PATTERNED NONWOVEN FABRIC OF MULTIFILAMENT YARNS AND JET STREAM PROCESS FOR ITS PRODUCTION

Filed Jan. 18, 1968 3 Sheets-Sheet 1

FIG. 1

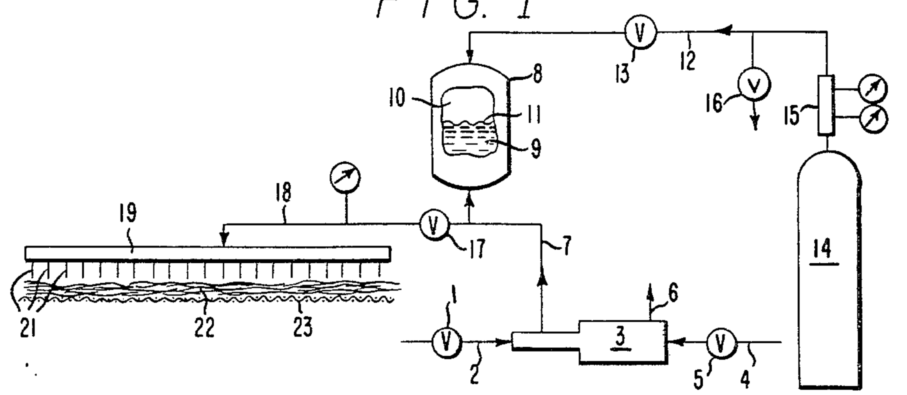
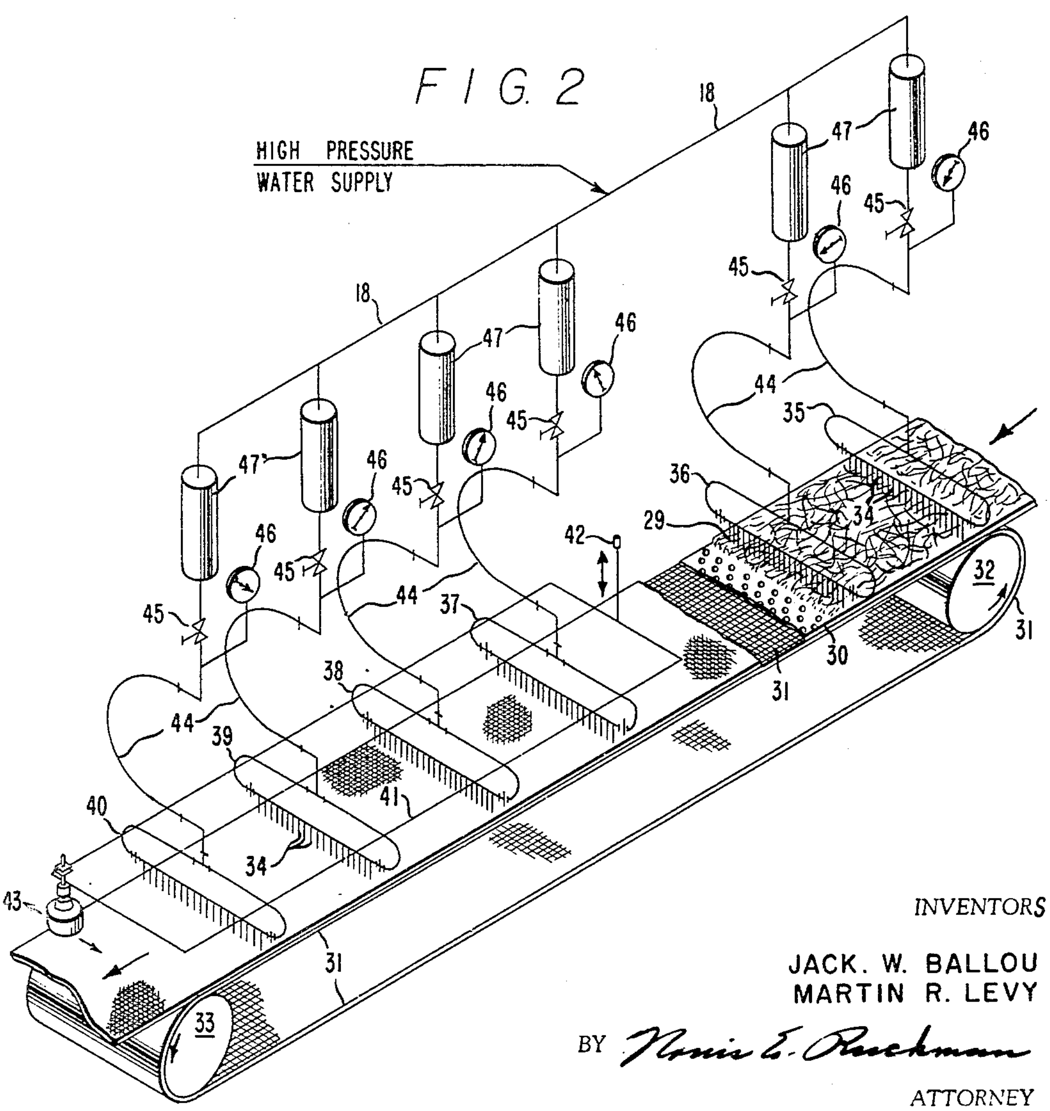


FIG. 2



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PATTERNED NONWOVEN FABRIC OF MULTIFILAMENT YARNS AND JET STREAM PROCESS FOR ITS PRODUCTION

