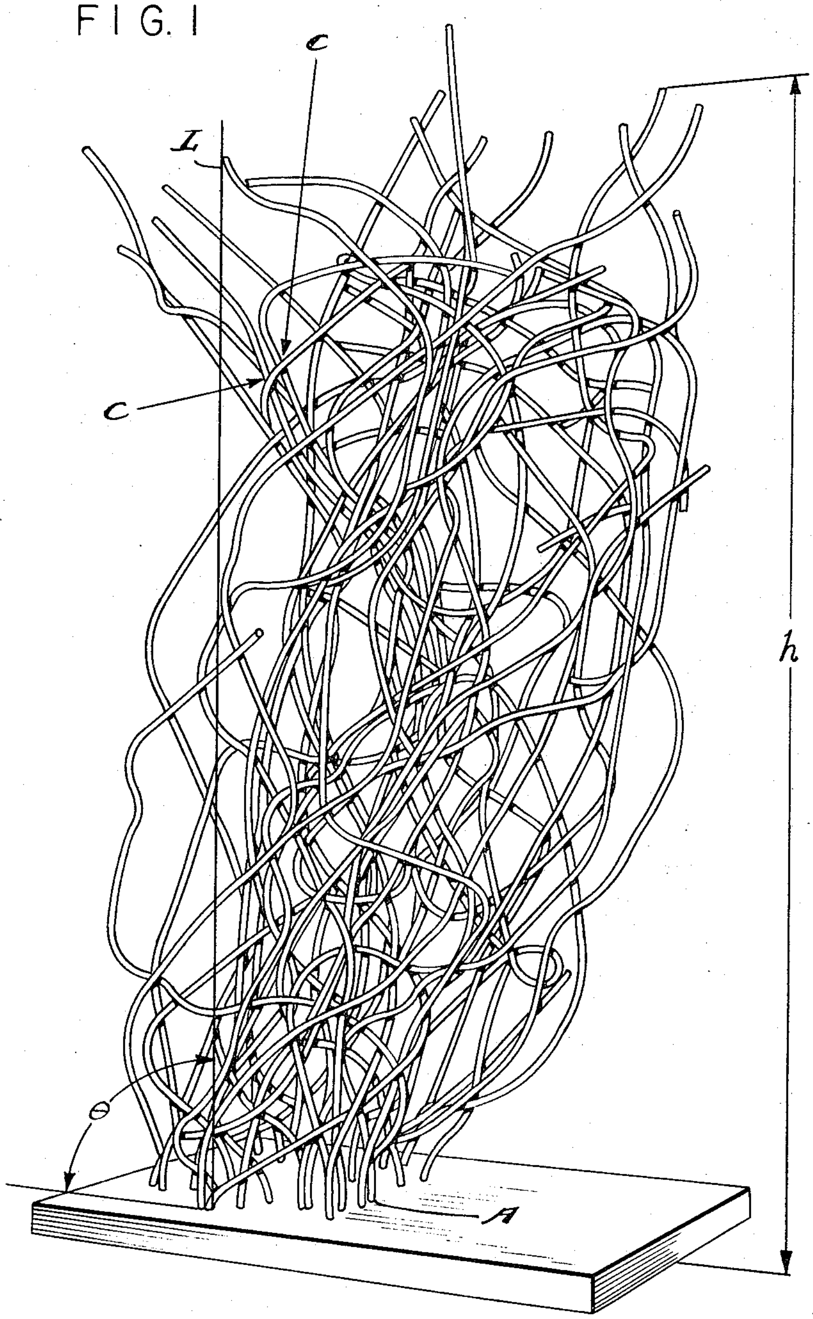
Dec. 20, 1966 C. R. KOLLER 3,293,105

PILE ARTICLE

Filed Jan. 22, 1963 2 Sheets-Sheet 1

FIG. 1



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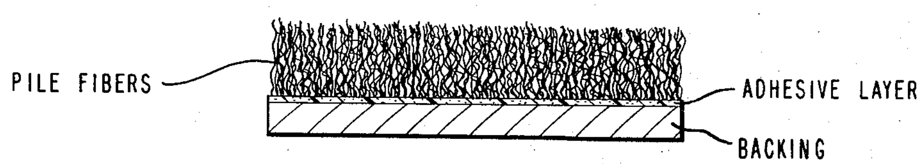
PILE ARTICLE

Filed Jan. 22, 1963 | 2 Sheets-Sheet 2

FIG. 2



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3,293,105
Patented Dec. 20, 1966

3,293,105

PILE ARTICLE

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Filed Jan. 22, 1963, Ser. No. 253,175
4 Claims. (Cl. 161—67)

This invention relates to novel pile articles and, more particularly, to pile articles having a unique combination of structural characteristics which give rise to outstanding functional qualities.

It is an object of the invention to provide a group of pile articles such as carpets, fleeces and furs, which articles are of high quality, luxurious, and have an unusal set of aesthetics. An additional object is to provide pile fabrics having a combination of optimum performance properties with respect to load support, thickness recovery, bulk, cover, and insulating values. A further object of the invention involves a critical selection of structural characteristics in producing a pile fabric so that the product will utilize the pile fibers to maximum efficiency. Other objects will be apparent from the description of the invention given below.

This application is a continuation-in-part of copending application Serial No. 787,662 filed January 19, 1959, now U.S. Patent No. 3,085,922.

