1.5 inches.

Using apparatus of the type shown in FIGURE 1, patterned structures are prepared as follows. An initial batt is placed on a twill weave wire screen selected from the following:

	Shown in FIG. No.	Mesh Size (wires/inch)	Wire Diameter (inch)	Open Area (percent)
Screen Used for Product:				
A	20	20 x 30	0.018	31
B	21	24 x 24	0.023	20
C		30 x 30	0.017	23.9
D		40 x 40	0.0135	21

The surface of each screen is characterized by regularly spaced rectangular channels, staggered with respect to one another along a path running diagonally of the screen and separated from one another by intervening screen wires as shown in FIGURES 20 and 21.

A 0.003-inch thick, perforated plate having 50% open area, 462 holes/in.², and 0.037-inch diameter holes is laid on top of the batt. The top plate merely helps to hold the batt in place during initial processing; it does not influence the patterning of the batt. The assembly is passed under the high-energy-flux streams of water (about 50° C.) issuing from 0.005-inch orifices arranged in line along a 5-inch length of pipe at a density of 40 orifices/inch. Using a water pressure of 2000 p.s.i., the assembly is passed under the streams 20 times. The top plate is then removed and the web is subjected to 80 passes under the streams. Passes are made in the directions of the screen axes and the batt is held approximately 1 inch from the orifices. The patterned structures thus obtained are dried on the patterning screen at about 40° C. in an air oven. Properties of each structure are measured along the four major axes of the structure, including the twill line and the direction 90° thereto, and the average of the four values is reported in Table 12.

TABLE 12

Product Code	Product shown in FIGURES	Weight (oz./yd.²)	Strip Tensile Strength (lb./in.// oz./yd.²)	Elongation (percent)	5% Secant Modulus (lb./in.// oz./yd.²)	Bending Length (cm.)	Fiber Interlock Value
A	24–24a	2.5	6.1	76	1.1	1.8	
B	25–25a	2.6	5.6	78	.7	1.5	
C		2.6	5.6	92	.8	1.7	20
D		2.2	4.3	89	.7	1.6	19

(E) In a similar way, a 3 oz./yd.² nonwoven fabric is made by treating at up to 1000 p.s.i.g. an initial random web of acrylic staple fibers, using a 2 x 2 twill weave screen of 20 x 15 mesh (19% open area) of 0.032-inch diameter wires. FIGURES 28 and 28*a* show the two faces of the fabric. The basic twill structure is similar to that of items A to D of this example but both faces are almost identical in appearance. Tensile strengh is 3.5 (lb./in.)/(oz./yd.²).

The basic arrangement of fibers in these twill-patterned structures is shown in the schematic drawings of FIGURES 26 and 27. The structures are characterized by rectangular, ridge-like elements, staggered with respect to one another along a path running diagonally of the fabric. The ridges contain areas of high fiber parallelization adjacent areas of high fiber randomness and entanglement. These ridge-like elements correspond to rectangular channels of the patterning screen surface. The fibers in the ridges are continuous with fibers lying in a second level of the structure and predominantly visible from the upstream face of the structure. The fibers in the second level form interconnections between successive ridges of the first level. These interconnections may take the form of well-ordered, wide bands of parallelized fibers arching out of the surface as shown in FIGURES 24 and 25, or they may comprise bundles of randomly interentangled fibers as shown in FIGURE 28, or a combination of both. The interconnections and the ridges together define regularly spaced apertures which also proceed along diagonal lines and correspond to the protuberant wire crimps. The apertures corresponding to the wire crimps may at times be only partially formed as observed in FIGURE 25. In general, increasing the weight of the initial material and/or decreasing the height of the wire crimps will diminish the size and extent of apertures present in the final product, and will increase the extent and intensity of fiber-randomness and fiber-entanglement. When these fabrics are viewed from the upstream face, it will be observed that band-like groups of fibers proceed from one aperture to an adjacent one and are oriented perpendicularly to the surface of the structure at the periphery of the apertures.

Example 46

This example illustrates the preparation from polyester staple fibers of a herringbone-twill-patterned structure having characteristics of a stretch fabric.

The initial material is a web of randomly-disposed fibers prepared by an air-laying technique. The web weighs 2 oz./yd.² and is prepared from postshrinkable 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% lengthwise when immersed in boiling water.

Using apparatus of the type shown in FIGURE 1, the batt is patterned on a herringbone-twill-weave, 40 x 40 mesh screen, having about 25% open area and woven from 0.12-inch diameter wires. The twill line of the screen reverses itself at about every 20 wires.

The batt is subjected to the high-energy-flux streams of water (about 50° C.) issuing at 1300 p.s.i. from 0.005-inch orifices arranged in line along a pipe at a density of 40 orifices/inch. The batt is first subjected to 20 passes under the streams while covered with a top plate of the same type and for the same reason described in Example 40. The plate is then removed and the batt is subjected to 80 passes. All treatment is done with the batt spaced about 1 inch from the orifices and each pass is done at a right angle to the preceding pass. It is treated to develop the latent shrinkage properties of the fibers by immersing the structure in water at about 90° C. for about 1 minute, drying, smoothing (low temperature ironing), and heat-setting at 185–190° C. for about 2 minutes in a standard sheet drier under slight restraint. Area shrinkage is about 45%. The structure is a soft, strong and drapable material having good elastic recovery properties. It is suitable for use in apparel, upholstery and the like as a stretch-fabric. Properties of the fabric are as follows:

Weight (oz./yd.^{2})	3.7
Tensile strength (lb./in.//oz./yd.^{2})	4.1
Elongation, percent	126
Bending length (centimeters)	1.5
5% secant modulus (lb./in.//oz./yd.^{2})	0.5
Tensile recovery at 15% elongation (0.5 lb./in.//oz./yd.^{2} stress), percent	81
Fiber interlock value	17

Tensile recovery of the above 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). 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:

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

Example 47

This example illustrates the preparation from polyester staple fiber of patterned structures prepared on Dutch weave twill screens and on oblong screens.

The initial material is a web of randomly-disposed fibers prepared by an air-laying technique. The web weighs 2.5 oz./yd.^{2} and is prepared from postshrinkable 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% lengthwise when immersed in boiling water.

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

	Screen Type	Shown in FIG. No.	Mesh Size (wires/inch)	Wire Diameter (inch)
Screen Used for Product:				
A	Dutch Twill	22	14 x 40	0.023.
B	Oblong	23	30 x 8	.018 x .032.
C	do		24 x 5	.025 x .035.
D	do		12 x 5	0.032.

A top plate of the type described in Example 45 is laid on top of the web to help hold it in place during initial processing; it does not influence the patterning of the web. The assembly is passed under high-energy-flux water streams (about 50° C.) issuing from 0.005-inch orifices arranged in line along a 5-inch length of pipe at a density of 40 orifices per inch. Using a water pressure of 2000 p.s.i., the assembly is passed under the streams 20 times. The top plate is then removed and the web is subjected to 80 passes under the streams (only 40 passes for Sample D). Passes are made in the directions of the axes of the screen 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 each structure are measured along each major axis of the structure and in the 45° bias direction and are reported in Table 13 below. The patterned structures are shown with magnification in FIGURES 29 and 30 (upstream faces) and 29*a* and 30*a* (downstream faces) as identified in the table. 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.

Product (E) is prepared by treating a web of blended staple fibers consisting of 50% by weight of 1.5-inch, 1.5 d.p.f. acrylic fibers and 50% by weight of 0.25-inch, 1.5 d.p.f. rayon fibers. The fibers are randomly deposited in the web by an air-laying technique, and the web is patterned on a screen surface of the type used for Product (B) above. FIGURES 31 and 31*a* show the normal appearance of the upstream and downstream faces of the fabric, and FIGURES 32 to 34 show the patterned structure at moderate magnification. A zig-zag pattern of ridges is observed on both the upstream face (FIGURE 32) and downstream faces (FIGURE 34). FIGURE 33, a view by light transmitted through the fabric, shows a characteristic zig-zag pattern of dark entangled regions along fiber bands which are formed between the widely spaced screen wires. The zig-zag entangled regions lock the fibers in place in the fabric.

TABLE 13

Product	Product shown in FIGURES	Weight (oz./yd.^{2})	Tensile strength (lb./in.//oz./yd.^{2})			Elongation (percent)			5% Secant modulus (lbs./in.//oz./yd.^{2})			Bending Length cm.			Fiber Interlock value
			MD	XD	BIAS	MD	XD	BIAS	MD	XD	BIAS	MD	XD	BIAS	
A	29–29a	2.4	7.0	5.2	5.9	46	58	60	6.0	1.6	0.5		1.6	1.9	
B	30–30a	2.4	5.0	5.1	5.6	57	55	63	2.1	2.1	0.4	1.8	1.7	1.8	20
C		2.4	6.8	5.4	6.4	56	67	71	4.1	1.4	0.6	2.2	1.6	1.7	24
D		2.6	5.9	5.9	6.3	49	56	63	8.0	0.5	0.2	2.7	1.7	1.8	20
E	31–34	2.5	4.7	3.2		32	52		21.7	2.2		2.6	1.6		

MD: For Product A, MD is measured along ridges shown in FIGURE 39. For Products B, C, and D, MD is measured along ridges shown in FIGURES 40a, 41a and 42a, respectively.
XD: Measured 90° to MD.
BIAS: Measured 45° to MD.

Example 48

This example illustrates the preparation from a blend of acrylic fiber and rayon fiber of a patterned structure having sinusoidal ridges on one surface and randomly oriented fibers on the opposite surface.

The initial material is a batt of randomly-disposed staple fibers prepared by an air-laying technique from a 50/50 blend of acrylic staple and rayon staple. Both fibers have a denier per filament of 1.5 (0.17 tex). The acrylic fiber has a length of 1.5 inches. The rayon staple has a length of 1.56 inches. The batt weighs about 3 oz./yd.^{2}.