Filed Jan. 18, 1968 3 Sheets-Sheet 2

FIG. 3

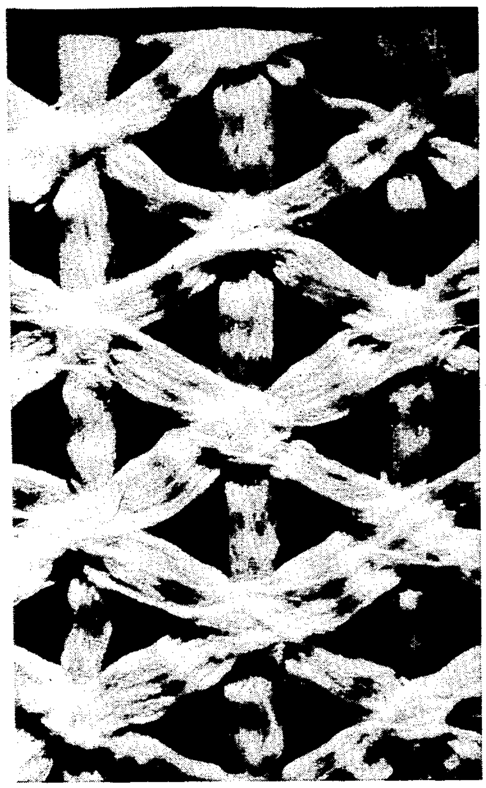

FIG. 4

FIG. 5

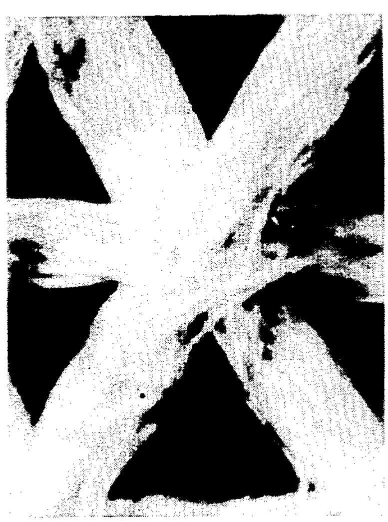

FIG. 6

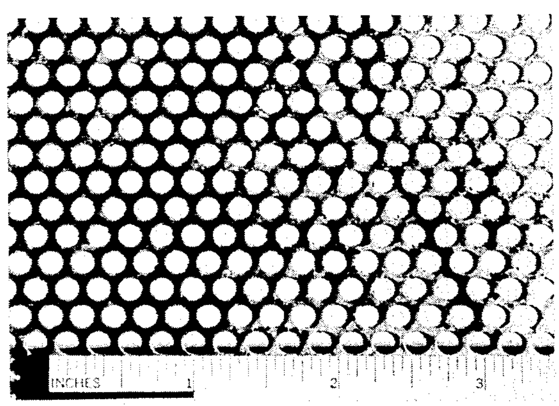

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FIG. 7

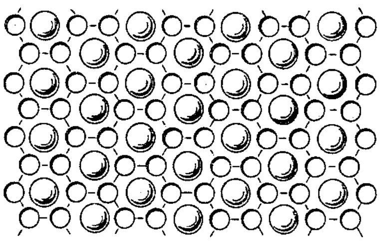


FIG. 8

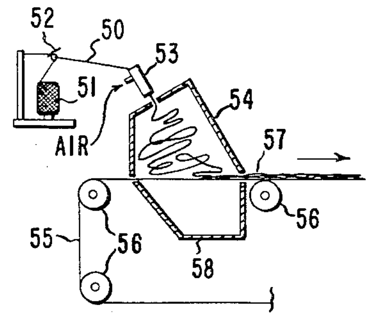
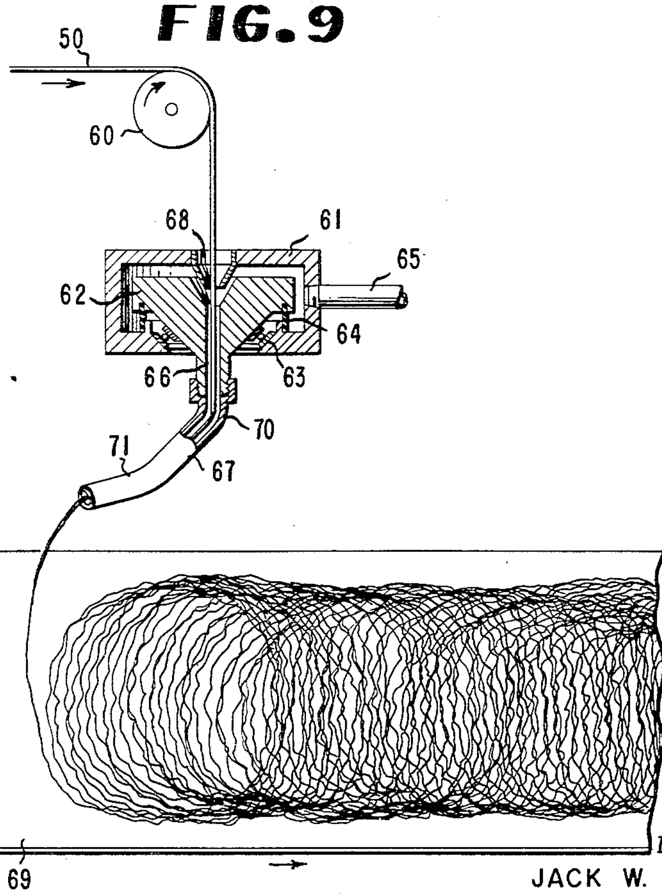


FIG. 9



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1

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PATTERNED NONWOVEN FABRIC OF MULTIFILAMENT YARNS AND JET STREAM PROCESS FOR ITS PRODUCTION

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Continuation-in-part of application Ser. No. 446,640, Apr. 8, 1965. This application Jan. 18, 1968, Ser. No. 727,112

Int. Cl. D04h 1/44, 3/10, 3/02

U.S. Cl. 161—72 13 Claims

ABSTRACT OF THE DISCLOSURE

Pattern nonwoven fabrics of multifilament yarns, having a repeating pattern of entangled fiber regions which lock the yarns in place without the need for bonding agents, are produced by collecting yarn in a layer in which the yarn retains its identity and is free to move sideways, supporting the layer on a perforated plate or woven wire screen, 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 a unified strong fabric which is particularly suitable for industrial uses.

CROSS-REFERENCE TO RELATED APPLICATION

This is a continuation-in-part of our copending application Ser. No. 446,640, filed Apr. 8, 1965 and now abandoned.

SPECIFICATION

This invention relates to nonwoven fabrics and to their preparation. More particularly, it relates to nonwoven fabrics comprising an ordered array of yarns and to the preparation of such fabrics by treatment of yarn webs with high-energy-flux liquid streams.

For many end uses, notably for industrial uses such as filter-cloths, tarpaulins and the like, high strength fabrics are required. In still other uses, such as in tire reinforcement or in conveyor belting, highly directional properties are desired. In general, these uses also demand fabrics which have a low breaking elongation and are resistant to deformation. These properties have been provided in the past by weaving fabrics from high strength yarns, especially continuous-filament yarns. In such woven fabrics, the cooperative effort of the filaments aligned in a given direction is fully utilized in that direction to provide strength in the fabric. However, weaving is a slow and costly process, and a substitute therefor has long been sought.

It has been proposed to prepare nonwoven fabrics by cross-lapping warps of continuous filaments and uniting the warps by adhesive bonding. However, the complexity and cost of the equipment required to cross-lap the warps to form a continuous length of fabric, plus the added cost of applying a binder to the fabric, renders this process economically unattractive. It has also been proposed to convert glass-filament bundles into nonwoven mats by directing the bundles in random loops and swirls onto a conveyor belt, or the like, and thereafter applying resin to bond the filaments into a mat. Since the filaments are randomly disposed in the nonwoven mat, the filaments can contribute only a small fraction of the strength which could be obtained by aligning the filaments in a regular pattern as in a woven fabric. In practice, moreover, the strength of such nonwoven mats depends primarily upon the strength of the adhesive that bonds adjacent filaments of crossing bundles together.

2

In accordance with the present invention, nonwoven fabrics are provided which are suitable for industrial uses without dependence upon binder. The invention further provides nonwoven fabrics of yarns arranged in a regular pattern in which the yarns are aligned with respect to one another to provide directional strength to the fabric. The present invention further provides nonwoven fabrics comprising an ordered array of yarns wherein filament interentanglement imparts strength and unity to the fabric without bonding. This invention further provides a process for the direct preparation of such fabrics in a continuous manner.

These and other advantages of this invention will become apparent in the course of the following specification and claims.

In accordance with the present invention, patterned nonwoven fabrics are prepared from multifilament yarns without weaving, and without adhesive bonding, by a process which comprises collecting one or more yarns in a layer to form an initial web in which the yarn generally retains its identity and is free to move sideways in the plane of the web, supporting the web on a patterning member having apertures in an order arrangement corresponding to the desired fabric pattern, and traversing the supported web with fine, essentially columnar streams of liquid at high-energy-flux to produce entangled areas interconnected by ordered groups of yarn in a repeating pattern.

The products of the present invention are patterned nonwoven fabrics formed of multifilament yarns, the fabric having a repeating pattern of entangled areas, and identities of individual yarns being substantially retained as they pass through the entangled areas, and the nonwoven fabric having strength and coherence due to fiber-interaction at the entangled areas. The fiber-interlock test described at the end of the specification provides a measure of this fiber interaction. The fabrics of the present invention have a fiber-interlock value due solely to fiber interaction of at least 7. The examples show patterned nonwoven fabrics made from yarns and having fiber interlock values ranging from 11.5 to 50.

Fabric bonded with binder will give higher fiber-interlock values than the same fabric before bonding. Since the avlue determined in the absence of bonding 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. However, the examples illustrate products having much higher values than are obtained when bonding is substituted for the hydraulic treatment disclosed.

In general, it has been found that patterned nonwoven fabrics prepared by hydraulic treatment as discussed herein, using webs of randomly disposed, unopened continuous-filament yarns differ from fabrics prepared under identical conditions but using webs prepared by opening the same yarns (e.g. by using electrostatic treatment to separate the filaments and lay them down individually). An important difference is that the nonwovens from unopened yarns have a higher modulus and lower breaking elongation. In a typical preparation, as illustrated in Example 9, the nonwoven from unopened yarns has 2 to 4 times the modulus of the nonwoven prepared from the individual filaments (opened yarn), and from 50 to 75% of the breaking elongation. The higher modulus and lower elongation products, prepared from the unopened yarns, provide advantages for these products in industrial uses.