The present invention provides a pile article comprising an adhesive layer and upstanding therefrom, at an average angle of between 45° and 90°, crimped synthetic organic polymeric filamentary structures aligned generally in the same direction having an average denier per filament *d* of 2 to 25, the said filamentary structures within the adhesive layer penetrating the surface thereof in randomly spaced apart fashion and being anchored thereby, the said filamentary structures without the adhesive layer being characterized by: (a) forming a highly porous pile having a pile fiber density D between about 0.5 and 3.2 lbs./ft.^{3}, having a number of filamentary structures N between about 5,000 and 16,000 per square inch and having a face defined by the ends of the filamentary structures, (b) being intermingled in non-fixed touching engagement to provide a K value of between about 1.3 and 3.0, wherein K is the ratio of the average extended length of the filamentary structures to the height of the said pile, and (c) being uniformly spaced such that the standard deviation of the number of filamentary structures per sample area in any given plane parallel to said adhesive layer is less than 0.75 times the average number of filamentary structures per sample area in that plane, wherein the sample area is of such size to contain an average of 5 to 25 filamentary structures, with (d) the proviso that said pile fiber density bears such relation to K and *d* that K is at least

$$1+\frac{0.9}{D}$$

and *d* is between 2D and (14.3D−3.8).

In essence the foregoing describes a unique combination of structural characteristics for a pile article. Such articles which fulfill each of these essential characteristics will possess optimum performance properties with respect to load support, thickness recovery, blulk, cover and insulating value. As is apparent therefrom, the invention involves not only the finding that the parameters of denier, pile fiber density, and K ratio must be within specified numerical ranges, but in addition the fact that these parameters must bear a definite relationship to one another.

As will be apparent from the detailed description given herein, a number of the characterizing features of the products of the invention relate to fibre spacing relationships or angular considerations which appear from examination of the pile articles. While for practical purposes these aspects could frequently be observed by the naked eye, particularly when the manufacturing details of the sample are known, microscopic examinations are required for precise measurements. It is to be understood that the herein contained description is based upon such microscopic examinations and that conclusions stated with respect to many critical features of the pile articles are in part founded thereon. In this regard FIGURE 1 is a schematic diagram at .5× of an exact three-dimensional model of a section of a pile article. The model, whose dimensions are 63.5 times those of the original sample, accurately exemplifies the space and angular considerations involved.

FIGURE 2 shows a schematic illustration of a pile fabric of the invention as comprising a layer of upstanding pile fizers adhered to a layer of adhesive which in turn is bonded to a backing layer.

To a large extent the above defined pile articles provide a unique combination of functional qualities owing to certain fiber spacing relationships and to the amount of fiber crimp which are expressly and inherently prescribed by the recited limitations. In this regard reference is made to the following equation which taken in conjunction with the above mentioned numerical values and limits is useful in expressing the relationship between certain structural characteristics in the pile article:

$$K=\frac{93,000\times D}{N\times d}$$

Therein K denotes the average degree of crimp in the filamentary structures, D is the pile fiber density of that portion of the pile above or without the adhesive layer in the fabric, N is the number of filamentary structures per square inch in any given section of the fabric which is cut parallel to the adhesive layer, and *d* is the average denier per filament of the filamentary structures.

In order to satisfy the objects of this invention, it has been found that the filamentary structures must be arranged in the pile portion of the article so that they are intermingled, e.g. entangled with one another, in non-fixed touching relationship (i.e., being unbonded or otherwise free of permanent connections) when the pile article is in a static state. This intermingled relationship is achieved by combining a certain amount of crimp in the filamentary structures together with a certain spacing between said structures in the pile article. If the pile fabric is prepared so that the above intermingled relationship exists between the filamentary structures in the static state, then the pile article will be of such character that when compressed, worn, used, or otherwise placed in a dynamic state, the filamentary structures thereof will coact in positive relationship with one another to produce more touch points than in the static state. As a consequence it will thus exhibit optimum performance with respect to load support, bulk, cover, and other properties.

One additional structural characteristic must be employed in the pile articles in order to obtain the necessary intermingled relationship or engagement between the filamentary structures which will lead to optimum coaction between them when placed under a load. This additional characteristic involves the orientation of the filamentary structures. The pile article is formed such that an adhesive layer securely and permanently anchors the root ends of nearly every filamentary structure in upstanding relationship from points within the adhesive layer, e.g. the filamentary structures are arranged so that the average angle thereof formed by engagement with the adhesive layer is between 45° and 90°. The angle formed by each filamentary structure in the pile layer of the article is determined by drawing a straight line from the root end of each filamentary structure at the surface of the adhesive layer to the tip end of said structure in the face of the pile article. This straight line distance is drawn between the two ends of each filamentary structure as it exists in the pile article under static conditions, e.g. the straight line distance between the two ends without extending the filamentary structure or, in other words, without pulling out any of the crimp. The angle which this straight line distance between the ends makes with the adhesive layer is the angle of orientation for that particular filamentary structure in the pile article. Such a straight line distance L, and angle θ are shown for a typical filamentary structure in FIGURE 1 of the drawings. It has been found that at least 85% and preferably 95% of the filamentary structures in each pile article of this invention are positioned at an orientation angle of between 45° and 90° from the adhesive layer. Accordingly the filamentary structures are said to be "aligned in substantially the same direction" or simply aligned. As further shown in FIGURE 1, h is the pile height, C indicates fiber cross-over points, and A indicates the upper surface of the adhesive layer.