Using apparatus of the type described in FIGURE 1, the batt is treated on a 15-mesh, plain weave wire screen, of the type shown in FIGURE 14, having 15.2% open area and woven from wires of 0.041-inch diameter. Using a perforated top plate having 462 holes/inch and 50% open area for the same reason described in Example 40, the batt is subjected to 20 passes under the high-energy-flux streams of water (about 50° C.) issuing from 0.005-inch orifices arranged at a density of 40 orifices per inch along a 5-inch length of pipe, having a wall thickness of 0.015 inch. The top screen is then removed and treatment repeated for another 30 passes. The sample is then removed, turned over, and replaced on the screen, taking care to maintain the original registry with the screen pattern. The above described treatments, with and without top screen, are then repeated. Passes are made along each of the axes of the screen. Water pressure is maintained at 2000 p.s.i. and the batt is held about 1 inch from the orifices during treatment. The patterned fabric is dried on the screen at about 40° C. Properties are given in Table 14 below, both as-made and after washing in an agitator-type, commercially available, household washing-machine, using a "cotton" or high-heat setting, and a laundry detergent.

As may be seen from Table 14, the patterned structure is strong and fabric-like in properties, retaining these properties after laundering. The fabric is soft and particularly well suited for uses requiring high absorbency, such as diapers, bandages and the like. Washing, moreover, tends to incease its bulk and softness.

TABLE 14

Fabric	Weight (oz./yd.^{2})	Strip Tensile Strength (lb./in./oz./yd.^{2}) MD	Strip Tensile Strength (lb./in./oz./yd.^{2}) XD	Elongation (percent) MD	Elongation (percent) XD	Fiber Interlock Value	5% Secant Modulus (lb./in.//oz./yd.^{2}) MD	5% Secant Modulus (lb./in.//oz./yd.^{2}) XD	Bending Length (cm.)
As-Made	2.9	4.7	3.8	61	50	15	1.5	2.8	2.7
After washing	2.8	4.5	4.0	61	47	15	0.7	2.7	2.2

MD: Measured in direction of sinusoidal ridge.
XD: Measured 90° to MD.

The fabric is similar in appearance to the fabric shown in FIGURE 18. The sinusoidal ridges contain tightly packed regions of highly parallelized fibers alternating with regions of highly entangled fibers. These parallelized fiber groupings are contiguous with regions of random fiber arrangement situated on the upstream face and with intermediate ribbon-like ordered groups of parallelized fibers running beneath the sinusoidal ridges (inside the fabric) and generally transverse to the ridges, in an integral structure having a regular pattern of oval-shaped holes. Entangled regions of the fabric are clearly visible on the downstream face, extend through the thickness of the structure and provide its integrity and strength. On the upstream face are a plurality of fibers which loop-over the entangled fiber regions and proceed vertically toward the other face of the fabric around the edges of the holes to disappear into the entangled fibers on the other side of the fabric.

Example 49

This example illustrates the preparation of patterned structures similar to those of Example 48, under slightly modified process conditions.

The fabrics are made from two initial batts (A and B) of the type described in Example 48, the two batts differing slightly in weight. The batts are processed as described in Example 48 except that the water pressure and method of passing the webs under the streams are modified as follows:

Each batt is subjected to 20 passes at 250 p.s.i. 20 passes at 500 p.s.i., and 80 passes at 1800 p.s.i. No top screen is used throughout the treatment and the batt is not turned over on the screen at any stage of treatment. The patterned fabric is removed from the screen and dried on a sheet drier at about 100° C. in the absence of pressure. Properties of the fabrics are given in Table 15 below.

TABLE 15

Fabric	Weight (oz./yd.^{2})	Strip Tensile Strength (lb./in./oz./yd.^{2}) MD	Strip Tensile Strength (lb./in./oz./yd.^{2}) XD	Elongation (percent) MD	Elongation (percent) XD	5% Secant Modulus (lb./in./oz./yd.^{2}) MD	5% Secant Modulus (lb./in./oz./yd.^{2}) XD	Bending Length (cm.)	Fiber Interlock Value
A	3.9	4.2	3.3	50	57	1.3	2.3	2.4	12.0
B	2.5	4.2	3.4	38	45	1.6	4.6	1.9	12.4

MD: Measured in direction of sinusoidal ridge.
XD: Measured 90° to MD.

Example 50

This example illustrates the preparation of triangular mesh patterned fabrics directly from continuous filament yarns.

A 40 denier, 27 filament, zero twist, polyethylene terephthalate continuous-filament yarn is unwound from a yarn package, drawn through a water bath to wet it, and deposited by hand randomly on a patterning plate. The plate has 0.063-inch diameter holes arranged on 0.094-inch centers. The thus formed batt, while supported by the plate, is then treated with essentially columnar streams of water emerging from 0.005-inch orifices, using apparatus of the type shown in FIGURE 1. The batt is first wetted by placing a fine-mesh screen on top and then passing the assembly under the streams. The top screen is then removed and the batt is passed under the streams at water pressures up to 1200 p.s.i. Then, using the same type of apparatus, but with a manifold having 0.007-inch orifices, the batt is further treated at pressures up to 1200 p.s.i. Passes are made both along and across the batt.

Examination of the fabric thus obtained reveals that the yarns are arranged in a triangular-mesh pattern and are joined together at the apexes of the triangles by entanglement. Although there is a high degree of fiber interentanglement of those sections of the yarns passing through the apexes, the identity of individual yarns is still discernible within that region. The products has a fiber interlock values of 16.5.

Example 51

This example illustrates the preparation of a triangular mesh patterned fabric directly from continuous filament yarns using a mechanical yarn-deposition technique.

A 40 denier, 27 filament, zero twist, polyethylene terephthalate continuous-filament yarn is fed from a bobbin, over a yarn guide, down to a water bath, up and over a guide and then to a motor-driven pulley. From the pulley the yarn is permitted to fall randomly onto a patterning plate which is moved back and forth beneath the pulley. The patterning plate has 25 holes/sq. in. and 46% open area, the holes being 0.156-inch in diameter.

Using apparatus of the type shown in FIGURE 1, the batt is treated with streams issuing from 0.005-inch orifices. During inital treatment a top screen having 726 holes/sq. in. and 33% open area is placed on the batt and the assembly is passed under the streams eight times at each of the following pressures: 200, 400, 600, 1000 and 1500 p.s.i. The top screen is then removed and the web, while still on the patterning plate, is subjected to the following additional passes under the streams: one pass at 100 p.s.i., eight passes at 200 p.s.i., eight passes at 400 p.s.i., eight passes at 600 p.s.i. and two passes at 1000 p.s.i. The fabric is then removed from the patterning plate and dried.

Examination of the fabric thus obtained reveals that the yarns are arranged in a triangular-mesh pattern and are joined together at the apexes of the triangles by entanglement. Although there is a high degree of fiber interentanglement of those sections of the yarns passing through the apexes, identity of individual yarns is still discernible within such areas.

The fabric has the following properties:

	MD	BIAS
Strip Tensile Strength (lbs./in.//oz./yd.²)	14	12
Elongation (percent)	35	35
Modulus (5% secant) (lbs./in.//oz.yd.²)	22	3
Fiber Interlock Value		50

The high tensile strength and relatively low elongation of this fabric make it particularly desirable for industrial uses.

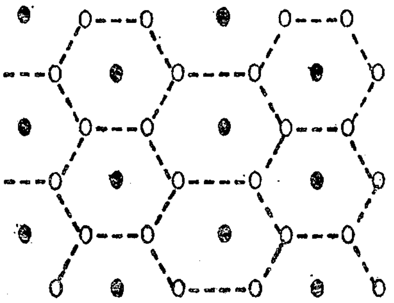
Instead of using the above described method for producing the initial batt, the yarn can be drawn from the bobbin, over a yarn guide and through an aspirating jet by which it is forwarded onto a moving conveyor belt, the jet being arranged to move in an arc so that the yarn traverses the belt as the belt passes under the jet. In this manner, uniformity of the initial batt and of the final product is improved.

Example 52

This example illustrates the preparation of a hexagonal-mesh-patterned, nonwoven fabric from a continuous filament web.

The initial material is a web of randomly-disposed, shrinkable, continuous filaments of polyethylene terephthalate. The filaments are capable of a linear shrinkage of about 30% when immersed in boiling water. Filament denier is about 1.5 (0.17 tex). The web has a weight of about 1.3 oz./yd.².

Using apparatus of the type shown in FIGURE 1, the web is treated with the high-energy-flux streams of water (about 50° C.) issuing from 0.005-inch orifices at 1500 p.s.i. while supported on a patterning plate. The web is spaced about 1 to 2 inches from the orifices during treatment and the web is passed under the streams a number of times until a clearly defined pattern is obtained. The patterning plate is obtained by modifying a perforated brass plate having 0.075-inch diameter holes arranged in staggered array, the plate having 50% open area and 112 holes/in.². One-third of the holes in the plate are filled by inserting rivets in them, the rivet head providing a hemispherical protuberance on the surface of the plate wherever a rivet is inserted, to provide a modified plate wherein the remaining holes define a pattern of hexagons. This is shown below wherein blackened circles indicate rivet heads, open circles indicate holes in the plate, and dotted lines show the hexagon pattern.



In general, a web can be patterned and entangled on the modified plate with greater ease than on the unmodified plate. The product obtained on the modified plate has entangled fiber areas corresponding to the apertures of the plate and which are linked with one another by bundles of parallelized fibers as indicated by the dotted lines, above, to define a hexagonal-mesh pattern. In this particular product, the entangled fiber areas lie substantially in the same plane as the fiber bundles, i.e., they do not protrude from the remainder of the fabric. This is believed to be due in part to the particular arrangement of fibers in the hexagonal pattern where 3 radial bundles only are entangled together at each Y-shaped intersection.

The web thus obtained is removed from the plate, immersed in boiling water for about 2 minutes to shrink the fibers, and then heat-set by pressing it at 200° C. while it is held under slight restraint between 100-mesh screens. Properties of the fabric are as follows:

Weight (oz./yd.²)	1.92
Strip tensile strength (lbs./in.//oz./yd.²)	6.6
Elongation (percent)	137
5% secant modulus (lbs./in.//oz./yd.²)	0.28

The product is a highly drapable, strong fabric suitable for apparel uses.

Example 53

This example illustrates the preparation of an anisotropic fabric having high tensile strength along one axis thereof by further treatment of a triangular-mesh-patterned, nonwoven fabric.

Two initial materials are prepared. Sample A is a web of randomly-disposed, polyethylene terephthalate, staple fibers having a denier per filament of 1.5 (0.168 tex). Sample B is a carded web of the same fiber.