Products which are particularly preferred for industrial uses are the patterned nonwoven fabrics made from yarns and having a 5% secant modulus of at least 20 (lb./in.)/(oz./yd.^{2}) in the direction of alignment of the yarn bundles, and having a breaking elongation of less than 35%. Products of this type are illustrated in Example 2.

One of the advantages of the invention is that the initial web can be formed by depositing yarn on a collecting surface with simple forwarding means, e.g., by mechanical means such as forwarding rolls, or by fluid means such as air jets, and the yarn can even be deposited by hand. The yarn or yarns can proceed randomly through the web, thereby eliminating the expense of costly yarn-aligning or filament-dispersing equipment. Preferably the web is formed by depositing yarn on an apertured patterning plate or screen having a surface configuration corresponding to the pattern desired in the nonwoven fabric. Then the treatment with high-energy-flux streams of liquid converts the web into a patterned fabric directly on the surface used in preparing the initial web.

The term "apertured patterning member" includes any screen or plate having a perforated, grooved or recessed surface configuration on which the yarn web is supported during processing and which, by reason of its surface configuration, influences the movement of the fibers into a repeating pattern in response to the high-energy-flux liquid streams. The patterning member may have a planar or a non-planar surface or a combination of planar or non-planar areas.

The term "multifilament yarns" means yarns made up of continuous filaments or of staple length fiber.

The web can be formed from a single continuous yarn or a plurality of yarns. An ordered group in the patterned fabric may be a bundle composed of different portions of the same yarn. For convenience such portions will be referred to as yarns, regardless of the actual number of distinct initial yarns which are present in the fabric. The treatment with high-energy-flux liquid rearranges the yarns into entangled areas, overlying apertures in the patterning member, where yarns intersect, overlap and are locked into place by fiber interaction in a unique manner. The yarns then separate and proceed onward from intersection to intersection through the fabric in ordered groups of yarns. The yarns generally maintain their identity as they follow these paths, which may be quite random. Although individual yarns can be traced through the entangled areas at intersections of ordered groups, the yarns do not merely cross over and under one another in overlapping relationship as in a woven fabric. These entangled intersections are characterized in detail hereinafter.

The novel products of the present invention are nonwoven fabrics of multifilament yarns arranged in intersecting groups in an ordered pattern wherein the individual yarns of the groups overlap and interlace with one another in the plane of the fabric at the intersections of the groups and maintain their identity and continuity as they pass from intersection to intersection, and the intersections are entangled areas which lock the yarns into place by interaction of the fibers. Although the fabric has an ordered pattern, the individual yarns will generally proceed randomly through the fabric, leaving one intersecting group and joining another at the intersections. The yarn groups and the intersections define or delimit apertures which are substantially free from fibers or have a low concentration of fibers relative to the adjacent fabric.

In general, the nonwoven fabrics of the present invention are flat or two-dimensional. However, the fabrics are slightly thicker at the intersections of yarn groups since the overlapping and interlacing of the yarn as they pass through the intersection results in a slight bulge.

The process and products of the invention will be discussed with reference to the accompanying illustrations wherein:

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, entangled textiles,

FIGURE 3 is a photomicrograph showing in plan view, at 8× magnification, a portion of a triangular-mesh-patterned, entangled fabric prepared as described in Example 2,

FIGURE 4 is a corresponding view, also at 8× magnification, of the reverse face of the fabric shown in FIGURE 3,

FIGURE 5 is a photomicrograph showing in plan view, at 10× magnification, a portion of a triangular-mesh entangled fabric prepared as described in Example 3,

FIGURE 6 is a plan view of a patterning plate for preparing triangular-mesh patterned fabrics as illustrated in FIGURES 3 to 5,

FIGURE 7 is a plan view of a patterning plate for preparing hexagonal-mesh patterned fabrics as disclosed in Example 5,

FIGURE 8 is a schematic side elevation, partly in section, of apparatus for forming yarn into random webs preparator to high-energy-flux treatment with liquid in accordance with this invention, and

FIGURE 9 is a schematic side elevation, partly in section, of apparatus for forming another type of yarn web for use in the process of this invention.

The fabric shown in FIGURES 3 and 4 is illustrative of one preferred product which is obtained by the process of this invention when a web of randomly deposited yarn is treated on an apertured patterning plate such as the one shown in FIGURE 6. This plate has evenly spaced holes arranged in staggered rows with adjacent holes centered on the apices of equilateral triangles. The treatment causes the yarn to rearrange into groups of yarns which intersect in entangled areas or bulges over the holes of the plate and extend between adjacent holes on the patterning plate. In the product illustrated, the yarn groups are bundles of substantially parallelized fibers. These yarn bundles intersect at 60° angles around the nubs and define an apertured fabric of triangular-mesh-pattern. The hole of arrangement in the plate determines the pattern, and fabrics can be prepared with a repeating mesh pattern of squares, hexagons, octagons or other geometrical shapes. Furthermore, apertures in the fabric need not be defined by bundles of substantially parallelized yarns. For example, the fabric may have a repeating mesh-pattern wherein diagonally interconnected regions comprised of groups or assemblages of random and/or substantially parallel yarns, alternate in staggered arrangement with the apertures of the fabric. For such structures the diagonal interconnections may be considered to be the intersections of the yarn groups.

In a particular embodiment of the type illustrated, patterned nonwoven fabrics are made from highly drawn, stiff, strong, uncrimped and untwisted continuous-filament yarns. When made from such yarns, the nonwoven fabrics are characterized by a high strength, a particularly low elongation and good resistance to deformation, making them eminently suitable for use as industrial fabrics. Other desirable fabrics may be made from textured or interlaced continuous-filament yarns of types disclosed in Breen U.S. Patent No. 2,783,609 dated Mar. 5, 1957, and Bunting and Nelson U.S. Patent No. 2,985,995 dated May 30, 1961. Yarns from staple fibers may also be used. Other desirable products may be made by employing yarns whose individual fibers or filaments are highly crimped and/or are elastic or have a latent ability to elongate, crimp, shrink or otherwise change in length, which latent property is subsequently activated so as to alter the free length of the fibers. Depending on the fineness of the pattern, or following such after-treatments as shrinkags, development of fiber-crimp or the like, apertures and the ordered arrangement of yarns to form the pattern may or may not be readily apparent upon visual inspection with the naked eye. However, they will be readily discernible when magnified, as with a microscope.

At the intersections of yarn bundles, as illustrated in FIGURES 3 and 4, individual yarns can be seen crossing over from one bundle to another in random fashion. There is also a high degree of fiber entanglement in these areas.

The fiber interaction which occurs at the intersections locks the yarns into place without the need for binder or other supplementary treatment. This fiber interaction is complex and random.

By "locked into place" is meant that individual yarns of the structure not only have no tendency to move from their respective positions in the patterned structure, but are physically restrained from such movement to such an extent that breakage of fibers will occur when yarns are pulled free.

In the products of the present invention, the fiber interaction is one in which the individual yarns pass around and over one another at random in interlacing fashion as they pass through the intersection and are also highly compacted with respect to one another so that the intersection is an area of high density. The interaction of the fibers in the densely-packed intersection causes the fibers to cooperate with, act upon, and interlock with one another when the fabric is subjected to stress to thereby provide coherency and strength. Because the yarns have been locked into position in the fabric, the fabric pattern remains stable. For example, a strip of the illustrated entangled, triangular-mesh-patterned fabric, when subjected to stress in a conventional fabric-tensile-strength test in the absence of any binder, retains its triangular-mesh-pattern until the fabric eventually ruptures. Moreover, when the linking bundles contain approximately the same number of fibers or filaments, the strength is approximately the same in all directions because of the unique triangular-mesh-pattern.

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

APPARATUS

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

A pump, 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 is used to provide uniform pressure.

Liquid at the uniform high pressure is supplied 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 manifold 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 may be used beneath the carrier belt and in line with the orifice manifolds to help remove liquid during high-speed treatment.