As further described in parent application S.N. 787,-662, one suitable method for preparing the pile articles of this invention comprises arranging in a mold a plurality of aligned crimped filamentary structures so that the structures have an orientation angle between 45° and 90° with respect to the top and bottom of the mold. The filamentary structures are placed in the mold so that they are intermingled in touching arrangement with one another. The mold is then filled with a fugitive binder composition so as to completely impregnate all of the interstices between the intermingled filamentary structures. The mold is then drained to remove most of the binder composition. Upon drying to remove the vehicle or volatiles of the binder composition, adjacent filamentary structures become bonded to each other at their touch points throughout the three dimensions of the product within the mold, e.g. become attached at a plurality of spaced points along their lengths by small particles of the dried binder composition. Thereafter the walls of the mold are removed and the resulting porous fibrous block is cut transversely to the direction of the filamentary structures to provide a thin self-supporting sheet. For most pile article uses the thickness of the sheet will vary between about 1/16 and 3/4 inch. The fibrous sheets are porous layers with the top and bottom faces of each sheet being defined by the respective ends of each of the filamentary structures therein. The porous bonded sheet is then attached to an adhesive layer by applying a continuous layer of suitable adhesive to a cut face of the sheet, followed by curing and/or drying to solidify the adhesive layer. The adhesive layer can be used alone as the backing for the final pile article or one or more additional layers can be attached below the adhesive layer. The additional backing layer can be applied by pressing the adhesive coated sheet while still tacky against a layer such as burlap, a plastic film or the like, and allowing the adhesive to set. As an alternative method, the adhesive may be applied to the backing alone, or to both the backing and the cut face of the sheet prior to assembling the sheet material on the backing. If desired, the adhesive layer may support the backing. After one face of the bonded porous sheet has been attached to suitable backing, the next step is to treat the resulting laminate to remove substantially all of the binder composition contained in the pile layer outside the adhesive layer. In essence the binder is used only as a temporary means of keeping the filamentary structures in the desired spacial arrangement for purpose of cutting the sheet and attaching it to a backing. The binder composition is originally selected to be fugitive so that it can be readily removed in later processing without damaging either the filamentary structures, adhesive layer, or additional backing and without greatly affecting the spacial arrangements established in the bonded sheet. Therefore, the fugitive binder should be soluble in a liquid medium which is inert to the filamentary structures, adhesive layer and additional backings. Normally, the fugitive binder is removed by washing, leaching, scouring or otherwise dissolving the binder by immersing the backed bonded sheet in a suitable liquid medium, which may be aqueous or organic. Removal of the binder composition from these portions of the filamentary structures which are outside the adhesive layer does not effect removal of the small amount of binder composition which is attached to those sections of the filamentary structures which are embeded within the adhesive layer.

Another method of preparing the pile articles of the invention involves assembling a group of crimped filamentary structures into an elongated body or "billet" such that the majority of the aligned filamentary structures are arranged at an angle of between 45° and 90° with respect to the longest dimension of the body or billet. After the assembly of filamentary structures has been formed, shaped or otherwise arranged into a body so that the structures are intermingled in touching arrangement, the body is impregnated with a fugitive binder composition throughout the interstices of the body, and then the excess binder is allowed to drain out followed by drying to leave only small particles of binder attaching the structures together at their contact points. Alternatively, the assembly of intermingled filamentary structures may be sprayed on the outside of the assembly with a fugitive binder composition to attach together only the filamentary structures on the periphery of the body, leaving the interior structures unattached. Several of these bodies or billets are then sliced transversely to the longest dimension of the body into thin discs or wafers, each of these being characterized by two cut faces at either end with the cut faces containing the two ends of each filamentary structure. Thereafter a number of these discs are attached to an adhesive layer by using a suitable adhesive composition as described above. For this purpose a number of the discs may be placed in side-by-side contact with the longitudinal axes thereof parallel to each other. Such parallel relationship is maintained by placing the discs in a mold or other holding means so that one cut face of each is exposed during the application of adhesive composition to all of the fiber ends in one of the faces which is formed. The continuous adhesive layer is then cured, dried, or otherwise solidified. Again one or more additional backing layers may be appropriately incorporated into the product. Subsequently the resulting laminate may be washed or otherwise treated as indicated above to remove the fugitive binder remaining on that portion of the filamentary structures without the adhesive layer. The resulting pile article is composed of a continuous adhesive layer with an upstanding pile composed of filamentary structures which are intermingled in non-fixed touching arrangement.

The pile articles of the invention can be prepared batchwise or in a continuous manner starting with a variety of filamentary structures. The filamentary structures must have a certain amount of crimp, as more fully described below. However, they may be prepared from carded webs of staple fibers or from a warp of sliver, top, roping, roving, tow, steam bulked tow, steam crimped continuous filament yarn, gear crimped continuous filament yarn, twist set-backed twisted continuous filament yarn, knife edge crimped continuous filament yarn, spun yarns, continuous monofilaments, continuous multifilaments, or any other form of filamentary structures which possess a three-dimensional crimp or curvilinear contortion between the ends of sufficient magnitude to fulfill the quantitative requirements specified below. The fibers and filaments may be bulked or unbulked, drawn or undrawn, or twisted or untwisted, and may be of round cross section or may have a cross section of other different geometry, such as trilobal, tetralobal, pentalobal, elliptical, ribbon shaped, crescent shaped, and the like.