Using apparatus of the type shown in FIGURE 1, each sample is treated, while supported on a patterning plate, with the high-energy-flux streams of water (about 50° C.) issuing from 0.005-inch orifices arranged along a 2 inch line in a tube having a diameter of 0.25 inch at a density of 40 orifices/inch. The patterning plate has 112 holes/in.² and 50% open area, the holes being 0.075 inch in diameter and being in staggered array. Using a water pressure of 1500 p.s.i., each sample is passed under the streams about 10 times.

The nonwoven, triangular-mesh-patterned fabric so obtained is dried and is then subjected to stretching along an axis defined by a line bisecting the triangles in the fabric, whereby the fabric pattern collapses somewhat like a pantograph. The fabric is stretched to a length about 20% greater than its original length. For the carded sample, the stretch direction also coincides with a line 30° from the original machine direction of the carded web.

While in the stretched state, the samples are heat-set for 2 minutes at 190° C. Properties of the original nonwoven, patterned fabric and the stretched and heat-set fabric are given below.

Sample	Direction	Strip Tensile Strength (lbs./in.//oz./yd.^{2})		Elongation (percent)	
		Original	Treated	Original	Treated
A	(MD)	8.0	12.0	58	23
A	(TD)	8.1	4.1	69	176
B	(MD)	14.8	20.6	60	29
B	(TD)	5.8	3.2	111	238

MD = Measured along axis of stretching.
TD = Measured normal to MD.

As may be seen from the above properties, the heat-set, stretched fabrics are characterized by a high, unidirectional tensile strength, resulting from the alignment of the linking bundles of fibers along a single direction. Such fabrics are particularly suitable for use as conveyor belting, tying ribbons, adhesive tape backing, pipe wrap, tire reinforcement, and the like.

Instead of nonwoven, triangular-mesh-patterned fabrics, those having square-mesh, hexagonal-mesh or other patterns may be used, the stretching being carried out so as to collapse the pattern pantograph-wise and thereby align the fiber bundles. The fibers may be stabilized in the new direction by other means than heat-setting, e.g., by impregnation with a binder such as rubber or the like.

Example 54

This example illustrates the effect of duration of treatment on the properties of several multilevel, patterned nonwoven structures.

As initial material there is used a web of randomly-disposed staple fibers, the web having a weight of about 2.3 oz./yd.^{2} and prepared from a 50/50 blend of acrylic fiber and rayon fiber. Both fibers have a denier per filament of 1.5 (0.17 tex). The acrylic fiber is 1.5-inches long; the rayon fiber is 1.56-inches long.

Apparatus of the type shown in FIGURE 1 is used with a manifold having 0.005-inch orifices spaced 40/inch, the manifold having a wall thickness of 0.015 inch. This provides a flow rate of 0.9 gal. per linear inch at a water pressure of 1800 p.s.i. At this pressure, and using orifices spaced along a one-yard length of the manifold, the orifices deliver to total of 32.4 gal./min. A sample passing thereunder at 1 yd./min.. uses about 32 gallons of water per square yard of sample.

Fabrics are prepared by treating the initial material as it is supported on the desired apertured patterning member, passing under the manifold in the manner of a conveyor belt at 1 to 10 yds./min. and spaced about 1 inch from the orifices, the manifold being arranged to oscillate so that the uniformity of the treatment is improved. Fabrics are made (1) on a plain weave, 15-mesh patterning screen having 0.041-inch diameter wires and 15.2% open area and (2) on a screen having oblong apertures, 21% open area, and 30 x 8 wires/in., the wire diameters, respectively, being 0.018 x 0.032 inch. A series of samples is prepared on each screen by subjecting the initial material to anywhere from 1 to 100 passes under the streams, the corresponding water consumption being from 3.2 to 3200 gal./yd.^{2} of fabric.

The fabrics thus obtained are subjected to 15 washings in a conventional, household washing-machine and are then subjectively rated for surface stability by two testers. A rating is assigned to each sample with 5 being excellent, 3—acceptable, and 1—poor. When acceptability ratings are plotted against gal./yd.^{2} of water used in making the fabric, it is observed that an acceptable rating of 3 can be reached at about 160 gal./yd.^{2} with the 15 mesh screen and at about 60 gal./yd.^{2} with the oblong screen for the processing conditions described in this example. It is to be noted that the above water consumption figures do not represent the absolute minimum amounts necessary to achieve nonwoven pattern products of high surface stability, since other processing conditions can be varied to achieve the same surface stability at different water consumptions.

Example 55

This example illustrates the preparation of a patterned nonwoven fabric wherein the entangled areas are adjacent one another, i.e., placed so close to one another that they are interconnected by individual very short fiber segments spaced fairly uniformly about the mass of entangled fibers, the segments being discernible only upon close examination.

(A) The initial material is prepared by crosslapping three carded batts, each having a weight of about 1 oz./yd.^{2}, the batts being prepared from postshrinkable acrylic staple fibers having a denier per filament of 6 (0.67 tex). The initial material is placed on a patterning plate having 57 holes/in.^{2}., 49% open area and a hole diameter of 0.1 inch, the holes being arranged in staggered array.

Using apparatus of the type shown in FIGURE 1, the initial material, while on the plate, is passed under streams issuing from 0.005-inch orifices arranged in line in a manifold and spaced 40 holes/inch. Water at about 50° C. is used and all passes are made at about 1 to 2 inches from the orifices. The assembly is subjected to 2 passes at each of 100, 300, 500 and 800 p.s.i. The sample is then removed from the plate, turned over, and replaced on the plate. Three additional batts, crosslapped with respect to one another, are then laid on the sample and the above treatment is repeated. The product thus obtained is then turned over on the plate and given 2 passes at 500 p.s.i., 2 at 1000 p.s.i., and 6 at 1200 p.s.i.

The patterned product has entangled fiber areas staggered with respect to one another and adjacent one another. Upon close examination it is observed that individual fibers extend in an almost continuous pattern around the periphery of the area and almost immediately disappear into a neighboring entangled fiber area.

The patterned nonwoven fabric thus obtained is given a 5 minute boil-off in water, whereupon it under goes an area shrinkage of about 24%. It is then subjected to five wash cycles in a conventional household washing-machine. Properties of the thus treated fabric are as follows.

Weight (oz./yd.^{2})	6.5
Strip tensile strength (lbs./in.//oz./yd.^{2})	1.3
Elongation (percent)	55
5% secant modulus (lb./in.//oz./yd.^{2})	0.6
Thickness (in.)	0.058
Bending length (cam.)	2.4
Fiber interlock value	12
Entanglement completeness	0.75

In general, staggered-hole patterning plates can be used to prepare patterned products having adjacent entangled areas (as opposed to entangled areas linked with one another via bundles of parallelized fibers) by using an initial material having a high area weight in relation to hole size. For the conditions used in this example, the appropriate relationship is reached at about 6 oz./yd.^{2} for the acrylic staple web. The fabrics of this type which are of primary interest have dense entangled fiber regions which occupy at least 40% of the total patterned area and are arranged in a regular pattern with the centers of entangled fiber regions at substantially uniform distances from the centers of adjacent entangled regions. Preferably the entangled regions have a compact shape, such as a circular, triangular, square, rectangular, or hexagonal shape, for which the diameter of the inscribed circle is at least 50% of the diameter of a circle circumscribed about the perimeter of the entangled region. Between the adjacent entangled regions are interconnecting fibers which are closely distributed along the peripheries of the entangled regions, lie in the plane of the fabric and project at abrupt angles from the perimeters of the entangled regions. Where these adjacent perimeters are substantially parallel, the interconnecting fibers are substantially parallel to each other and perpendicular to the perimeters. At other locations the interconnecting fibers are generally more or less parallel to lines projected between centers of the adjacent entangled fiber regions.

Further examples follow:

(B) The inital material consists of two webs, one laid on the other, each web having a weight of about 2.5 oz./yd.^{2}. The webs contain randomly-disposed continuous filaments of polyethylene terephthalate. The filaments of one web are capable of undergoing a linear shrinkage of about 29% upon treatment with hot water.

This initial material is placed on a patterning plate having 33 holes/sq. in. and 63% open area. Hole diameter is 0.156 inch and the holes are arranged in staggered array on 0.188-inch centers. The assembly is treated with water streams issuing from a line of 0.007-inch orifices at 1000 p.s.i.g. at a web-orifice distance of 2 inches until a well-defined pattern of entangled fiber regions is obtained.

The thus-obtained fabric is then removed from the plate and immersed in water at about 85° C. for about 5 minutes. This causes the fabric to undergo an area shrinkage of about 32%. Original thickness of the fabric is about 0.04 inch; final thickness is about 0.055 inch. The final fabric weighs approximately 7 oz./yd.^{2} and has a fiber interlock value of 31.

(C) The initial material is a carded batt (3 oz./yd.^{2}) of rayon staple fibers having a length of 1.5 inches and a denier per filament of 1.5.

This initial material is placed on the patterning plate for item (B) and the assembly is treated with water streams at 1000 p.s.i. issuing from a line of 0.005-inch orifices at a web-orifice distance of 2 inches until a well-defined pattern of entangled fiber regions is obtained.

The fabric so obtained is then removed from the plate, dried and tested. Properties of the fabric are given below. The fiber interlock value is greater than 7.

Tensile strength [(lb./in.)/(oz./yd.^{2})]	2.64
Elongation (percent)	40
Initial modulus (lb./in.//oz./yd.^{2})	7.3
Tongue tear strength (lb./oz./yd.^{2})	0.69

The fabric of item (C) is lighter in weight than the fabric of item (B). However, both fabrics have good bulk and high covering power. When viewed without magnification, both fabrics have entangled fiber regions which are so close to each other as to appear to be almost touching. Under magnification, the interconnecting radial arrays are discernible.

Other fibers and/or patterning plates can be used for such products; coarser or finer patterns are also possible. Products having adjacent entangled regions are particularly suitable for end uses requiring high covering power and/or bulk such as, for example, blankets or heavy apparel fabrics.

Example 56

This example illustrates the preparation of nonwoven, 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 .054 inch. The wires running in one direction have a low crip 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 as illustrated in FIGURE 14. 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.

Using apparatus of the type shown in FIGURE 1, the composite, while on the screen, is treated with the 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/inch^2 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 entanglement in the region of intersection with the ribbon-like bundles, certain fiber segments passing above and below the ribbon-like bundles at these intersections. The resulting fabric is dried and removed from the screen.

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.

Table 16 illustrates other types of reinforced products.