Preferred products of the present invention are produced by a rapid, inexpensive process for the continuous preparation of patterned nonwoven fabrics which involves continuously depositing a plurality of continuous-filament yarns on an apertured-patterning-member to form a random web thereon, continuously conveying the thus supported web to a treating zone wherein the yarns are entangled into a coherent fabric with fine columnar streams of liquid at high-energy-flux, drying the thus obtained fabric and continuously winding it up to form a package. Yarn deposition is preferably done by means of a traversing air-aspirating jet. For high strength products drawn yarns are preferred. The air jet may perform the added function of drawing the yarn or the yarn may be drawn in a separate step by conventional means, such as draw rolls, and then be deposited on the patterning member by an air jet.

FIGURE 8 is a schemtaic illustration of one form of apparatus for preparing a random web of yarn. Yarn **50** is supplied from a suitable source and may come directly from a spinning operation or from a separate drawing process. The drawing shows the yarn coming from a package **51** through yarn guide **52**. The yarn passes through jet apparatus **53**, of conventional type, and is forwarded by a jet of air into chamber **54**. A conveyor belt **55** forms the bottom of the chamber. The belt travels continuously in the direction indicated by the arrow, and is supported by rollers **56**. The yarn falls through the chamber in random folds, as shown, and is deposited on the belt to form web **57**. Although not shown, jet apparatus **53** should include oscillating means for directing the yarn from side to side of the web being produced. Deposition of the yarn is assisted by using a screen conveyor belt to provide for escape of air from the chamber, which may be assisted by a suction hood **58**. The conveyor belt may be the patterning member, on which the web is to be treated, and may proceed through the apparatus illustrated in FIGURE 2.

FIGURE 9 illustrates another form of jet apparatus which can be used to form the yarn web. Yarn **50** from a suitable source (not shown), passes over a roller **60** and downward into the jet apparatus. This apparatus has an outer housing **61** within which is an annular block **62** supported on bearing **63**. An annular seal **64** prevents leakage of air through the bearing. Air introduced into the housing through pipe **65** flows into passageway **66** through the center of block **62** and downward into yarn tube **67**, which is secured to the block and forms a continuation of the passageway **66** therethrough. A funnel-shaped guide **68**, in the housing at the upper end of the passageway, directs the yarn and air downward through the block and into the tube. The yarn is carried through the tube by the flowing air and deposited on a conveyor belt **69**. Tube **67** is bent at **70** so that rotation of block **62** causes the yarn to be deposited in loops as shown. The tube may be bent at **71** so that the air discharge rotates the block, or a positive drive can be provided.

PROCESSING CONDITIONS

Patterned, entangled fabrics are produced in accordance with this invention by a process in which yarns 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 areas 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%). A yarn web is supported on the patterning member and is traversed with fine, essentially columnar streams of liquid, such as water, until the yarns are rearranged into groups extending between and intersecting at the apertures of the patterning member, in an ordered pattern, and are entangled to lock the yarns into position in this pattern. In order to adequately entangle the yarns, a stream or streams must be impinged on the batt at an energy flux of at least 23,000 foot-poundals/square inch-second and in order to avoid excessive treatment times, the streams should be formed by jetting liquid from orifices at high pressure. The liquid should be supplied to the jets at a pressure of at least 200 pounds per square inch (14.1 kg./cm.^{2}) above atmospheric pressure (hereinafter abbreviated p.s.i.g.), and 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 0.007 inch (0.0076 to 0.0178 cm.) in diameter with orifice-to-web 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° to 99° C. is suitable.

The initial web may consist of one or more yarns disposed in random relationship with one another or in some degree of alignment, such as might be produced by positioning the yarns back and forth on a conveyor or the like. The fibrous elements may be of any natural, cellulosic, and/or wholly synthetic material. The initial web may be made by an desired technique, such as by random laydown, air deposition, etc. It may consist of

yarn blends or blended yarns containing fibers of different types and/or sizes. If desired, an assembly of webs may be used. The initial web may include coarse fabric or other reinforcing material, which is incorporated into the final product by the treatment. Additionally useful products may be obtained by utilizing yarns of highly crimped fibers or fibers which have a latent ability to elongate, crimp, shrink or the like and then, after the formation of the patterned textile, developing the latent properties of the fibers. The processibility of stiff yarns 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 products is desired. The aperatures 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 yarns of the web being treated to move into an entangled yarn 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 patterned and entangled 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 non-planar 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 screens 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 0.025 inch (0.0127 to 0.0635 cm.), and having from about 10% to about 98% open area. Other examples are perforated metal plates having 25 to 4000 circular holes per sq. in. (3.8 to 620 holes per sq. cm.) 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. Perforater 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 lateral 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.

In operating the process, as illustrated in the examples, 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 loose initial web is placed on the selected apertured backing member, and the assembly is moved, web 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 yarns to move in the general direction of the nearest aperture while simultaneously forcing segments of the individual yarns to move into and about other yarns and about themselves as they bridge the gap of the aperture, until the yarns overlap and interlace with one another in the area overlying each aperture, the overlapping and interlaced portions being interlocked with one another by entanglement. During this impingement, portions of a given yarn may be caused to move toward one aperture while other portions of the same yarn are caused to move to one or more different apertures. As the impingement continues, that portion of the yarn which extends between adjacent apertures is reduced in length as portions over the apertures are driven into tighter and tighter entanglement with themselves and other yarns. Thus, the yarns 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 yarns arranged in an ordered geometric pattern of intersecting yarn bundles locked together at their intersections solely by fiber interaction. The ordered groups of yarns 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 interlaced and locked with one another at each intersection. The individual yarns may be seen as they pass through the intersection and migrate randomly from bundle to bundle. Since the yarns substantially maintain their continuity and identity as they pass through the intersections in the plane of the fabric, particular advantage is gained from the cooperation of the aligned filaments of the yarn. Thus the fabric has high strength, coupled with low elongation and good resistance to deformation.

When using a nonplanar apertured patterning member, such as a screen woven of heavy wire and having a relatively coarse mesh, a plate having protrusions thereon, or any other patterning member whose surface is characterized by the presence of channels or grooves, the high energy-flux streams force the yarns 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 yarn web is placed on such a screen and treated with high energy-flux liquid streams, the individual yarns or portions thereof are caused to move into the channels and to be consolidated with one another along the channels. In general, some yarns tend to move toward the lowest portion of the screen, i.e., into the deepest channels. As these channels become filled, yarns are caused to move into other channels of lesser original depth. Accordingly, the ultimate structure is of a layered or multilevel configuration. During their movement into the various levels of the screen, the yarns at certain localized regions are caused by the high-energy-flux streams to entangle with one another.

The ultimate fabric is one having ridges (corresponding to channels in the screen) on at least one surface, usually the surface adjacent the screen during processing. If the screen channels are sinuous, the fabric ridges will also be sinuous and will retain this configuration permanently in the fabric. Sinuous ridges are formed, for example, on the above-described screens having high- and low-crimped wires and result from the sinuous channels formed in the screen by the staggered protrusions of the high-crimped wires. The skeletal continuum of a fabric produced on such a screen may be formed of straight bundles of substantially parallelized yarns running along the fabric and sinuous bundles of yarns running transverse to the straight bundles, the bundles being in different zones or levels in the thickness of the fabric and being united across the fabric as well as in depth by fiber interaction where the bundles meet or intersect. The straight bundles and the sinuous bundles cooperate with the intersections to define apertures. In still other fabrics of this type, alternate apertures are partially or completely filled by variously disposed yarns so that when viewed from one face, the fabric has a repeating pattern of substantially rectangular groups of yarn, the rectangles being diagonally interconnected with one another and alternating in staggered arrangement with the apertures of the fabric.

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. The fabrics can be treated to fuse or otherwise bond the fibers, either at discrete regions or throughout the product.

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,

$$EF_i = 77\ PG/a$$

where:

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

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.g. can provide sufficient energy flux for several inches when using a highly efficient jet device. With other jet devices, the energy flux of a stream may become too low in a relatively short distance even when using higher pressures, due to tthe 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 Examples 1 to 8 are given in Table I.