The synthetic organic polymeric filamentary structures for use in this invention can be made from a wide variety of compositions, typical of which include those made of polyamides, such as poly(hexamethylene adipamide), poly(meta-phenylene isophthalamide), poly(hexamethylene sebacamide), polycaproamide, copolyamides and irradiation grafted polyamides, polyesters and copolyesters such as condensation products of ethylene glycol with terephthalic acid, ethylene glycol with a 90/10 mixture of terephthalic/isophthalic acids, ethylene glycol with a 98/2 mixture of terephthalic/5-(sodium sulfo)-isophthalic acids, and trans-p-hexahydroxylylene glycol with terephthalic acid, self-elongating ethyleneterephthalate polymers, polymerized hydroxypivalic acid, polyacrylonitrile, copolymers of acrylonitrile with other monomers such as vinyl acetate, vinyl chloride, methyl acrylate, vinyl pyridine, sodium styrene sulfonate, terpolymers of acrylonitrile/methylacrylate/sodium styrene sulfonate made in accordance with U.S. Patent 2,837,501, vinyl and vinylidene polymers and copolymers, polycarbonates, polyacetals, polyethers, polyurethanes, polyesteramides, polysulfonamides, polyethylenes, polypropylenes, fluorinated and/or chlorinated ethylene polymers and copolymers (e.g. polytetrafluoroethylene, polytrifluorochloroethylenes), cellulose derivatives, such as cellulose acetate, cellulose triacetate, composite filaments such as, for example, a sheath of polyamide around a core of polyester as described in U.S. 3,038,236 to Breen, and self-crimped composite filaments, such as two acrylonitrile polymers differing in ionizable group content cospun as described in U.S. 3,038,237 to Taylor. Preferred materials are those composed of linear polymers and especially those wherein the polymer has an initial tensile modulus above 2 grams per denier. Blends of two or more synthetic fibers can often be used to advantage.

The binder employed for temporarily attaching together the filamentary structures during the preparation of the unbonded pile fabrics of the invention must be fugitive, e.g. be selected so that they can be readily removed from the pile layer. Normally, a binder composition should be selected which is soluble in aqueous medium or in organic medium. Such medium should be essentially inert to the filamentary structures employed as well as to the adhesive layer and any additional backing layers which may be provided before removal of the binder. Examples of typically suitable binder compositions include polyacrylic acid, acrylic acid copolymers, and polyvinyl alcohol, all of which are water soluble. Examples of suitable alcohol soluble binders include the terpolymers formed by condensing together caprolactam, hexamethylene diamine, adipic acid and sebacic acid such that there are substantially equal proportions of polycaproamide, polyhexamethylene adipamide and polyhexamethylene sebacamide in the terpolymer. Other suitable organic solvent soluble binders include natural rubber or synthetic elastomers, these then being used in the form of a latex dispersion, emulsion, or in the form of a solution. Still other organic solvent soluble binders are acrylic and methacrylic ester copolymers, methoxymethyl polyamides and various vinyl resin polymers and copolymers.

A wide variety of materials can be employed to form the adhesive layer to which the filamentary structures are to be attached. By "adhesive" or "glue" or "cement" is meant the material used to cause the root ends of the filamentary structures to adhere to one or more backing layers, or is meant the material used to constitute the backing. Illustrative adhesives include: chloroprene rubber, elastomeric foams and sponges, butadiene-styrene rubber, polyvinyl chloride resin (e.g., those in combination with either a polymeric plasticizer or a monomeric plasticizer curable after application of the adhesive), polyvinyl acetate resins, polyurethane resins, polyamide copolymer of hexamethylene diamine and adipic and sebacic acids, casein resins, and epoxy resins such the reaction products of epichlorohydrin of 2,2-bis(parahydroxyphenyl)propane. For most purposes an adhesive material will be chosen which can be cured to a thermoset condition. Illustrative backings include: woven fabrics such as burlap, canvas, and nylon scrim fabrics, knit fabrics such as nylon tricot, non-woven fabrics such as polyethylene or polypropylene fiber webs, resin bonded polyethylene terephthalate fiber webs, papers of cellulosic and/or synthetic fibers, paper felts such as asphalt impregnated cellulose, elastomeric foams and sponges, plastic films such as from polyethylene terephthalate, polypropylene and polyvinyl chloride polymers, metal foils and rigid sheets such as fiber glass reinforced polyester resins, metals, ceramics and wood, elastic, stretchable or shrinkable fabrics and films, and the like.

The superior performance properties experienced with the products of this invention directly depend from the maintenance of critical structural parameters within the ranges of values and relationships given above. Although the reasons for superior performance are not fully known, it is believed that the following pertinent considerations constitute at least a partial explanation. In the products of this invention the fibers are aligned more nearly perpendicular to the backing than parallel to it; as a result, when the pile is compressed by application of a load the fibers buckle or bow, each fiber buckling in a preferred direction. The fiber segments, which are randomly oriented, contact segments of neighboring fibers and oppose their motion. The large number of contacts, or near contacts, in the structure, e.g. see points C in the drawings, as made insure that a fiber will interfere with neighboring fibers irrespective of the direction of its movement. At the beginning of buckling the lateral forces are weak. If fibers are placed close to each other, they will contact at the start of buckling, the weak lateral forces will be overcome, and a group of fibers will follow the direction preferred by the majority. Fibers bending in parallel do not provide maximum load support. At lower pile densities, the fibers are spaced farther apart and develop strong lateral forces before touching. Each contact remains fairly stationary during the further compression; the result is that portions of a fiber on either side of a contact point bend independently. This shortening of the bending length leads to increased pile stiffness, or increased load required for a given compression. The efficiency, or load borne per fiber, is then greater than it is for an isolated fiber or for more closely spaced fibers. If the fibers are quite far apart, the pile can be compressed a great deal before the mutual support of fibers makes itself felt; the efficiency will be low. If the fiber spacing is not uniform, the advantages of this invention will not be realized, because, even if the average density is in the preferred range, the regions of very high and very low density will both be inefficient for reasons given above. It is thus significant that low pile fiber densities can be so utilized that not only are savings in cost realized but also that superior functional qualities are afforded.