The multiple filament yarns of items *a* and *b* are commercially available yarns of 70 filaments and 1.3 to 2 d.p.f. The warp for item *c* is made by combing a tow of acrylic filaments having a potential shrinkage of about 25%. The random webs of items d_1 and d_2 are made using the method of British Patent No. 932,482. A zero-twist continuous filament yarn (34 filaments, 70 total 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 wide paper on a moving belt. The separate filaments of item *e* are 70 denier spandex yarn of coalesced multifilaments. The warp is stretched about 200% and held in that tension during the hydraulic treatment.

The reinforcing layers are combined with 1 or more layers of staple fiber webs, placed on a patterning member (typically a 10 to 30-mesh screen) and treated with essentially columnar streams of water at pressures of up to 1000 or 1500 p.s.i.g.

The column "product structure" shows the final sequence of staple fiber layers (S) and the reinforcing structures (R). The products may be made by entangling only two layers at a time and adding other layers with additional hydraulic treatment or by treating the entire composite as a whole.

The final products are strong, well-entangled products of this invention having weights of from 1.2 to 5.3 oz./yd.^{2}.

Upon steaming item *b* 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 warp directions and about 40% in the bias (diagonal) direction.

Heating item *c* to 120° C. affords 39% shrinkage in the warp direction and a 10% expansion in the opposite direction to give a strong, soft fabric with elongated apertures.

Items d_1 and d_2 have average tensile recoveries from 15% elongation of 70% and 98.5%, respectively.

The final product of item *e* is a bulky, puckered fabric with high elasticity in the warp direction. The pattern of apertures is readily apparent when the fabric is stretched flat.

Any elastic filaments and/or yarns may be used in the tensioned warp and any fibers may be used in the surface layer, including continuous filaments, staple or yarn. The surfacing fibers may be placed on one side only or on both sides of the tensioned elastic warp. A two-way-stretch, patterned nonwoven fabric is made by tensioning elastic filaments and/or yarns in a cross-warp arrangement, placing a layer of surfacing fibers on one or both sides of the cross-warp, placing the composite over a patterning member and treating with the high pressure columnar jets.

TABLE 16

Item	Reinforcing Layer			Staple Fiber		Product Structure	Fiber Interlock Value	Entanglement Completeness ($\bar{c}$)
	Fiber Form	Type	Structure	Type	Percent			
	Continuous Filaments							
a_1	Yarn	P	Warp	A	91	S/R/S	--------	*0.93
a_2					94		--------	
a_3					97		--------	
b	Yarn	B–P	Warp	A/R	82	S/R/S/R /S	14	*1.1
c	Separate	A	Warp	A/R	80	S/R/S	9.7	------------
d_1	Separate	N	Random web	A	83	S/R/S	15	0.85
d_2					88		13	**0.99
e	Separate	S	Tensioned warp	P	96	S/R/S		

*Measured at 45° to warp direction.

**One direction only.

Fiber type: A, acrylic; B bicomponent (crimpable); N, nylon; P, polyester; S, spandex; R, rayon.

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.

Other desirable products can be made by the above process using 3 cross-warps of highly crimped, textured yarns, with the top and bottom warps being transversely oriented to the intervening warp. The structures thus obtained have yarn-bundle intersections where the fibers pass straight through the intersection so that the fiber bundles in one axis of the fabric are completely mobile with respect to the fiber bundles in the other axis. These fabrics derive their strength and stability by entanglement of the fibers along the fiber bundles between the intersections rather than by entanglement at the intersection.

Continuous-fiber reinforced fabrics can be made in scrim-like light weights or in heavier weights. The scrim-like products are particularly suitable for use in medical applications such as gauzes and bandages and in industrial applications such as paper-reinforcement and bagging. Heavier structures are particularly suitable for reinforcement of rubber goods, such as tires, conveyor belts and the like or as replacement for woven fabrics such as crinolines, buckrams, marquisettes, voiles and other relatively open weave fabrics.

Example 57

This example illustrates the preparation of a triangular-mesh-patterned fabric of high drape and suede-like properties from a polyethylene nonwoven sheet.

The initial material is a film-fibril sheet of the type described in Belgian Patent No. 625,998 and made by the random overlapping deposition of continuous plexifilamentary strands. These strands, described in Blades et al. U.S. Patent No. 3,081,519, are each characterized as a three-dimensional network of film-fibrils which are interconnected at random intervals along and across the strand. The individual film-fibrils are composed of molecularly oriented crystalline organic polymer and have a thickness of less than four microns. In the present instance, the polymer is linear polyethylene and the strands are deposited in random overlapping relationship by electrostatic laydown on a moving belt. The initial product so obtained is then lightly compacted in a direction normal to the plane of the batt by means of pressure rolls to provide a product having a paper-like hand. The sheet has a weight of about 2 oz./yd.^{2}.

Using apparatus of the type shown in FIGURE 1, the sheet, while supported on a patterning plate, is subjected to the high-energy-flux streams of water issuing from 0.005-inch orifices spaced 20/inch and arranged in line in a manifold having a wall thickness of 0.015 inch. The patterning plate has 0.048-inch diameter holes in staggered array arranged on 0.08-inch centers. The sheet is given 8 passes under the streams in one direction and 8 passes normal to the first direction, the water pressure being between 1500 and 2000 p.s.i. and the sheet being about 1 inch from the orifices during treatment. Properties of the nonwoven, triangular-mesh-patterned fabric thus obtained are given below along with properties of the initial material. Abrasion resistance is determined as described in American Society for Testing and Materials (ASTM) Standards (1961), Part 9, pages 318–326, except that the flat sample-holding plate is replaced by a curved plate, having a radius of curvature of 6 inches at the surface over which the test sample is wrapped.

	Initial Sheet	Nonwoven Fabric
Tensile Strength (lbs./in.//oz./yd.^{2})	1.6	3.2
Bending Length (cm.)	5.9	1.3
Abrasion Resistance (Cycles to Failure):		
Side 1	6	27
Side 2	14	10
Fiber Interlock Value		17

As may be seen from the table, the nonwoven fabric is considerably stronger and more abrasion-resistant than the untreated sheet. While the initial material is paper-like in hand, the nonwoven fabric is supple and suede-like in texture, suitable for apparel fabrics. The improved drape of the nonwoven fabric is evident from the change in bending length over that of the initial material.

Example 58

This example illustrates the preparation of a non-woven patterned fabric having square areas of random fibers arranged in a geometrical design and interconnected with one another on diagonal axes by entangled fiber regions. Segments of fibers from adjacent random squares will be found in each entangled fiber region.

The initial material is a staple fiber web of randomly-disposed polyethylene terephthalate fibers, having a denier per filament of 1.5 (0.17 tex) and a length of 1.5 inches.

The patterning plate has (1) protruding pins of square base pyramid shape arranged in staggered rows across the plate and spaced 0.188 inch apart, (2) circular apertures having a diameter of 0.09 inch at the four corners of the base of each pyramid, such that the pyramids are separated diagonally by apertures and (3) smooth plateau areas located between pyramids.

The web is placed on the plate and is passed several times under essentially columnar streams of water issuing from 0.005-inch orifices arranged in line in a manifold at a density of 30 orifices/inch. During treatment the web is spaced about 1.25 inches from the orifices and water pressure is increased progressively from 500 to 1500 p.s.i.

The patterned, nonwoven fabric has (1) regularly spaced apertures corresponding to the areas where pyramids are present on the patterning plate, (2) square areas of randomly-disposed fibers corresponding to the plateau-areas of the plate, and (3) entangled fiber areas or nubs connecting the random areas diagonally and corresponding to the apertures in the plate.

The fabric has good drape and textile properties. The tensile strength is 2.3 lbs./in.//oz./yd.^{2} and the elongation is 68%.

Example 59

This example illustrates the preparation of a patterned nonwoven fabric having generally oblong-shaped entangled regions interconnected with one another by fibers which form a substantially continuous array around peripheries of the entagled fiber regions.

The initial material is a 3 oz./yd.^{2} (101.4 g./m.^{2}) web of randomly-disposed acrylic staple fibers having a length of 1.5 inches (3.81 cm.) and a denier per filament of 1.5 (0.17 tex).

The initial material is placed on a patterning plate having closely-adjacent oblong-shaped openings in a staggered arrangement; the plate having 45% open area.

Using apparatus of the type shown in FIGURE 1, the initial material while on the plate is treated with streams of water (60° C.) issuing from 0.007-inch orifices arranged in line and spaced 20 orifices/inch, the web being spaced about 1.5 inches from the orifices during treatment. Initially a top screen (14 x 18 wires/inch) is placed on the web and the assembly is passed under the streams 8 times at 100 p.s.i., 8 times at 200 p.s.i. and 8 times at 500 p.s.i.

The top screen is used to help hold the web in place; it does not influence the patterning of the web. The top screen is then removed and the web on its patterning plate is passed under the streams 8 times at each of the following water pressures: 200, 300, 500, 700, 900 and 1200 p.s.i. Half of the above passes are made along one direction of the patterning plate and half at 90° thereto.

The fabric so obtained is then removed from the plate and dried. It is shown with magnification in FIGURE 10. The fiber interlock value of the fabric is 17.5.

Example 60

This example illustrates the preparation of triangular-mesh-patterned, nonwoven fabrics from blends of staple fibers to produce products having improved surface stability.

The initial material is a batt of randomly-disposed, blended staple fibers prepared by an air-laying technique. The batt contains 50% by weight of 1.5 denier per filament (0.17 tex), 1.5-inch acrylic staple fibers and 50% by weight of 1.5 denier per filament, 0.25-inch rayon staple fibers.

Using apparatus of the type shown in FIGURE 1, a nonwoven fabric is prepared from the batt as follows. The batt is placed upon a stainless-steel patterning plate having a planar surface. The plate has 112 holes/square inch arranged in staggered array, the diameter of the holes being 0.075 inch, and has 50% open area. A thin plate having 132 holes/sq. in. and 41% open area is laid on top of the batt, to help hold it in place, and the assembly is passed under the high-energy-flux streams of water issuing from 0.005-inch orifices, arranged in line at a density of 40 orifices per inch, using a water pressure of 1500 p.s.i. After 8 passes under the water streams, the top plate is removed and the batt is then subjected to four passes at 1000 p.s.i. and 4 at 1500 p.s.i. The batt is then removed from the patterning plate, turned over, and replaced on the plate without attempting to maintain the original registry of the batt with the holes of the plate. Treatment of the reverse side consists of 2 passes at 1000 p.s.i., 2 at 1500 p.s.i., and 4 at 1800 p.s.i. During all of the above treatment, each pass is made at a right angle to the preceding pass.