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 web, batt or sheet of yarns. 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 ease with which a web can be processed. Factors which influence fiber mobility include, for example, the density, modulus stiffness, surface-friction properties, denier and/or length of the fibers in the yarns. In general, yarns from fibers which are highly wettable, or have a high degree of crimp, or have a low modulus or low denier, can also be processed more readily. Yarns having zero twist process more readily than do highly twisted yarns.

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

TABLE I.—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.g., stream density (a/A)	0.0758	0.0625	0.0545
200 p.s.i.g., energy flux	85,000	70,000	61,000
500 p.s.i.g., stream density (a/A)	0.0758	0.0522	0.0405
500 p.s.i.g., energy flux	330,000	230,000	180,000
1,000 p.s.i.g., stream density (a/A)	0.0758	0.0441	0.0349
1,000 p.s.i.g., energy flux	940,000	540,000	430,000
1,500 p.s.i.g., stream density (a/A)	0.0758	0.0405	0.0304
1,500 p.s.i.g., energy flux	1,720,000	920,000	690,000
For 5 Mil Orifice Diameter:			
200 p.s.i.g., stream density (a/A)	0.241	0.103	0.0758
200 p.s.i.g., energy flux	270,000	115,000	88,000
500 p.s.i.g., stream density (a/A)	0.214	0.0763	0.0565
500 p.s.i.g., energy flux	930,000	330,000	250,000
1,000 p.s.i.g., stream density (a/A)	0.190	0.0595	0.0108
1,000 p.s.i.g., energy flux	2,340,000	730,000	130,000
For 7 Mil Orifice Diameter:			
200 p.s.i.g., stream density (a/A)	0.357	0.125	0.0563
200 p.s.i.g., energy flux	400,000	140,000	63,000
500 p.s.i.g., stream density (a/A)	0.281	0.097	0.037
500 p.s.i.g., energy flux	1,225,000	421,000	162,000
1,000 p.s.i.g., stream density (a/A)	0.236	0.079	0.0196
1,000 p.s.i.g., energy flux	2,910,000	972,000	242,000
1,500 p.s.i.g., stream density (a/A)	0.236	0.0645	0.0125
1,500 p.s.i.g., 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 inch² second. Such streams are preferably obtained by propelling a suitable, noncompressible fluid, such as water, at high pressure through small-diameter orifices under conditions such that the emerging streams remain essentially columnar at least until they strike the initial material. By "essentially columnar" is meant that the streams have a total divergence angle of not greater than about 5 degrees. Particularly strong and surface-stable, 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.

Depending upon the nature of the initial yarn web 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.

When treating fibrous material with streams of water impinged on the material at an energy flux (EF) of at least 23,000 ft.-poundals/in.^{2} sec., patterned, highly entangled nonwoven fabrics can be prepared at expenditures of total energy (E) of at least 0.2 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 piling 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.

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 yarns, and is less for 66-nylon than for acrylic yarns and polypropylene yarns. Using the same fiber composition and length, yarns of small denier are more readily entangled than higher denier yarns. Using the same fiber composition and denier, shorter yarns are more readily entangled than longer yarns. Using the same fiber composition, denier and length, yarns having greater crimp frequency and amplitude of crimp are entangled more readily than less crimped yarns.

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.

In general, webs having a weight ranging from 0.25 oz./yd.^{2} (8.5 gm./M^2) or less to about 12 oz./yd.^{2} (406 gm./M^2) or more and composed of yarns of natural, cellulosic, and/or wholly synthetic fibers, can be readily converted into patterned fabrics through the use of water as the fluid and process conditions within the following ranges:

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

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

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/sq. 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: 10% to 98%
Aperture Size: 0.01 to 0.25 inch (0.025–0.63 cm.)

If the 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 or the like, may also be produced 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 reproduced by blocking out selected portions of the backing member used in the production of the nonwoven fabric.

In the following examples, which illustrate specific nonwoven fabrics of this invention and processes for producing them, 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. 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 & Materials (A.S.T.M.) Standards E6–61, part 10, page 1836. 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 values are determined by the test described at the end of the specification.

EXAMPLE 1

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

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 132 holes/sq. in. (20.4 holes/cm.^{2}) and 41% open area, the holes being 0.063-inch (0.160-cm.) in diameter and arranged on 0.094-inch (0.238-cm.) staggered centers. The thus formed web, while supported by the plate, is then treated with high-energy-flux streams of water emerging from 0.005-inch (0.0127-cm.) orifices, using apparatus of the type shown in FIGURE 1. The web is first wetted by placing a fine-mesh top screen on it and then passing the assembly under the streams. The top screen is then removed and the web is passed under the streams at water pressures up to 1200 p.s.i.g. (84.5 kg./cm.^{2}). Then, using the same type of apparatus with a manifold having 0.007-inch (0.0178-cm.) orifices, the web is further treated at pressures up to 1200 p.s.i.g. (84.5 kg./cm.^{2}). Passes are made both along and across the web.

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-intertanglement of those sections of the yarns passing through the apexes, the identity of individual yarns is still discernible within that region. The product has a fiber-interlock value of 16.6.

EXAMPLE 2

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

(A) 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 to a second yarn 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 about 1 foot (0.3 meter) beneath the pulley. The patterning plate is shown in FIGURE 6. It has 25 holes/sq. in. (3.8 holes/sq. cm.) and 46% open area, the holes being 0.156-inch (0.397-cm.) in diameter and arranged on staggered centers.

Using apparatus of the type shown in FIGURE 1, the web is treated with streams issuing from 0.005-inch (0.0127-cm.) orifices. During initial treatment a top screen having 726 holes/sq. in. (110.3 holes/sq. cm.) 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.g. (14.08, 28.16, 42.24, 70.4, and 105 kg./cm.^{2}). 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.g. (7.04 kg./cm.^{2}), eight passes at 200 p.s.i.g. (14.08 kg./cm.^{2}), eight passes at 400 p.s.i.g. (28.16 kg./cm.^{2}), eight passes at 600 p.s.i.g. (42.24 kg./cm.^{2}) and two passes at 1000 p.s.i.g. (70.4 kg./cm.^{2}). The fabric is then removed from the patterning plate and dried.

The fabric has the following properties:

	M.D.	Bias
Strip tensile strength:		
(lbs./in.)/(oz./yd.^{2})	14	12
(g./cm.)/(g./m.^{2})	73	63
Elongation, percent	35	35
Modulus (5% secant):		
(lbs./in.)/(oz./yd.^{2})	22	3
(g./cm.)/(g./m.^{2})	116	16
Fiber-interlock value	50	

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

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, as illustrated at 8× magnification in FIGURE 3 (upstream face) and FIGURE 4 (downstream face). 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 such areas.

(B) A nonwoven fabric is prepared as in (A) above except that the passes and pressures used during treatment without a top screen are as follows: 8 passes at 200 p.s.i.g., 8 at 400, 8 at 600, 8 at 1000, and 8 at 1500. Fiber-interlock value of the fabric is 29.6.

(C) A nonwoven fabric is prepared as in (B) except using 8 passes at 200 p.s.i.g., 8 at 400 and 8 at 1000. Fiber-interlock value is 40.7.

(D) A nonwoven fabric is prepared as in (B) except using 4 passes at 200 p.s.i.g., 4 at 400, 4 at 1000 and 4 at 1500. Fiber-interlock value is 24.4 (one specimen tested in each of two directions).

EXAMPLE 3

A random web is prepared as described in Example 2A except that the patterning plate (FIGURE 6) is lowered with respect to the motor-driven pulley so that the yarn falls a greater distance (about 6 ft.) before being deposited on the plate. The thus obtained random web of 40 denier, 27 filament yarn is then treated, while still on the patterning plate, with high-energy-flux streams of water

as described in Example 2A except that the number of passes and water pressures are as follows:

Treatment with top screen:
- 8 passes at 200 p.s.i.g.
- 8 passes at 400 p.s.i.g.
- 8 passes at 600 p.s.i.g.
- 8 passes at 1000 p.s.i.g.
- 4 passes at 1500 p.s.i.g.