With respect to the nature and function of the adhesive layer which bonds the filamentary structures at their root ends in the pile article, it is significant that these contribute greatly to the overall performance properties. In particular the spacial distribution of the fibers below the glue line, e.g. below the surface of the adhesive as indicated by point A in the drawings, does not differ significantly from the distribution of fibers without the adhesive layer. Essentially each fiber penetrates the surface of the adhesive in randomly spaced apart fashion and is anchored therein. Because the root end of nearly every fiber extends within the adhesive and is separated from the root ends of adjacent fibers, the adhesive can contact the entire surface thereof and firmly secure it in a fixed position; thus shedding problems can be essentially avoided. Aside from the functional benefits which occur by virtue of this adherent relationship, it is significant that improved economics are afforded because only very minor quantity of fiber sections do not contribute to the aesthetics of the pile article.

A more complete characterization of the structural features in the pile layer of the products of this invention will now be given.

At least 80% of the tip ends of the filamentary structures, i.e. those forming the face of the pile fabric, are positioned at least 0.8 times the pile height *h* above the adhesive layer. The more preferred pile articles of this invention are those in which essentially all of the tip ends of the filamentary structures reach the face of the pile. What this means is that for optimum properties the greatest majority of crimped fibers should extend to essentially the same height above the adhesive.

Another critical structural characteristic of the pile layer is that the filamentary structures must have a three-dimensional crimp between the two ends of each filamentary structure. The amount of crimp or contortion between the two ends may, in part, be characterized by specifying K, which is defined as the ratio of the average extended fiber length (the length of a given fiber after pulling out all of the crimp) to the pile height *h*. Another measure of the amount of crimp in each filamentary structure may be specified in terms of the crimp frequency, which preferably should have a minimum average value of about 6 crimps per inch. The *crimp frequency* can be determined by counting under a magnifying glass the number of crimps along the length while the filament is maintained at its relaxed length. Another measure of the amount of crimp between the ends of each filamentary structure may be expressed in terms of crimp index, which should be at least 20%. The *crimp index* is defined as the difference in length between a fiber in crimped and in uncrimped condition expressed as a percentage of the uncrimped length.

An additional characteristic of the filamentary structures in the pile layer of the preferred products of this invention is that no adjacent filamentary structures run parallel for more than one quarter of their length. Still another feature of the pile layer is that the filamentary structures contact adjacent structures on an average of at least 40 times per inch of pile height *h*. Considering these factors, the words intermingled or entangled are an apt description of the engagement between adjacent filamentary structures. Typical examples of three different types of suitable three dimensionally crimped filamentary structures include the following:

(1) The random, three dimensional, curvilinear crimped fibers described in Belgian Patent 573,230. More specifically filaments having this type of crimp can possess alternate "S" and "Z" twist sections throughout their length, and have a random number of turns between twist reversals, a random continuously varying angle of twist along their length, a random number of twist reversals per inch, at least one "S" turn and at least one "Z" turn per inch which have a twist angle averaging at least 5°, a random persistent three-dimensional, helical, curvilinear crimped configuration continuously along their length which may or may not be substantially free from crunodal loops.

(2) The three-dimensional helical crimp described in Kilian U.S. Patent 3,050,821.

(3) The three-dimensional crimp possessed by the composite filaments described in Taylor U.S. Patent 3,038,237.

As will be apparent from the above, three-dimensionally crimped fibers are necessary. In order to determine the three-dimensional character of such fibers it is helpful to plot the projection of the fiber within a plane parallel to the adhesive layer as viewed from above. The three-dimensional character will be reflected in the area of a parallelogram which circumscribes the projection in that plane and hence defines the two dimensional crimp amplitude of the fiber. The average area of the circumscribing parallelogram of the fiber projections is at least as great as the average area occupied by the number of fibers which is equal to 8 times the pile density. On the average, the narrowest dimension of the parallelogram should be at least 0.25 times the widest dimension.

Another critical structural requirement for the pile layer in the products of this invention relates to uniformity of spacing between the filamentary structures. That is, filamentary structures should be spaced uniformly from each other at their root ends where they are attached to the adhesive layer, as well as throughout substantially the entire pile height *h*. It has been found that in order to obtain the optimum compressional and other properties in the pile structures of this invention, it is necessary that the filamentary structures be spaced so that the standard deviation, σ, of the number of fibers per sample area in any plane parallel to the adhesive layer be less than 0.75 times the average number of fibers per sample area. Pile layers which fulfill this limitation with respect to standard deviation do not have localized areas of high fiber density and low fiber density near the glue line as would be the case with tufted pile articles.

Uniformity of fiber distribution

The measurement of uniformity starts with an accurate plot of the relative positions of all the fibers which pass through a plane approximately parallel to the backing. The plot may be obtained by any one of a number of methods: (1) The pile fabric may be immersed in a polymerizable compound such as butyl methacrylate, the compound may be polymerized to a tough plastic, and the plastic may be cut into thin slices parallel to the backing by means of a microtome. Enlarged photographs of some of the slices may then be taken with the help of a microscope; on the photographs (enlarged further if necessary) one will see the ends of all the fiber segments which pass through the slice. (2) With the help of an optical instrument such as the Nikon Comparator, and without slicing the fabric, one may measure the positions of the fiber segments crossing a given plane; using the instrument readings, one may then plot the positions on graph paper.

If the results are to be meaningful, the "total area" to be analyzed in a given plane must contain at least 500 fibers. If the fibers give evidence of being segregated into yarns or bundles, the total area must contain a number of fibers equal to at least six times the average number of fibers per bundle.

For the analysis the "total area" chosen is ruled into a grid of squares of equal size. (This ruling into small "sample areas" will greatly facilitate counting the total number of fibers.) The average number of fibers per square and the standard deviation, σ, of the distribution into squares are determined by well-known routine methods. The average number of fibers per "sample area" must lie between 5 and 25, and at least 20 sample areas should be counted in the "total area."