The patterned, nonwoven fabric is then removed from the plate, dried and tested. Physical properties of the fabric are as follows:

Weight (oz./yd.^{2})	3.8
Strip tensile strength (lbs./in.//oz./yd.^{2})	3.9
Elongation (percent)	59
5% secant modulus (lbs./in.//oz./yd.^{2})	0.51
Bending length (cm.)	1.33
Thickness (inch)	0.047
Entanglement completeness	0.89
Entanglement frequency	44

In a separate test, samples are subjected to vigorous washing in a commercially available, household washing machine of the agitator type. To more nearly simulate normal washing conditions (full load) and to provide a source of lint, the sample is washed together with 10 new, woven, cotton hand towels. Warm water (about 50° C.) and a laundry detergent are used, and washing is continued for 100 minutes. The sample is then removed, rinsed, dried, and examined for lint pick-up, fuzzing, pilling or other signs of surface distortion. The sample is found to have excellent surface stability.

A series of samples is then prepared and tested as above which illustrates the effects of fiber length and fiber proportions on the surface stability of the product. If the length of the acrylic staple is kept at 1.5 inch and the ratio of acrylic staple to rayon staple is kept constant, it is observed that surface stability increases as the length of the rayon staple is decreased, from approximately the same as that of the acrylic staple, to 0.75 inch, and to 0.25 inch. Similarly, the series shows that for a given length ratio, e.g., when using ¼ inch rayon with 1.5 acrylic staple, surface stability increases as the proportion of the shorter fiber is increased from 10% to 25% and to 50%. For this particular combination of fibers, it was found that satisfactory surface stability could be achieved by blending the acrylic staple with as little as 10% of the 0.25 inch rayon staple or 50% of the 0.75 inch rayon staple. Products composed of a 50/50 blend of the 1.5 inch rayon and acrylic staple, or of 100% acrylic staple, lacked adequate surface stability for many end-uses.

Example 61

This example illustrates the preparation of a multilevel pattern structure from blends of staple fibers to produce products having improved surface stability.

The initial material is a batt of randomly-disposed, blended staple fibers prepared by an air-laying technique. The batt contains 50% by weight of 1.5 denier per filament (0.17 tex), 1.5-inch acrylic staple fibers and 50% by weight of 1.5 denier per filament, 0.25-inch rayon staple fibers and has a weight of approximately 3 oz./yd.^{2}.

Using apparatus of the type shown in FIGURE 1, a nonwoven, multilevel patterned structure is prepared from the batt as follows. The batt is placed on a 15-mesh plain weave screen having 15.2% open area and made from wires having a diameter of 0.041 inch. The screen wires have a moderate degree of crimp amplitude in one axis and a greater degree of crimp amplitude in the transverse axis. Accordingly, the screen surface is characterized by a series of slight protrusions, corresponding to the wire crimps, along one axis and a series of high protrusions along the transverse axis. The difference in crimp amplitude in the two axes of the screen and the interweaving of the wires impart to the screen a contour characterized by longitudinal and transverse, regularly-spaced channels or grooves, which are in addition to the actual drainage apertures formed by the crossing wires. The channels running in one direction follow generally sinusoidal paths, which are parallel and 180 degrees out of phase with respect to each adjacent one.

A thin pate having 462 holes/in.^{2} and 50% open area is laid on top of the batt to help hold it in place and the assembly is passed four times under high-energy-flux streams of water issuing from 0.005-inch orifices arranged in line at a density of 40 per inch using a water pressure of 1200 p.s.i. The top plate is then removed and the batt is passed under the streams twice at 500 p.s.i., twice at 750 p.s.i., twice at 1000 p.s.i., and 30 times at 1500 p.s.i. The batt is then removed from the screen, turned over, and replaced on the screen without attempting to maintain the original registry of the batt with the holes of the screen. Treatment of the reverse side consists of two passes at 1000 p.s.i. with the top plate described above and, after removal of the top plate, 60 passes at 1500 p.s.i. Water at a temperature of 65° to 70° C. is used in the treatment. Half of the above passes are made in one direction and half are made transverse thereto.

The resulting nonwoven product is removed from the patterning screen and found to have an appearance similar to the fabric shown in FIGURE 18. One face of the product has ridge-like elements comprising parallelized-fiber groups interconnected axially at entangled regions, which protrude from the face of the structure and follow generally sinusoidal paths across the structure. Running generally transverse to the sinusoidal ridges and present in a different thickness zone or level intermediate of the structure are groups of parallelized fibers interconnected axially at entangled regions and following a substantially straight path. On the other side of the transverse fibers, and forming the face of the structure opposite to the face having the sinusoidal ridges, are ordered groups of fibers which provide a repeating pattern of rectangles interconnected diagonally via localized areas of entanglement, individual fibers in the rectangles being randomly disposed with respect to one another to provide a felted appearance. The above three groups of fibers (the sinusoidal ridge fibers, the intermediate transverse fibers and the fibers forming the pattern of rectangles) are integrated with one another through the thickness of the structure at the localized areas made up of highly entangled fibers common to all groups.

After removal from the screen, the product is immersed in boiling water for about five minutes, dried in a household-type, hot-air tumble dryer and tested. The resulting nonwoven fabric is soft, drapable, strong and particularly suitable for use as a diaper fabric. Properties are as follows:

Weight (oz./yd.^{2})	2.6
Strip tensile strength (lbs./in.//oz./yd.^{2})	3.3
Elongation (percent)	42.0
5% secant modulus (lbs./in.//oz./yd.^{2})	1.1
Thickness (inch)	0.042

A sample of the fabric is also subjected to a laundering test to determine surface stability. The test load consists of 22 conventional diapers (to provide a source of lint and to simulate normal washing conditions), the above sample and a control sample made without the short fibers. This is washed in an agitator-type, commercially available household washing machine, using a "cotton" or high-heat setting and a laundry detergent. The load is put through a complete wash, rinse and a damp-dry cycle after which it is removed and dried for 20 minutes in a household drier of the "tumble-dry" type at maximum drier temperature. The above wash-and-dry procedure is repeated 25 times, after which the sample is removed and subjectively rated for fuzz and pill resistance. Both of the nonwoven, patterned fabrics remain integral after this severe treatment. The sample prepared from the blend of fibers is observed to be superior in fuzz and pill resistance to the one prepared without the short fibers.

Example 62

This example illustrates the preparation of apertured, patterned nonwoven fabrics from rayon fibers by treatment with essentially columnar streams jetted at 200 p.s.i. pressure, and demonstrates the criticality of the intensity and amount of treatment.

A series of 6 samples, coded A to F, is prepared using as initial material a web of randomly-disposed fibers prepared by an air-laying technique. Each initial web is made up of 50% of 1.5-inch, 1.5 denier per filament rayon fibers and 50% of 0.25-inch, 1.5 denier per filament rayon fibers. Initial web B weighs 1 oz./yd.^{2}; each of the other webs weighs 2 oz./yd.^{2}.

Using apparatus of the type shown in FIGURE 2, each web is treated with streams of water while supported on a 14 mesh (14 x 14 wires per inch), plain weave, patterning screen, having 18% open area.

The manifold assembly used in the treatment has a single row of funnel-shaped orifices spaced 20 per inch and arranged so that the treating liquid enters the cylindrical portion of the funnel and exits as a stream from the frusto-conical portion. The over-all length of the orifice is 0.012 inch. The cylindrical portion is 0.0012-inch long, 0.0034-inch diameter, and has a sharp edge at the liquid entrance. The frusto-conical portion is 0.011-inch long and has a diameter of 0.015 inch at the exit edge of the cone. During treatment the manifold assembly is oscillated approximately 3 cycles/second. Special care is taken in the cleaning and boring of the orifices to get as sharp an entry into the orifice and as smooth a bore along the walls of the orifice as possible so as to minimize any breaking up of the stream issuing from the orifice.

Uniformity of water distribution to the orifices is facilitated by use of a cylindrical filter which is mounted coaxially within the manifold assembly, spaced from the walls thereof, and extends over the full length of the manifold assembly. The filter is constructed from a 0.006-inch thick nickel plate containing 0.002-inch diameter holes to give a total open area of 3.5%.

The web and screen assembly is passed repeatedly under the streams of water (at 50° C.) at a distance of 4 inches from the orifices for Sample F and 6 inches for all other samples. The water pressure is 200 p.s.i. and the web speed is 2 yds./min. for all treatments. Processing of each web includes an initial number of passes while the web is supported on the patterning screen and covered by a top screen of high open area (14 x 18 mesh and 71% open area), which initial treatment serves only to hold the web in place, followed by treatment without the top screen for a larger number of passes.

Table 17 gives the number of passes, determinations of the energy flux (EF), and energy (E) expended during the processing, and results of physical tests for each sample. In physical appearance, Sample B is similar to the product shown in FIGURE 13 and the other samples are similar to the product of FIGURE 18.

TABLE 17

Sample Code	Initial Web Wt., oz./yd.^{2}	Initial Treatment Passes (No.)	Final Treatment Passes (No.)	Energy Flux (EF) (ft.-poundals/ in.^{2}/sec.)	Energy (HP-hr. per lb.)	Strip Tensile Strength (lb./in.// oz./yd.^{2})	Entanglement Frequency (f) (per inch)	Entanglement Completeness (c)	Fiber Interlock Value
A	2	2	8	23,000	0.17	1.1	20	0.28	8.8
B	1	2	8	23,000	0.34	1.9	26	0.48	---------
C	2	10	20	23,000	0.51	1.9	36	0.48	---------
D	2	10	50	23,000	1.0	2.2	28	0.53	---------
E	2	56	526	23,000	9.8	2.8	62	0.59	8.9
F	2	40	160	61,000	3.4	2.6	93	0.57	10.2

The table shows that values of about 0.5 entanglement completeness (*c*) are obtained at energy flux (EF) values of 23,000 ft.-poundals/in.^{2} sec. or higher and at energy (E) values of 0.2 or more HP-hrs./lb. of product (Samples B to F). At a given energy flux (EF), the strip tensile strength increases with increased expenditure of energy (E). Thus, at EF=23,000, tensile strength increases from 1.9 lb./in.//oz./yd.^{2} at E=0.34 HP-hrs./lb. to 2.8 lb./in.//oz./yd.^{2} at E=9.8 HP-hrs./lb. (Samples B to E). The strip tensile strength is also dependent upon the energy flux (EF). A strength of 2.8 is reached as EF=23,000 and E=9.8 (Sample E), whereas almost the same strength (2.6) is reached at E=3.4 when EF=61,000 (Sample F).