Treatment after removal of top screen:
- 8 passes at 200 p.s.i.g.
- 12 passes at 400 p.s.i.g.
- 12 passes at 1000 p.s.i.g.

A triangular-mesh-patterned fabric is obtained which is similar to that of Example 2A. A portion of the fabric is shown at 10× magnification in FIGURE 5. In the figure, the individual yarns passing through the apexes of the triangles can be clearly seen. The yarns are firmly joined together at the apexes by entanglement.

EXAMPLE 4

This example illustrates the preparation of a triangular-mesh-patterned fabric directly from continuous-filament yarns deposited by means of an air jet.

A 40 denier, 27 filament, zero twist, polyethylene terephthalate continuous-filament yarn is fed from a bobbin, over a yarn guide, and through an air aspirating jet by which it is forwarded onto a conveyor belt moving beneath the jet as illustrated in FIGURE 8. The aspirator jet is arranged to move in an arc so that the yarn traverses the belt as the belt passes under the jet. Belt speed is about 6 inches (15.24 cm.) per minute and air jet pressure is about 85 p.s.i.g. (5.98 kg./cm.^{2}).

The web of continuous-filament yarn thus obtained is doubled on itself and the two-ply web is placed on a patterning plate having 57 holes/sq. in. (8.8 holes/cm.^{2}) and 49% open area, the holes being arranged on staggered centers and having a diameter of 0.100 inch (0.254 cm.). Using apparatus of the type shown in FIGURE 1, the web, while on the plate, is treated with streams of water issuing from 0.005 inch (0.0127 cm.) orifices. During initial treatment a top screen (60×60 wires/inch) [23.6×23.6 wires/cm.] is placed on the web and the assembly is passed under the streams four times at each of the following pressures: 200, 500, 1000, and 1500 p.s.i.g. (14.08, 35.2, 70.4, and 105 kg./cm.^{2}). 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: 8 passes at 100 ps.i.g. (7.04 kg./cm.^{2}), 12 passes at each of 200, 400, and 500 p.s.i.g. (14.08, 28.16, and 35.2 kg./cm.^{2}), and 4 passes at 1000 p.s.i.g. (70.4 kg./cm.^{2}).

The fabric is then removed from the plate and dried. The triangular-mesh-paterned fabric thus obtained is similar in appearance to that described in Example 2A. It has a high degree of entanglement, as evidenced by a fiber interlock value of 44.6. The uniformity of the initial web and hence of the final product is improved by the use of the traversing aspirating jet to deposit the yarn.

In continuous production, the yarn is fed directly from its spinning unit over suitable guides to a drawing device and then to the aspirating jet. The web is formed on a conveyor belt having the desired arrangement of apertures to serve directly as the patterning member. The belt then carries the web to the patterning zone where the web is treated with high-energy-flux streams of water as illustrated in FIGURE 2. The patterned fabric is then passed through a drying device and is continuously wound up to form a package.

EXAMPLE 5

This example illustrates the preparation of a hexagonal-mesh-patterned fabric directly from continuous-filament yarns.

A yarn web is prepared as described in Example 4. A single thickness of the web is placed on a specially modified patterning plate. Originally, the plate has 261 holes/sq. in. (40.5 holes/cm.²) and 50% open area, the holes being arranged on staggered centers and having a diameter of 0.049 inch (0.125 cm.). It is modified by plugging one-third of the holes with a small metal insert having a shaft portion connected and axially aligned with a cone portion. The shaft is 0.2 inch (0.51 cm.) long and 0.049 inch (0.125 cm.) in diameter; the cone is 0.2 inch (0.51 cm.) high and has a diameter of 0.082 inch (0.208 cm.) at the base. The shaft is inserted in the appropriate hole of the patterning plate so that the conical portion of the insert protrudes from the plate and serves to deflect the liquid streams as they impinge on web-covered plate. The arrangement of the cones in the plate is shown in FIGURE 7. In the drawing, the dashes show the hexagon pattern.

Using apparatus of the type shown in FIGURE 1, the web, while on the plate, is treated with streams of water issuing from 0.005 inch (0.0127 cm.) orifices. The web is subjected to 8 passes at 50 p.s.i.g. (3.52 kg./cm.²), 8 passes at 150 p.s.i.g. (10.56 kg./cm.²), and 12 passes at each of the following pressures: 200, 300, 400 and 1000 p.s.i.g. (14.08, 21.12, 28.16 and 70.4 kg./cm.²). The patterned fabric is then removed from the plate and dried. It is observed that a clear hexagonal-patterned arrangement of fibers is formed by bundles of yarn which follow the paths shown by the dashes in FIGURE 7 and are entangled with one another where they meet in areas overlying the holes in the patterning plate. The fabric is firmly entangled at intersections of the yarn bundles, as evidenced by a fiber-interlock value of 32 (one specimen tested in one direction only), but the individual yarns can still be seen as they pass through these entangled areas.

EXAMPLE 6

This example illustrates the preparation of triangular-mesh-patterned fabrics from low denier continuous-filament yarn.

(A) An 18 denier, 12 filament, zero twist, polyethylene terephthalate continuous-filament yarn is fed from a bobbin over a yarn guide and through an air-aspirating-jet by which it is deposited on an apertured patterning plate moved by hand beneath the jet. The aspirator jet is arranged to move in an arc so that the yarn traverses the plate as the plate is passed under the jet. The yarn has a tenacity of 5.0 g.p.d. (45 g./tex.), an elongation of 23.6%, and an initial modulus of 105 g.p.d. (945 g/tex.).

The patterning plate has 33 holes/sq. in. (5.1 holes/cm.²) and 63% open area, the holes being arranged on staggered centers and having a diameter of 0.156 in. (0.396 cm.).

Using apparatus of the type shown in FIGURE 1, the web, while on the plate, is treated with streams of water issuing from 0.007 inch (0.0178 cm.) orifices drilled into a manifold at a spacing of 14 holes/inch (5.5 holes/cm.). During treatment the web is kept at a distance of about 1.5 inch (3.81 cm.) from the orifices. A coarse-mesh wire screen is placed on top of the web during treatment to help hold the web in place; it has no influence on the patterning. The treatment involves passing the assembly under the streams for a total of 8 passes at each of the following pressures: 300, 500 and 1000 p.s.i.g. (21.12, 35.2, and 70.4 kg./cm.²) and finally for 18 passes at 2000 p.s.i.g. (140.8 kg./cm.²). The triangular-mesh-patterned fabric thus obtained is then removed from the plate and dried. It has a fiber-interlock value of 48.8 (2 specimens tested in each of 2 directions). Properties of the fabric are given below:

	M.D.[1]	Bias [2]
Weight:		
(oz./yd.²)	2.5	2.5
(g./m.²)	84.7	84.7
Tensile strength:		
(lb./in.)/(oz./yd.²)	9.8	11.8
(g./cm.)/(g./m.²)	51.5	62.1
Elongation, percent	30	30
5% Secant modulus:		
(lb./in.)/(oz./yd.²)	4.0	1.8
(g./cm.)/(g./m.²)	21.0	9.5

[1] M.D.=Measured along yarn bundles.
[2] Bias=Measured 90° to M.D.

(B) A 22 denier, 13 filament, polyethylene terephthalate, continuous-filament yarn is used to make a web of randomly disposed yarn on a patterning plate having 33 holes/sq. in., in staggered array, the plate having 63% open area. A 5-inch long manifold, having 0.007-inch diameter orifices, spaced 14 orifices/inch is used and a top screen is placed over the web during all passes. Orifices are 1.5 inches above the web. The web is treated with the streams of water for 30 seconds at 500 p.s.i.g., 30 sec. at 1000 p.s.i.g., 30 sec. at 1500 p.s.i.g., and finally, 60 sec. at 2000 p.s.i.g. Total water flow is 33 gallons/sq. yd. of fabric. Fiber-interlock value is 19.4 (two specimens tested in each of 2 directions).