Pile fabric compression test

Specimens measuring 4" x 4" are taken from pile fabric samples to be tested. Two specimens are normally taken from each sample and the data reported are the average of results from both. The specimens are conditioned in two steps according to common textile testing procedures wherein a pre-conditioning at 130°±10° F. in moving air for a minimum of two hours is followed by a final conditioning at 65% RH and 70° F. in moving air for a minimum of sixteen hours. The conditioned specimens are weighed to the nearest 0.01 gram and measured to the nearest 0.02 inch taking an average of three measurements in both length and width.

Each specimen mounted on a compression cell is subjected to compression with pile side up at the rate of 0.2

inch/minute on an Instron Tester using a circular presser foot of 10 in.^{2}.

The load cycling controls of the tester are set so as to cause the crosshead to return when the desired full load has been applied. In the case of carpets of high denier fiber (12–25 d.p.f.), a maximum load of 10 p.s.i. is used; whereas for fleeces and lower denier fiber (2–12 d.p.f.), the maximum load is 1.1 p.s.i. The crosshead stops when the pressure has returned to zero. After a two-minute interval a second compression cycle is run in the same manner. Following the second cycle of compression and unloading, the specimen is taken from the tester and the pile is sheared off as evenly and cleanly as possible from the surface of the adhesive using heavy duty barber clippers equipped with a No. 000 (fine) clipper head. The sheared backing is then weighed to the nearest 0.1 gram. The sheared backing is subjected to compression testing in the same manner as in the unsheared form except that it is loaded at a rate of 0.1 inch/minute crosshead speed. During the compression test the stress is recorded and appears on the chart as a pen line whose coordinates are stressed in lbs. and separation between cell and presser foot in inches. From this graphic data, specific points can be extracted. On the first compression cycle, a specific point of interest is the cell presser foot separation when the presser foot barely touches the sample and the pressure starts to increase. This separation is used as the initial thickness of the specimen. From the second cycle and its record, the integrator count for the load portion of the cycle is obtained.

Other tests and measurements

The *pile height h* of the pile fabric is the height of the shearable fibers above the adhesive line. The pile height in inches is obtained by subtracting the initial thickness of the adhesive and any backing layers from the initial thickness of the specimen, both measured on the first compression cycle as indicated above. In the sample depicted in the drawings, *h* would be equal to the value of H less the thickness of the adhesive layer.

The *pile weight* in ounces per square yard of the fibers in the specimen is calculated by subtracting the weight of the sheared backing from the total weight of the unsheared conditioned specimen, and then dividing the net weight expressed in ounces by the area (length×width) of the conditioned specimen in square yards.

The *pile fiber density* (sometimes called "pile density" herein) reported in pounds per cubic foot is a measure of the density of the fibers in the pile layer above the adhesive layer. The pile fiber density is calculated by dividing the pile weight of the fibers in the pile layer by the volume these fibers occupy when the specimen is under no load. This volume is determined by multiplying the average width by the average length of the conditioned specimen by the pile heigth *h* and then applying suitable conversion factors to obtain the volume in units of cubic feet.

The *work-to-compress* of the pile fabric specimen to the point of maximum load is calculated from the second compression cycle by measuring the area under the stress-strain curve for the second load cycle and multiplying this by the value of inch lbs. per unit area of the chart. This value is then divided by the area in square inches of the presser foot to provide the value in units of inch lbs./in.^{2}.

The *specific volume* of the pile layer at a given load is calculated as the volume of the pile at the given load divided by the pile weight. The pile volume at the given load is determined from the second compression cycle as the difference between the thickness of the pile fabric and the backing at the given load times the specimen area, suitable conversion factors being applied.

One of the chief advantages of this invention is that by following the critical structural specifications as taught herein, it is possible to produce pile articles having maximum compressional properties (e.g., load support), bulk, cover, and insulating value. In this regard, carpet structures prepared in accordance with the invention usually have a specific volume of at least 7.0 cc./gram at 3.1 p.s.i. and a work-to-compress to 10 p.s.i. value of at least 0.1 plus (0.025 times the effective pile weight expressed in oz./yd.^{2}). The pile fabrics of this invention have a high luxurious set of aesthetics which are pleasing to the eye as well as to the hand. As is apparent from the numerous references thereto in this description, the invention is particularly applicable for pile articles to be used as floor coverings, such as carpets, and the like. Nevertheless such articles also find application for other uses where retention of bulk is a significant factor, e.g., as fleeces, blankets, coating and suiting interliners, brushes, paint and ink rollers, buffing, polishing and scouring pads, upholstery fabrics, and the like.

The pile layers of the products of the invention preferably consist essentially of the filamentary structures, e.g., minor amounts of materials such as dyes, pigments, stabilizers, antistatic agents and the like may be included which, either distributed within or on the surface of the filamentary structures, do not appreciably affect structural characteristics or impair the desired properties. From the volume standpoint, air will be the dominating component of the highly porous pile layer, usually to the extent of 90% or more. Further in this regard it will be apparent that the products of the invention can be so prepared or otherwise treated, e.g., stylized such as sculptured or embossed that minor deviations from the defined characteristics and relationship may exist in small localized areas without significantly affecting the overall properties of the product.

The average denier per filament *d* of the products of the invention is in the range of 2 to 25. Alternatively this range may be expressed as 0.2 to 2.8 Tex. For carpets and other floor covering purposes, which constitute a preferred embodiment of the invention, the average denier is 12 to 25.

The following examples are given to illustrate the invention, but are not intended to limit it in any manner.