Example 63

This example describes preparation of additional patterned, apertured nonwovens and illustrates the type of entanglement obtained.

Sample A is prepared from a 2.5 oz./yd.^{2} web of 1.5-inch, 1.5 denier per filament, polyethylene terephthalate staple. Using apparatus like that in FIGURE 2, the web is supported on a 15 x 15 wires per inch, 15.2% open area screen woven from 0.041-inch wires and is moved at about 2 yd./min. under streams of water issuing from 0.007-inch drilled orifices arranged in line at a density of 20 orifices/inch. Web-to-orifice spacing is about 1 inch and the manifold is oscilalted at 200–300 r.p.m. During the first pass, a top screen is placed over the web to help hold it in place and a water pressure of 500 p.s.i. is used. Energy expended is 0.22 HP-hr./lb. The web-screen assembly is then passed 5 times under the streams at a pressure of 1440 p.s.i. without the top screen. Energy expended is about 5.9 HP-hr./lb. of fabric. Energy flux is about 21×10^6 foot-poundals/in.^{2}-sec. After treatment, the sample is boiled in water for 10 minutes and laundered once. One repeat unit of the fabric pattern is shown at considerable magnification in FIGURE 19. The fabric has a fiber interlock value of 15.

Sample B is prepared from a 2.5 oz./yd.^{2} web of randomly-disposed, 1.5 inch, 1.5 denier per filament acrylic stample. Patterning screen and processing treatment are the same as for Sample A, except that the treatment without a top screen involves 4 passes at 1300 p.s.i. with an expenditure of energy of 4.25 HP-hr./lb. of fabric. An entangled fiber region is shown greatly enlarged in FIGURES 35 and 36. Magnifications are indicated by the scales. The fabric has a filter interlock value of 19.

Sample C is prepared from random webs of 1.5 inch, 1.5 denier acrylic staple fiber of a type which shrinks and crimps intensely when heated at boil-off. Webs are assembled into an 8 oz./yd.^{2} layer and supported on a 4 x 4 mesh/inch patterning screen having 33% open area. Using apparatus like that in FIGURE 2, the supported fiber layer is moved at about 1 yd./min. under streams of water issuing from 0.005-inch drilled orifices arranged in line at a density of 20 orifices/inch. The assembly is passed under the streams at a pressure of 3000 p.s.i. with the fiber layer 1 inch from the orifices. The treatment is repeated with the orifice pressure 800 p.s.i. and then 3 passes are made at 1500 p.s.i. After treatment, the sample is boiled in water to shrink and crimp the fibers. A bulky, patterned nonwoven product is obtained, which is entangled as above and has the following properties (two directions):

Weight (oz./yd.^{2})	11.3
Strip tensile strength (lbs./in.//oz./yd.^{2})	1.45/1.08
Elongation (%)	77/74
5% secant modulus (lbs./in.//oz./yd.^{2})	0.27/0.32
Bulk (cc./gm.)	9.6
Fiber interlock value	17

Example 64

This example illustrates the preparation of patterned nonwoven fabrics having ridges on one face, composed of heavier denier acrylic staple fibers in a multilevel structure.

(A) Random webs of 6 denier, 1½-inch acrylic fiber, 2 to 3 oz./yd.^{2} basis weight, are plied to give an initial fiber layer and treated on a 40 x 40 mesh, 21% open area patterning screen of the type shown in FIGURE 14. Using apparatus of the type shown in FIGURE 2, the assembly is treated with columnar streams of water from 0.007-inch diameter orifices arranged in line at a density of 20 per inch along a jet manifold. An initial pass is made with the fiber layer covered with a 14 x 18 mesh, 71% open area top screen to hold the layer in place until until wetted down. This is followed by 3 treatment passes without a top screen. Then the filter layer is turned over and the treatment is repeated. The final two passes are made at 1500 p.s.i. water pressure with the jets oscillating 210 strokes per minute at 3/16-inch amplitude. Other treatment passes are at 1000 p.s.i. The orifice-to-web spacing is ¾ inch, where the high density streams have an energy flux of approximately 22×10^6 at 1500 p.s.i. and 12×10^6 at 1000 p.s.i. The web is conveyed during treatment at a uniform speed to give a total treatment energy of 7.5 HP-hrs./lb. The results are given in Table 18.

(B) A product of 6 denier fiber and weighing 4 oz./yd.^{2} is prepared by a treatment of 5.2 HP-hrs./lb. which also differs from the above in using, as the patterning support, a screen of 14 x 14 mesh and 18% open area. The results are summarized in Table 18. The product has a surface stability rating of 3.3 and 2.8 on the two faces based on a visual evaluation of the effect of subjecting the fabric to washing and drying with a full load of towels in household laundry equipment. A rating of 5 indicates that the appearance is still excellent, and a rating of 1 indicates a poor appearance due to pilling or other surface distortion.

TABLE 18

Product Code	Fiber Denier (d.p.f.)	Screen Mesh	Basis Weight (oz./yd.^{2})	Strip Tensile Strength (lb./in.// oz./yd.^{2})	Elongation (percent)	Entanglement		Fiber Interlock Value
						Frequency (f)	Completeness ($\bar{c}$)	
A	6	40 x 40	5.6	2.6	72	24	0.87	16
B	6	14 x 14	4.0	3.5	81	23	0.68	13

Example 65

An apparatus similar to that of FIG. 2 is used having a vacuum box (15 inches of water vacuum) under the screen, a single row of orifices (upper cylindrical section of 0.007-inch diameter and a lower frustoconical exit) spaced 40 per inch and located 0.75 inch above the screen. The screen is 24 x 24 mesh (21% open area) and is woven using a 0.020-inch diameter wire that has been flattened to 0.025 x 0.012-inch dimensions as the warp and 0.020-inch diameter round wire as the filling or shoot.

A random web (1.2 oz./yd.^{2}) of 0.75-inch rayon fibers of 1.5 d.p.f. is passed at 45.6 y.p.m. under the water streams at 300 p.s.i for the first treatment and at 1100 p.s.i. for the second treatment for a total energy of 0.125

HP-hrs./lb. based on the initial web weight. The energy flux for the two treatments is about 2×10^6 and 14×10^6 foot-poundals/inch^2-second. The row of orifices is not oscillated.

The apertured, patterned product has a tensile strength in the two directions of 1.6 and 0.8 (lbs./inch)/(oz./yd.^{2}) elongations of 36 and 42%, and a fiber interlock value of 15.

Example 66

The reinforcing web is a 1.6 oz./yd.^{2} weight random web containing about 88% 2.5 d.p.f. polyethylene terepthalate continuous filaments (prepared so that they have a spontaneous elongation of about 12% upon heating at 200° C. or higher) and about 12% continuous filaments, about 2.5 d.p.f., of a copolymer of ethylene terephthalate and ethylene isophthalate units (80/20 weight percent). The latter fibers can be fused at a lower temperature than the former to provide binder. 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 1.8 d.p.f. polyethylene terephthalate of 0.38-inch length with a weight of 0.6 oz./yd.^{2}.

The reinforcing web is placed on a 24 x 24 mesh screen, covered with the above staple web and passed under streams of water from a row of 5 mil diameter orifices spaced 40 per inch. Treatments at a maximum of 1000 p.s.i.g. are given to afford a total treatment of about 1.0 HP-hrs./lb. of product. The product is reversed on the screen and a second staple web placed on top of the continuous filament face. The composite is again treated as above.

The dried product (A) is a strong, foraminous, patterned product of entangled fibers. A portion of product (A) is placed between a 30 mesh and a 40 mesh screen and heated in a press at 230° C. under 200 p.s.i. pressure for two minutes to fuse the copolymer fibers. Properties of the original fabric (A) and the bonded fabric (B) are given below:

	A	B
Tensile strength (lbs./in.)/(oz./yd.^{2})	4.7	6.1
Fabric weight, oz./yd.^{2}	2.7	2.7
Fiber interlock value	24	20
Entanglement completeness	1.0	0.95
Entanglement frequency	16	52
Internal bond value, foot-pounds	0.5	0.5
Abrasion resistance (minutes to hole formation)	1	15

(Abrasion resistance is measured by pressing the fabric down upon a rotating abrasion disc at a standard load.)

As may be seen from the foregoing examples, a wide variety of products may be made in accordance with the present invention. Further novel effects may be achieved by choice of the initial fibrous layer and processing conditions. For example, decorative fabrics may be made by patterning and tanglelacing metallic flakes or other particulate material with the initial fibrous material. If desired, the fluid used in the production of the fabric may be chosen so as to impart special effects. Thus, for example, the fluid may contain a dye, pigment or other coloring material or it may be utilized to impart special properties to the web by incorporating therein an antistatic agent, a flame-proofing agent, an adhesive or other treating agent.

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, upholstery and other decorative materials, tarpaulins, padding and/or insulating materials, covering materials, and the like. Absorbent products are provided which are useful for diapers, bandages and especially for various uses where a combination of absorbency, wet-strength, durability and aesthetic properties is desirable. The nonwoven fabrics may be laminated to similar products or to different materials. Interesting packaging materials are made, for example, by laminating patterned, nonwoven fabrics to metal foils or films. The patterned, nonwoven fabrics may be cut into strips, if desired, and twisted into yarns. The high strength, patterned, nonwoven fabrics are particularly suited for industrial applications such as bagging materials, reinforcing materials for rubber or other goods such as belting or tires and the like. The patterned, nonwoven products having high drape and conformability are eminently suitable for use in clothing, including outerwear such as suits, jackets, shirts, blouses and the like.

TESTS FOR EVALUATING PHYSICAL PROPERTIES

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. Grab tensile strength is measured on a sample 4-inches wide and elongating at 400% per minute. Initial modulus is determined by measuring the initial slope of the stress-strain curve. The 5% secant modulus is defined by American Society for Testing and Materials (ASTM) Standards E6–61, part 10, page 1936. The 20% secant modulus is defined in the same way. Bending length is determined by using a sample 1-inch wide and 6-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 horizontnal. One-half of this length is the bending length of the specimen, reported in centimeters. Opacity is determined by Technical Association of the Pulp and Paper Industry, Test T425M–60. Thickness is measured with Ames thickness gauges. Tongue tear strength is measured in accordance with ASTM D–39–61 except that a sample 2.25 inches by 2 inches and having a 1-inch slit is used and a constant cross-head speed of 10 inches per minute is used.