(C) A yarn as in (6B) is used to make a web of randomly disposed yarn on a patterning plate having 132 holes/sq. in. in staggered array, the plate having 41% open area. An 8-inch long manifold having 0.005-inch diameter holes drilled therein in line at a frequency of 40/inch is used and a top screen is placed over the web during all passes. The orifices are 1.5 inches above the web. The web is treated with the streams of water for 30 seconds at 500 p.s.i., 30 sec. at 1000, 30 sec. at 1500, and 60 sec. at 2000 p.s.i. Total water flow is about 100 gallons/sq. yd. of fabric. Fiber-interlock value is 14.8 (2 specimens tested in each of 2 directions).

EXAMPLE 7

This example illustrates the preparation of a triangular-mesh-patterned fabric from the same yarn as in Example 6A, the pattern being of a finer mesh.

A web is prepared on a patterning plate as described in Example 6A except that the patterning plate used has 132 holes/sq. in. (20.4 holes/cm.²) and 41% open area, the holes being arranged on staggered centers and having a diameter 0.063 inch (0.16 cm.) Using apparatus of the type shown in FIGURE 1, the web, while on the plate, is treated with streams of water issuing from 0.005 inch (0.0127 cm.) orifices spaced 40/inch (15.8/cm.). During treatment the web is spaced about 1.5 inch (3.81 cm.) from the orifices. Using a coarse-mesh top screen as in Example 6A, the assembly is passed under the streams 8 times at each of the following pressures: 300, 500, 1000, 1500 and 2000 p.s.i.g., (21.12, 35.2, 70.4, 105, 140.8 kg./cm.²). The top screen is then removed and the assembly is subjected to 8 passes under the streams at each of 500, 1000 and 1500 p.s.i.g. (35.2, 70.4, and 105 kg./cm.²). The fabric is then removed from the plate and dried. It has a fiber-interlock value of 27.7 (2 specimens tested in each of 2 directions). Properties are given in the table below:

	M.D.[1]	Bias [2]
Weight:		
(oz./yd.²)	2.4	3.2
(g./m.²)	81.3	108.5
Tensile Strength:		
(lb./in.)/(oz./yd.²)	5.1	5.2
(g./cm.)/(g./m.²)	26.9	27.4
Elongation, percent	31	34
5% Secant modulus:		
(lb./in.)/(oz./yd.²)	2.7	3.0
(g./cm.)/(g./m.²)	14.2	15.8

[1] M.D.=Measured along yarn bundles.
[2] Bias=Measured 90° to M.D.

The use of a low denier continuous-filament yarn as in Examples 6 and 7 permits the preparation of fabrics having improved surface stability. In addition, the low denier yarns can be converted into a finer mesh fabric, than can the heavy denier yarns, when using a given weight of web material.

EXAMPLE 8

This example illustrates the preparation of multilevel, mesh-patterned fabrics from an interlaced yarn, using a wire screen as the patterning support to form a fabric having a mesh pattern wherein regions comprised of groups of yarns alternate in staggered array with the apertures of the fabric.

(A) A 37 denier, 27 filament, zero twist, polyethylene terephthalate continuous-filament yarn is treated to lightly intermingle the filaments along the length of the yarn by passing the yarn through fluid vortices as described in Bunting et al., U.S. Patent No. 2,985,995, dated May 30, 1961. The interlaced yarn has a tensile strength of 4.7 g.p.d. (42.3 g./tex.) and an initial modulus of 101 g.p.d. (909 g./tex.).

A web is prepared from this yarn by the technique described in Example 6A, except that it is prepared on a 10-mesh (3.9 wires/cm.), plain weave, wire screen having 34% open area and woven from wires having a diameter of 0.041 inch (0.104 cm.). The wires running in one direction have a low crimp amplitude, forming minor protrusions in that direction; the wires running transverse thereto have a high crimp amplitude to form major protrusions in the transverse direction.

Using apparatus of the type shown in FIGURE 1, the web, while on the screen, is treated with streams of water issuing from 0.005 inch (0.0127 cm.) orifices spaced 40/inch (15.8/cm.). During treatment the web is kept at a distance of about 1 inch (2.54 cm.) from the orifices. The treatment involves passing the assembly under the streams for a total of 4 passes at 500 p.s.i.g. (35.2 kg./cm.^{2}) and then for 8 passes at each of 1000, 1500, and 2000 p.s.i.g. (70.4, 105, and 140.8 kg./cm.^{2}) The fabric is then removed from the screen and dried. The fabric has a mesh-pattern wherein regions of substantially rectangular shape composed of intermingled yarns are joined together diagonally by entangled areas. Between the rectangular yarn regions, and staggered with respect to the yarn regions, are apertures corresponding to the position of protruding wire crimps in the screen. Although there is a high degree of interentanglement of those sections of the yarns passing through the intersections (i.e., the entangled areas), the identity of the individual yarns is still discernible within the intersection.

Properties of the fabric are as follows—

Weight:	
(oz./yd.^{2})	2.58
(g./m.^{2})	87.5
Tensile strength:	
(lb./in.)/(oz./yd.^{2})	4.8
(g./cm.)/(g./m.^{2})	25.2
Elongation, percent	49
5% secant modulus:	
(lb./in.)/(oz./yd.^{2})	0.57
(g./cm.)/(g./m.^{2})	3.0
Tongue-tear strength (average):	
[lbs./(oz./yd.^{2})]	3.25
[g./(g./m.^{2})]	43.4
Fiber-interlock value (one specimen tested in each of 2 directions)	11.5

The arrangement of yarns in this fabric will be better understood from the following discussion. The crimped wires provide the screen with a surface having channels or grooves running along and across the screen at different depths. Treatment of the yarn web on this screen causes the yarns to be realigned and simultaneously entangled to form an apertured fabric which has a basic skeletal structure formed of groups of yarns which proceed along and across the fabric at different levels. These yarn groups are united with one another across the fabric and throughout the thickness of the fabric by interaction of the yarns occurring particularly in the entangled areas. These are the areas which overlie the holes in the screen during treatment. When viewed from its top face (i.e., the face nonadjacent the screen during treatment), the fabric has a repeating pattern of generally rectangular areas interconnected diagonally by the entangled areas and cooperating with the entangled areas to define substantially oval apertures. Individual yarns maintain their identity and continuity as they wander randomly from area to area in the plane of the fabric. In their random paths, the yarns overlap and interlace with one another many times, especially at the intersections, i.e., the entangled areas. Yarns and/or groups of yarns at times appear to loop down into the fabric; often, the entangled areas appear to be covered by yarns which loop over the area and disappear into the fabric along the edges of the apertures. When viewed from its bottom face (i.e., the face adjacent the screen during treatment), the fabric has protruding, ordered groups of yarns forming ridges on that face of the fabric. The ridges follow sinuous paths along the fabric and are parallel and 180° out of phase with respect to each adjacent ridge. These ridges correspond to sinuous channels in the screen formed by the staggered arrangement of the crimped-wire protrusions. Along the bottom face, individual yarns may be seen to wander randomly from ridge to ridge within the basic skeletal structure. From this face it is also possible to see, deep within the fabric, substantially parallelized yarns running between the entangled areas in a direction generally perpendicular to the sinuous ridges. These yarns actually lie beneath the rectangular areas which are visible from the top face of the fabric.

(B) A 40 denier, 27 filament, polyethylene terephthalate, continuous-filament yarn, lightly interlaced, is used to form a web of randomly disposed yarn on a 15 mesh wire screen (15 wires/inch, 15% open area, 0.041-inch diameter wire). The web is treated, without any top screen, using an 8-inch long manifold having 0.005-inch diameter orifices drilled in it in a single line at a frequency of 40 orifices/inch. The orifices are 1 inch above the web. Processing under the water streams includes 8 passes at 500 p.s.i.g., 8 at 1000, 8 at 1500, and 8 at 2000; the fabric is then turned over on the screen, without attempting to maintain registry of the fabric pattern with the screen pattern, and is then treated with 4 passes at 500 p.s.i.g., 2 at 1000 p.s.i.g., and 8 at 2000 p.s.i.g. Fiber-interlock value is 24.1 (2 specimens tested in each of 2 directions).