EXAMPLE I

Steam-bulked continuous-filament polyhexamethylene adipamide yarn (3700 denier, 204 filaments, ½ "Z" twist and having a "Y" cross section), prepared according to Example 2 of Belgian Patent 573,230, is creeled into warp sheets of aligned yarns about 30 inches wide x 3 inches thick x 16 feet long. These warps are pleated into a metal mold, 30 inches long x 30 inches wide x 12 inches deep having an open top and bottom, in such a manner that the folds of the pleats extend above and below the mold and the fibers are essentially all aligned in a direction running from top-to-bottom of the mold. The pleated yarn protruding from top and bottom of the mold is trimmed off, leaving approximately 14 lbs. of fiber in the mold. Two perforated metal screens are placed over the top and bottom of the mold, and cover plates fitted with inlet and outlet pipes are attached, using air-tight gaskets, to the top and bottom of the mold over the screens. The binder used in this experiment is an alcohol soluble terpolymer formed by condensing together caprolactam, hexamethylene diamine, adipic acid and sebacic acid, such that there are substantially equal molar proportions of caproamide, hexamethylene adipamide and hexamethylene sebacamide units in the terpolymer. A solution of 4% by weight terpolymer in 80/20 alcohol/water mixture by volume is drawn through the mold from bottom pipe to top pipe by means of suction applied to the top pipe and allowed to drain back through the mold out the bottom pipe by gravity so that the contact time of binder with fibers is about 5 minutes. Hot dry compressed air (300° F.) is passed through the mold from top to bottom until all the volatile matter is removed from inside the mold. The mold is then disassembled, leaving a dry porous block consisting of fibers, binder polymer and air. The block is composed of the bulky fibers, all of which run essentially from the bottom to the top surface, the block having a fiber density of 2.5 lbs./cu. ft. and a binder density of 0.17 lbs./cu. ft. The block is passed through a horizontal band knife such that the knife blade passes perpendicular to the direction of the fibers in the block, and sheets 7/16, 3/8, and 1/4 inch thick are obtained, the faces thereof being defined essentially by fiber ends. The sheets are cemented to rubber-impregnated burlap backing with a rubber-base adhesive, the binder is removed by washing in ethanol/water (80/20 by volume), and the resulting pile fabric is dyed with a disperse type dyestuff. This pile fabric exhibits high load support, good cover, pleasing aesthetics and is suitable for use as a carpet.

By this process a product having the following characteristics is obtained:

D	2.5 lbs./cu. ft.
N	9270/sq. in.
d	18.9.
K	1.35.
Pile height, *h*	1/4 inch.
Fiber angle	Average, 79°; range, 53° to 90°.
Average number of fiber contacts/in. of pile fiber height	61.
Average horizontal component	0.67 *h*.
Two-dimensional crimp amplitude (average area of parallelogram).	0.0029 sq. in. (area occupied by 27 fibers).
Average length of parallelogram	0.074 inch.
Average width of parallelogram	0.038 inch.

Uniformity of spacing:

Total area analyzed=0.0944 sq. in.=approximately 1/4 in. x 3/8 in.

A. As determined 1/16 in. above the backing (877 fibers)

Number of sample areas counted	Average fibers per sample area	σ	σ/average
60	14.6	6.8	0.47
40	21.85	8.9	0.41

B. As determined 1/7 in. above the backing (858 fibers)

Number of sample areas counted	Average fibers per sample area	σ	σ/average
60	14.3	7.25	0.51
40	21.45	9.3	0.43

EXAMPLE II

Helically crimped polyethylene terephthalate staple fibers prepared according to U.S. Patent 3,050,821 having a 2½ inch staple length, 4 denier per filament, 27% crimp index and 7 crimps/inch are carded into a 300 grain/yard sliver on a worsted card. Six-inch lengths of this sliver are assembled in a side-by-side arrangement so that the fibers are aligned in the same general direction and then compressed laterally to a density of 0.7 lbs./ft.³. This assembly is placed in a 10″ x 10″ x 6″ deep perforated metal mold so that the fibers are directed toward the mold faces (10″ x 10″ faces). The mold is immersed in a 6% solution of polyacrylic acid dissolved in an acetone/water mixture (3/1 ratio by volume). The mold is removed slowly and excess solution is allowed to drain from the mold. The mold is heated at 220° F. in a hot air oven to remove the solvent and solidify the binder. The bonded fiber assembly is removed from the mold and sliced with a horizontal band knife cutter transverse to the fibers and in a plane parallel with the face of the block to give 10″ x 10″ x 3/16″ thick bonded fiber sheets with the fiber ends located in the sheet faces. A sprayed coating of 1.2 oz./sq. yd. of a polyurethane adhesive is applied to one face of a 3/16″ thick bonded sheet which is then cemented to the face of a woven cotton fabric. This assembly is held together under slight pressure and heated at 240° F. for 30 minutes to bond the fiber ends in one face of the sheet to the cotton backing. This product is washed in warm water to remove the binder and tumble dried.

There is obtained a soft, drapable pile fabric suitable for use as a pile lining for slippers. This pile fabric is found to have a specific volume at 0.34 p.s.i. load of 31.0 cc./gm. The pile layer is found to have an average of 8,600 fibers per sq. inch, a pile fiber density of 0.8 lbs./ft.³, an average fiber denier per filament of 4 and an average K value of 2.14. The average number of fibers per sample area is 13.4, the standard deviation, σ, of the number of fibers per sample area is 4.7 and the ratio of th estandard deviation to the average number of fibers per sample area is 0.35, determined on a total of 40 sample areas.