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 th elong 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 fiber interlock value. In some examples the result of only 1 determination is given.

In the event that the fabric contains more than 1 or 2% of water soluble materials such as salts or by-products of chemical reactions on the fabric, the fabric should be extracted with portions of a 60% (by volume) aqueous solution of methanol until clear, rinsed in 100% methanol and air dried before testing.

ENTANGLEMENT FREQUENCY AND COMPLETENESS TESTS

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

Entanglement frequency is a measure of the frequency of occurence of entanglement sites along individual lengths of fiber in the nonwoven fabric. The higher the value of entanglement frequency 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 is a measure of 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.

Durable non-bonded products have an entangle frequency of at least 20 per inch and an entanglement completenenss of at least 0.5

Entanglement frequency and completeness 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

In cutting the strips from fabrics having a repeating pattern or ridges or lines or high and low basis weight, integral numbers of repeating units are included in the strip width, always cutting through the low basis weight portion and 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 five or more at w_2 and w_0 using an "Instron" tester with standard rubber coated, flat jaw faces and the gauge lengths and elongation 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 ideally all fibers carry stress up to the breaking point, while with long gauge length, some poorly-entangled fibers slip out without breaking. A measure of the proportion of stress-carrying fibers is called (*c*).

Provided that (D) is less than ½w_1, then:

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

and D and *c* are:

$$D=\frac{w_1T_2-w_2T_1}{2(T_2-T_1)}\quad c=\frac{T_2-T_1}{w_2-w_1}\cdot\frac{w_0}{T_0}$$

In certain cases (D) may be nearly zero and even a small experimental error can result in the measured (D) being negative. 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. (*c*) and (D) are determined separately for each direction and the arithmetic means of the values for both directions, ($\bar{c}$) and ($\bar{D}$) are calculated. ($\bar{c}$) is called the *entanglement completeness.*

When ($\bar{c}$) is greater than 0.5, ($\bar{D}$) is a measure of the average distance required for fibers in the fabric to become completely entangled so that they cannot be separated without breaking. When ($\bar{c}$) is less than 0.5, it has been found that ($\bar{D}$) may be influenced by factors other than entanglement. Accordingly, when ($\bar{c}$) is less than 0.5, calculation of ($\bar{D}$) as described above may not be meaningful.

From testing various samples, it is observed that the surface stability of a fabric increases with increasing product of ($1/\bar{D}$) and the square root of fiber denier (*d*). Since 1.5 denier fibers are frequently used, all deniers are normalized with respect to 1.5 and *entanglement frequency* ($\bar{f}$) per inch is defined as

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

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

If the measured ($\bar{D}$) turns out to be zero or negative, it is proper to assume that the actual ($\bar{D}$) is less than 0.01 inch and ($\bar{f}$) therefore greater than $100\sqrt{d/1.5}$ per inch.

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. 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.

Meaningful results may not be obtained by the above Method (A) on (1) net-like products having an open area of more than about 15% (as in FIGS. 13 and 15) or (2) very thin fabrics having a fabric weight of less than 1.0 oz./yd.², 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, Ark.) 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 open area of a fabric can be estimated by measuring the size of the openings and counting for a given area.

jacent entangled fiber regions, are closely distributed along the peripheries of the entangled fiber regions and project in the plane of the fabric at abrupt angles to the perimeters of the entangled fiber regions.

20. Fabric as defined in claim **2** wherein said entangled fiber regions have a compact shape for which the diameter of the inscribed circle is at least 50% of the diameter of a circle circumscribed about the perimeter of the entangled fiber region.

21. Fabric as defined in claim **2** wherein the fibers extending between the dense entangled fiber regions hold these regions so closely together that the pattern is normally obscured, the pattern being revealed when the fabric is stretched.

22. Fabric as defined in claim **1** which comprises dense regions of fibers randomly entangled with each other, ordered fiber groups interconnected with one another at the entangled fiber regions to define an ordered geometric pattern of apertures, the fiber groups being located in different thickness zones of the fabric, and including fiber groups forming ridge-like protrusions on at least one suface of the fabric.

23. Fabric as defined in claim **2** having a repeating pattern characterized by a fabric face layer of fiber groups in a regular pattern of ridges separated by grooves lying along parallel straight lines, the ridge fiber groups being interconnected by fibers which bridge under the ridge-separating grooves, are generally parallel, and are locked into place in entangled fiber regions of the ridges.

24. Fabric as defined in claim **23** having a pattern of ridges and grooves on both faces, the ridge-inter-connecting fibers being in an intermediate layer.

25. Fabric as defined in claim **23** having a pattern of ridges and grooves on one face, an intermediate layer of ridge-interconnecting bands of generally parallel fibers, and a layer of random fibers on the other face.

26. Fabric as defined in claim **23** wherein the ridges extend in substantially continuous lines in the same general direction of the fabric.

27. Fabric as defined in claim **23** wherein the ridges are substantially straight and evenly spaced.

28. Fabric as defined in claim **23** wherein the ridge-interconnecting fibers form a substantially continuous array beneath the grooves.

29. Fabric as defined in claim **23** wherein the ridges and interconnecting fibers define a repeating pattern of apertures in the fabric.

30. Fabric as defined in claim **1** characterized by a repeating pattern of ridges separated by grooves lying along parallel straight lines on at least one fabric face and by a repeating pattern of apertures spaced along the grooves; the fabric structure comprising entangled fiber regions located in areas between adjoining grooves and interconnected into substantially continuous ridges following paths passing between the grooves adjacent to portions of the apertures, and bands of fibers interconnecting entangled fiber regions beneath the grooves and extending along sides of apertures.

31. Fabric as defined in claim **30** wherein said ridges follow sinusoidal paths which are substantially 180° out of phase with respect ot adjacent sinusoidal ridge paths.

32. Fabric as defined in claim **30** wherein the ridges comprise entangled fiber regions alternating with interconnecting parallelized fiber groups.

33. Fabric as defined in claim **30** wherein entangled fiber regions extend substantially continuously along the ridges.

34. Fabric as defined in claim **30** wherein the entangled fiber regions are of a roughly square shape and are interconnected by narrow ridge fiber groups which are parallel to the grooves, alternately on one side and then the other side of the ridge, and are attached to each entangled fiber region at portions almost diagonally opposed.

35. Fabric as defined in claim **1** having a structure characterized on one face by a regular pattern of sinusoidal ridges separated by evenly-spaced, parallel straight grooves; characterized on the other face by a repeating pattern of rectangular areas of random fiber arrangement interconnected diagonally to define oval-shaped apertures, and by fibers which loop over the interconnections between rectangles and proceed downward around the peripheries of the holes toward the opposite face of the fabric; and having an intermediate layer of ordered groups of parallelized fibers extending beneath the ridge-separating grooves in a direction generally transverse to the ridges; said dense entangled fiber regions being located in the ridges and extending through the thickness of the fabric structure to provide integrity and strength to the fabric.

36. Fabric as defined in claim **2** having the appearance of a twill-weave textile fabric, said repeating pattern being characterized by a fabric face layer of protruding ribs arranged in rows in a twill pattern and by fibers extending from entangled fiber areas in the ribs in parallelized fiber groups interconnecting entangled fiber areas in a principal fabric direction, parallelized fiber groups interconnecting entangled fiber areas transversely to said principal fabric direction, and bands of parallelized fibers interconnecting entangled fiber areas of ribs in a bias direction of the fabric.

37. Fabric as defined in claim **1** wherein said repeating pattern is characterized by a fabric face layer of protruding ribs separated by grooves lying along parallel straight lines and arranged in rows in a twill pattern, the ribs being interconnected by groups of parallelized fibers which extend from entangled fiber regions of the ribs in principal fabric directions and by bands of parallelized fibers which extend under said grooves to interconnect ribs in a bias direction of the fabric.

38. A twill-patterned nonwoven fabric as defined in claim **37** wherein said bands of parallelized fibers are arched and form protrusions on the fabric face opposite to said rib-separating grooves.

39. A twill-patterned nonwoven fabric as defined in claim **37** wherein said parallelized fibers form an intermediate layer which is overlaid with random fibers on the fabric face opposite to the ribbed face.

40. Fabric as defined in claim **2** wherein said repeating pattern is characterized on one fabric face by rectangular areas of entangled fibers which are interconnected by groups of generally parallel fibers and are arranged in parallel rows extending in a bias direction relative to a principal fabric direction, the rectangular areas being aligned with their long axes parallel to those in the same row and transversely to the long axes of the rectangles of adjacent rows; and is characterized on the other fabric face by bands of parallelized fibers extending between the long sides of entangled fiber areas.

41. Fabric as defined in claim **1** having a weight of 0.5 to 10 ounces per square yard and a strip tensile strength of at least 1.0 pound/inch per oz./yd.^{2}.

42. Fabric as defined in claim **2** wherein the dense entangled fiber regions and interconnecting fibers define a pattern of apertures which are substantially free from fibers.

43. Fabric as defined in claim **1** comprising textile staple fibers.

44. Fabric as defined in claim **1** comprising continuous filaments.

45. Fabric as defined in claim **1** comprising paper fibers.

46. Fabric as defined in claim **1** comprising short fibers and fibers at least twice as long as the short fibers; the short fibers being concentrated to a greater extent in said dense entangled fiber regions, wrapping around the longer fibers and being highly entangled to bind the long fibers securely into the body of the fabric.

It is observed that Method B gives substantially the same results as Method A on fabrics of low open area and weights greater than 1 oz./yd.^{2}.

Results on some products of this invention follow:

Example:	Internal bond value, foot-pounds
2:	
A	0.36
B	>0.5
C	0.48
D	>0.5
F	0.33
H	0.25
I	0.36
J	0.47
6—type products	0.38 to >0.5
7—type products	0.3 to >0.5
66	0.5

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.