EXAMPLE 9

This example compares a hydraulically patterned and entangled nonwoven fabric prepared from unopened, continuous filament yarn with one prepared from opened, continuous filament yarn.

Web A is prepared by depositing unopened yarn in random fashion on a patterning plate having 33 holes/inch^2 and 63% open area, the holes being in staggered array. The yarn is a 70 denier, 34 filament, zero twist, semi-dull yarn made up of nylon continuous filaments which are lightly interlaced with one another in the yarn. The web thus obtained is made up of the randomly disposed, unopened yarns.

Web B is prepared in the same manner as web A except that in depositing the yarn, electrostatic forces are used in order to separate the filaments from one another and thereby form a web of randomly disposed, individual filaments.

Each web is then converted into a patterned, entangled nonwoven fabric by treating the web, while on the patterning plate, with streams of water issuing from a manifold having 0.005-inch diameter orifices arranged in line at a frequency of 40 orifices/inch. The orifices are spaced

0.75 inch above the web during treatment and the web is moved under the streams at 2 yards/minute. A top screen is placed over the web to help hold the web in place, during one pass at 200 p.s.i. and one at 300 p.s.i. The top screen is then removed and the web is treated with 1 pass at 300 p.s.i., 1 at 500, 2 at 1000, and 2 at 1500 p.s.i. Properties of the nonwoven fabrics prepared from web A and from web B are given below:

Property (Average of M.D. and X.D.)	A (from unopened yarn)	B (from opened yarn)
Weight (oz./yd.^{2})	3.7	4.5
Fiber-interlock value, g./(g./m.^{2})	38	62
Tenacity (lb./in.)/(oz./yd.^{2}):		
1 inch [1]	19	21
0.5 inch [2]	14	19
Elongation at break (percent):		
1 inch [1]	44	73
0.5 inch [2]	42	71
5% Secant modulus (lb./in.)/(oz./yd.^{2}):		
1 inch [1]	8.8	2.1
0.5 inch [2]	5.5	2.6

[1] Determined using one inch wide test specimen.
[2] Determined using 0.5 inch wide test specimen.

Strong, patterned nonwoven fabrics are prepared in both instances. The product prepared from the unopened yarns has 2 to 4 times the modulus of the filament nonwoven, and from 50 to 75% of the breaking elongation.

Further novel effects may be obtained by choice of the initial fibrous layer and processsing conditions. For example, decorative fabrics may be made by patterning and entangling 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 flameproofing agent, an adhesive or other treating agent.

The products of the present invention have many applications. They may be employed in the same uses as are conventional fabrics. Typical applications include use in apparel backings, home furnishings, upholstery and other decorative materials, tarpaulins, padding and/or insulating materials, covering materials, and the like. They may be laminated to similar sheets or to different materials. Interesting packaging materials are made, for example, by laminating patterned, entangled fabrics to metal foils or films. The patterned, entangled fabrics may be cut into strips, if desired, and twisted to provide novelty products. The high strength, patterned, entangled fabrics are particularly suited for industrial applications such as bagging materials, reinforcing materials for rubber or other goods such as belting and the like.

FIBER-INTERLOCK TEST

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

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

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

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

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

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

We claim:

1. The process for preparing patterned nonwoven fabrics from multifilament yarns which comprises collecting yarn in a layer in which the yarn retains its identity and is free to move sideways, supporting the layer on an apertured patterning member having apertures in an ordered arrangement corresponding to the desired fabric pattern, 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-poundals/inch^2 second at the treatment distance, traversing the supported layer of yarn with the streams to form a fabric having entangled areas interconnected by yarn in a repeating pattern determined by the apertured supporting member, and treating the supported layer with the streams until the starting yarn is locked into place in entangled areas of the fabric in a uniform pattern of intersecting yarn groups wherein individual yarns of the groups overlap and interlace with one another at intersections of the groups and substantially maintain their identity as they pass from intersection to intersection, and individual fibers are so entangled at the intersections that fibers interlock with one another when the fabric is subjected to stress to thereby provide coherency and strength.

2. A process as defined in claim **1** wherein yarn is forwarded onto the apertured patterning member to form a layer and the layer of yarn is then treated on the patterning member with the liquid streams to form the fabric.

3. The process defined in claim **1** and which comprises forwarding yarns toward the surface of a screen having closely-spaced apertures arranged in a repeating pattern, depositing the yarns on the surface to form a web of yarns which proceed randomly through the web and are free to move sideways, and traversing the web, supported on the surface, with fine, essentially columnar streams of liquid to form a fabric having entangled areas which overlay said apertures and are interconnected by yarns in a regular pattern, said liquid streams being formed at a pressure of at least 200 p.s.i.g. and being impinged on the web at an energy flux greater than 23,000 foot-poundals/inch^2 second during at least a part of the treatment to lock the yarns in place in the entangled areas of the fabric.

4. The process defined in claim **1** and which comprises depositing the yarns in a loose layer on an apertured patterning surface having small openings arranged in a pattern corresponding to the location of entangled areas in the fabric product and of a size which provides a total open area in said pattern of 10% to 98%, traversing the supported layer with fine, essentially columnar, liquid streams formed at a pressure of at least 200 p.s.i.g which impinge on the layer at an energy flux greater than 23,000 foot-poundals/inch^2 second until the yarns are extended between the openings and are locked into place by entangled areas in a uniform pattern determined by the patterning surface, and then bonding the fabric.

5. The process as defined in claim **1** for preparing a patterned nonwoven fabric from a layer of loose multifilament yarns deposited randomly on a collecting surface to form a web weighing 0.25 to 12 oz./sq. yd. which comprises supporting the random yarn web on an apertured patterning surface which has about 25 to 4000 apertures per square inch of patterning area arranged in a uniform pattern, the apertures being 0.01 to 0.25 inch in diameter and providing a total of 35% to 65% open area in said patterning area, traversing the supported web with fine, essentially columnar streams of water from orifices 0.003 to 0.030 inch in diameter, supplied with water at 500 to 5000 pounds per square inch to impinge on the web at an energy flux greater than 23,000 foot-poundals/inch^2 second, until the yarns are extended between said apertures in ordered groups of yarns and are locked into place in entangled areas formed over the apertures.

6. A patterned nonwoven fabric of multi-filament yarns arranged in intersecting groups in an ordered pattern wherein the individual yarns overlap and interlace with one another in the plane of the fabric at the intersections of the groups and substantially maintain their identity as they pass from intersection to intersection, and the intersections are entangled areas which lock the yarns into place at a fiber-interlock value of at least 7 grams per gram/square meter when determined in the absence of binder, fibers in said areas being so highly entangled with a complex, random fiber interaction that fibers interlock with one another when the fabric is subjected to stress to thereby provide coherency and strength.

7. Fabric as defined in claim **6** wherein the yarn groups and the entangled areas at intersections of the groups define a regular pattern of apertures in the fabric.

8. Fabric as defined in claim **7** wherein the yarns are bundles of substantially parallelized fibers.

9. Fabric as defined in claim **8** wherein the yarns intersect at approximately uniform angles around the entangled areas and define an apertured fabric of geometric mesh pattern.

10. Fabric as defined in claim **8** wherein the yarns intersect at approximately 60° angles around the entangled areas and define an apertured fabric of triangular-mesh pattern.

11. Fabric as defined in claim **8** wherein the yarns intersect at approximately 90° angles around the entangled areas and define an apertured fabric which resembles a woven fabric.

12. Fabric as defined in claim **8** wherein the yarns intersect at approximately 120° angles around the entangled areas and define an apertured fabric of hexagonal-mesh pattern.

13. An entangled fabric as defined in claim **6** wherein the yarns are substantially parallelized, strong, uncrimped and nontwisted continuous-filament yarns, the yarns intersect at approximately uniform angles around the entangled areas and define an apertured fabric of geometric mesh pattern, and the entangled areas lock the yarns into place at a fiber-interlock value of 11.5 to 50 grams per gram/square meter when determined in the absence of binder.

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