EXAMPLE III

Bicomponent polyacrylonitrile staple fibers prepared according to U.S. Patent 3,038,237 having a 2½″ staple length and 3 denier per filament were treated in hot water (190° F.) for 15 minutes and dried at 120° F. in a tumble drier. These fibers having a crimp index of 24% and a crimp frequency of 11 crimps per inch are carded into a 150 grain sliver on a worsted card. This sliver is cut into 6 inch sections, the sections are stacked in a mold and formed into a bonded fiber assembly having a fiber density of 1.0 lb./ft.³, the bonded block is sliced into 1/4 in. thick sheets, and a sheet cemented to one face of a cotton fabric as described in Example II. The binder is washed out of the pile layer and there is obtained a soft bulky fabric suitable for use as a pile lining for garments. The pile layer of this fabric was found to have a specific volume at 0.34 p.s.i. of 32.6 cc./gm., an average number of fibers per square inch of 14,300, a pile fiber density of 0.99 lb./ft.³, a denier per filament of 3 and a K value of 2.15. The average number of fibers per sample area is 22.2, the standard deviation, σ, of the number of fibers per sample area is 6.3, and the ratio of the standard deviation to the average number of fibers per sample area is 0.28, determined on a total of 40 sample areas.

EXAMPLE IV

Steam bulked continuous filament polyhexamethylene adipamide yarns of about 3700 denier (each yarn containing 204 fibers of 18 denier per filament), prepared according to Example 2 of Belgian Patent 573,230, are formed into skeins having about 90 yards/skein. Each skein is cut transverse to the fibers into 6 inch long sections which are assembled side-by-side and compressed laterally to form a 10″ x 10″ x 6″ assembly of yarns oriented in the same direction at a density of 1.6 lbs./ft.³. This assembly is bonded with a polyacrylic acid binder and sliced into 3/8 inch thick sheets as in Example II. One face of these sheets is cemented to a burlap fabric using a polyurethane adhesive. The binder is removed from the pile layer by washing in water and the pile fibers dyed with a disperse type dyestuff. There is obtained a resilient pile fabric suitable for use as carpeting. The pile layer is found to have a specific volume of 9.3 cc./gm. at 3.1 p.s.i. load in the Pile Fabric Compression Test. The pile layer is found to have an average of 5,400 fibers per sq. in., a pile fiber density of 2.1 lbs./ft.³, an average denier per filament of 18 and a K value of 1.98. The average number of fibers per sample area is 8.4, the standard deviation, σ, of the number of fibers per sample area is 4.6, and the ratio of the standard deviation to the average number of fibers per sample area is 0.55, determined on a total of 40 sample areas.

EXAMPLES V–XI

A series of pile fabrics of this invention were prepared in accordance with the above examples. The fabrics in Examples V through X were prepared using the general procedure described in Example IV, whereas the fabric of Example XI was prepared according to the procedure described in Example II. The seven pile fabrics are characterized by the following structural features and exhibit the indicated properties. The specific volume of the fabrics in Examples V through X was determined under 3.1 p.s.i. load, whereas the specific volume of the fabric in Example XI was determined at 0.34 p.s.i. The data given for the uniformity of fiber distribution was determined on a total of 40 sample areas.

Example	Fiber	d	D (lbs./ft.³)	K	N	Sp. Vol. (cc./gm.)
V	Polyamide	18.5	3.05	1.46	10,450	10.2
VI	do	18.1	2.90	1.39	10,600	9.3
VII	do	18.5	2.98	1.67	8,950	8.1
VIII	do	18	1.84	1.34	7,060	8.9
IX	Polyacrylonitrile	16	2.97	1.80	9,620	9.0
X	Polypropylene	16.4	2.40	1.48	9,150	9.0
XI	Polyacrylonitrile	3	1.03	2.04	15,500	28

Example	Aver. No. fibers/sample area	σ	σ/aver. no. fibers
V	16.2	3.4	0.21
VI	16.5	5.0	0.30
VII	13.9	4.7	0.34
VIII	11.0	4.7	0.43
IX	14.9	4.6	0.31
X			
XI	24.1	7.8	0.32

What is claimed is:

1. A pile article comprising an adhesive layer and upstanding therefrom, at an average angle of between 45° and 90°, crimped synthetic organic polymeric filamentary structures aligned generally in the same direction and having an average denier per filament d of 2 to 25, the portions of said filamentary structures within the adhesive layer penetrating the surface thereof in randomly spaced apart fashion and being anchored thereby, the portions of said filamentary structures without the adhesive layer being characterized by: (a) forming a highly porous pile having a pile fiber density D between about 0.5 and 3.2 lbs./ft.³, having a number of filamentary structures N between about 5,000 and 16,000 per square inch and having a face defined by the ends of the filamentary structures, (b) being intermingled in non-fixed touching engagement to provide a K value of between about 1.3 and 3.0, wherein K is the ratio of the average extended length of the filamentary structures to the height of the said pile, and (c) being uniformly spaced such that the standard deviation of the number of filamentary structures per sample area in any given plane parallel to said adhesive layer is less than 0.75 times the average number of filamentary structures per sample area in that plane, wherein the sample area is of such size to contain an average of 5 to 25 filamentary structures, with (d) the proviso that said pile fiber density bears such relation to K and d that K is at least

$$1+\frac{0.9}{D}$$

and d is between 2D and (14.3D−3.8).

2. The pile article of claim 1 wherein at least 95% of said filamentary structures are positioned at an orientation angle of between 45° and 90° with respect to the adhesive layer.

3. The pile article of claim 1 wherein the average denier per filament of said filamentary structures is 12 to 25.

4. The pile article of claim 1 wherein a backing material is affixed to the said adhesive layer.

References Cited by the Examiner

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