I claim:

1. Textile-like nonwoven fabric comprising fibers locked into place by fiber interaction, the fabric having a regular repeating pattern of entangled fiber regions of higher area density than the average area density of the fabric and interconnecting fibers which extend between the dense entangled fiber regions and which are randomly entangled with each other in said regions, said fibers of the fabric being locked into place by a three-dimensional fiber entanglement characterized by a fiber-interlock value due to fiber entanglement of at least 7 with a fiber entanglement completeness of at least 0.5, said values being determined in the absence of binder, and wherein fibers in said regions turn, wind, twist back-and-forth, and pass about one another in all directions of said regions 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. Textile-like nonwoven fabric of fibers locked into place in a structure having a regular repeating pattern of entangled fiber regions of higher area density than the average area density of the fabric and joined by ordered groups of fibers which extend between the dense entangled fiber regions and which are randomly entangled with each other in said regions, said fibers of the fabric being locked into place 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 said regions turn, wind, twist back-and-forth, and pass about one another in all directions of said regions 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.

3. Textile-like nonwoven fabric comprising fibers locked into place by fiber interaction; having a repeating pattern of entangled fiber regions, of higher area density than the average area density of the fabric, and interconnecting fibers which extend between the dense entangled fiber regions and which are randomly entangled with each other in said regions; having an entangled fiber structure characterized by random fiber segments that penetrate entangled fiber regions of the fabric and have a re-entrant loop configuration in the fiber segment which binds other fibers in place in the fabric; said fibers of the fabric being locked into place by a three-dimensional fiber entanglement characterized by a fiber-interlock value due to fiber entanglement of at least 7 with a fiber entanglement completeness of at least 0.5, said values being determined in the absence of binder, and wherein fibers in said regions turn, wind, twist back-and forth, and pass about one another in all directions of said regions 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.

4. Fabric as defined in claim **3** of fibers which are randomly entangled and interlocked with each other in a repeating pattern of localized dense entangled fiber regions interconnected by fibers extending between adjacent entangled fiber regions to define regions of lower area density than that of the adjacent fabric, the fiber entanglement frequency for nonbonded fabric being at least 20 per inch with a fiber entanglement completeness of at least 0.5.

5. Fabric as defined in claim **4** wherein the dense entangled fiber regions are arranged in a regular pattern and joined by ordered groups of fibers to provide a fabric having an appearance similar to that of a conventional woven fabric.

6. Fabric as defined in claim **3** wherein the dense entangled fiber regions are interconnected by ordered groups of fibers which form ridge-like protrusions on at least one face of the fabric.

7. Fabric as defined in claim **3** wherein fiber entanglement is concentrated in the dense entangled fiber regions, said regions are arranged in a regular pattern and are interconnected by ordered groups of substantially parallel fibers.

8. Fabric as defined in claim **3** wherein the dense entangled fiber regions are localized areas, composed of fibers that are randomly entangled with each other and that join adjacent entangled fiber regions to define a repeating pattern of apertures in the fabric, and the non-bonded fabric is characterized by an entanglement frequency of at least 20 per inch of fiber with a fiber entanglement completeness of at least 0.5.

9. Fabric as defined in claim **8** wherein the localized entangled areas are joined by ordered fiber groups to provide a fabric having an appearance similar to that of a conventional woven fabric.

10. Fabric as defined in claim **8** wherein the localized entangled areas are joined by ordered fiber groups, and the individual fibers proceed randomly through the fabric from entangled area to entangled area.

11. Fabric as defined in claim **8** wherein the localized areas are joined by ordered fiber groups, and individual fibers proceed through the fabric to successive entangled areas aligned in the same direction.

12. Fabric as defined in claim **8** wherein the localized areas are joined by ordered fiber groups of substantially parallel fibers.

13. Fabric as defined in claim **8** wherein the localized areas are joined by ordered fiber groups, the fibers in a group being randomly disposed relative to one another.

14. Fabric as defined in claim **8** comprising fibers which are entangled with each other at intervals along their lengths in a repeating pattern of compact masses bound to adjacent masses by linking fibers, the linking fibers being locked into place in the compact masses by three-dimensional fiber interaction.

15. Fabric as defined in claim **14** which has approximately the same strength in all directions.

16. Fabric as defined in claim **14** wherein said masses are closely spaced at a high frequency of about 1000 to 4000 masses per square inch.

17. Fabric as defined in claim **14** wherein bundles of linking fibers are spaced about 90° apart around the masses and define a square-mesh pattern.

18. Fabric as defined in claim **14** wherein bundles of linking fibers are spaced about 60° apart around the masses and define a triangular-mesh pattern.

19. Fabric as defined in claim **2** wherein said entangled fiber regions are compact masses which occupy at least 40 percent of the total patterned area and are closely spaced with substantially uniform distances between adjacent entangled fiber regions, the spaces between entangled fiber regions of the fabric comprising a substantially continuous array of fibers which interconnect ad-

47. Fabric as defined in claim **1** composed of staple fibers and paper fibers of shorter length.

48. Fabric as defined in claim **1** composed of continuous filaments and fibers of less than one inch in length.

49. Fabric as defined in claim **1** composed of 90% to 25% continuous filaments and 10% to 75% paper fibers.

50. Fabric as defined in claim **1** composed of 90% to 40% staple fibers at least about 1.5 inches in length and 10% to 60% of short fibers of about ¼ inch to ¾ inch in length.

51. Fabric as defined in claim **1** of staple-length textile fibers randomly entangled in said repeating pattern of dense entangled fiber regions and reinforced with 3% to 90% of substantially continuous fibrous strands, based on the weight of the fabric.

52. Fabric as defined in claim **51** wherein said fibrous strands are textile yarns and constitute 10% to 70% of the weight of the fabric.

53. Fabric as defined in claim **51** wherein said fibrous strands are composed of continuous filaments.

54. Fabric as defined in claim **51** wherein said fibrous strands are spun yarns of staple fibers.

55. Fabric as defined in claim **51** wherein said fibrous strands are textured bulk yarns.

56. Fabric as defined in claim **51** wherein said fibrous strands are crimped stretch yarns.

57. Fabric as defined in claim **51** wherein said fibrous strands join the entangled fiber regions in a regular pattern to provide a fabric having an appearance similar to that of a conventional woven fabric.

58. Fabric as defined in claim **2**, weighing about one ounce per square yard and comprising textile staple fibers less than one inch long.

59. Fabric as defined in claim **3** which has a fiber entanglement frequency of at least 34 per inch with said fiber entanglement completeness of at least 0.5.

60. The process of consolidating fibers or filaments into a strong patterned structure by treatment with streams of liquid from jet devices which comprises, supporting a layer of fibrous material on an apertured patterning member having apertures arranged in a pattern corresponding to regions of fiber entanglement in the fabric product, jetting liquid supplied at pressures of at least 200 pounds per square inch to form fine, essentially columnar, liquid streams having over 23,000 energy flux in foot-pounds/inch^2 second at the treatment distance, and traversing the supported layer of fibrous material with the streams until the fibers are randomly entangled in regions interconnected by fibers extending between adjacent entangled regions in a pattern determined by the apertured supporting member, wherein fibers in said regions turn, wind, twist back-and-forth, and pass about one another in all directions of said regions in such an intricate entanglement that the fibers interlock with one another when the fabric is subjected to stress to thereby provide coherency and strength to the fabric.

61. The process defined in claim **60** wherein the supported layer is treated with the streams until a total of at least 0.1 horsepower-hour of stream energy per pound of treated fabric is provided.

62. The process defined in claim **60** wherein the supported layer of fibrous material is traversed with a plurality of essentially columnar streams which are spaced 0.01 to 0.1 inch apart in a row and are substantially parallel to each other.

63. The process defined in claim **60** wherein the essentially columnar streams have a total divergence angle of less than 3 degrees.

64. The process defined in claim **60** wherein the liquid is jetted through orifices 0.003 to 0.030 inch in diameter.

65. The process defined in claim **60** wherein the liquid is jetted to form streams of over 1,000,000 energy flux.

66. The process defined in claim **65** wherein the supported layer is treated with the streams until a total of at least 0.1 horsepower-hour of stream energy per pound of treated fabric is provided.

67. The process defined in claim **66** wherein a layer of fibrous material, weighing about one ounce per square yard and supported on an apertured patterning screen having up to 3,600 openings per square inch which provide 10 to 50% open area, is treated with streams jetted from orifices 3 to 10 mil in diameter and spaced 0.01 to 0.1 inch apart in a row in a manifold.

68. The process defined in claim **65** wherein liquid supplied at a pressure of 500 to 5,000 pounds per square inch gage is jetted to form said streams.

69. The process defined in claim **58** wherein the layer of fibrous material weighs 0.5 to 10 ounces per square yard.

70. The process defined in claim **60** wherein the apertured patterning member has 25 to 4000 openings per square inch which provide a total of 10% to 98% open area in the patterning member.

71. The process defined in claim **60** wherein the apertured patterning member is a plate perforated with circular holes of 0.01 to 0.25 inch in diameter.

72. The process defined in claim **60** wherein the apertured patterning member is a screen of 3 to 80 mesh per inch.

73. The process defined in claim **60** wherein the liquid is jetted through orifices and the fibrous layer is supported less than 6 inches from the orifices.

74. The process defined in claim **60** wherein the traversing streams impinge on the supported fibrous layer at over 100,000 energy flux and the treatment provides over 1 horsepower-hour of energy per pound of fibrous layer.

75. The process defined in claim **60** wherein the supported layer is treated until a patterned nonwoven fabric is formed which has the fibers locked into place by fiber interaction at a fiber entanglement frequency of at least 20 per inch of fiber with a fiber entanglement completeness of at least 0.5.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,485,706 Dated December 23, 1969

Inventor(s) Franklin James Evans

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 3, line 42, delete "evaluated by the".

Column 74, line 32, delete "and 6-inch wide".

Column 75, line 30, "entangle" should read -- entanglement --; line 32, "completenenss" should read -- completeness --; line 44, the first and third "or" should both read -- of --; last two lines in that column, the formulas should read:

$$D = \frac{w_1T_2 - w_2T_1}{2(T_2 - T_1)} \qquad c = \frac{T_2 - T_1}{w_2 - w_1} \cdot \frac{w_o}{T_o} \quad .$$

Column 76, line 27, the formula should read:

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

Claim 24, line 2, after "inter" delete the hyphen.

Claim 31, last line "ot" should -- to --.

Claim 69, line 1, "claim 58" should read -- claim 60 --.

SIGNED AND
SEALED
NOV 3 1970

(SEAL)
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