United States Patent

Gibbon

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[54] **FIBRILLATED FILM YARN**

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[73] Assignee: **Fiber Industries, Inc.**

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[52] **U.S. Cl.**.....**57/140 R,** 28/DIG. 1, 28/1.4, 57/34 B, 57/155, 57/157 F, 57/167, 161/168

[51] **Int. Cl.**.....**D02g 3/06,** D02g 3/22, D02g 1/16

[58] **Field of Search**.....57/140 R, 157 R, 157 F, 167, 57/151, 155, 34 B; 28/DIG. 1, 1.4, 72 R; 161/168, 169

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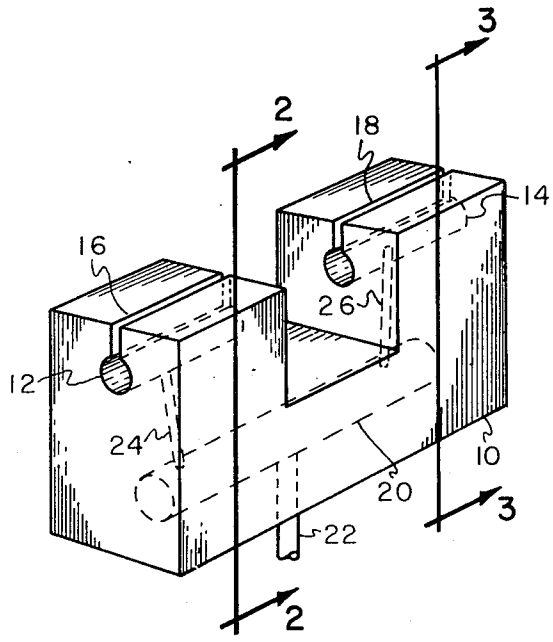
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[57] **ABSTRACT**

There is provided a fibrillated continuous filament yarn comprised of random-length fibrils of a synthetic organic high polymer wherein: the average width/thickness ratio of cross sections of the fibrils (the "aspect ratio") is from about 2/1 to about 12/1, and the aspect ratios of the cross sections of the fibrils range from about 0.5/1 to about 20/1; the fibrils in the yarn exceeding 40 centimeters in length comprise at least 70 percent (by weight) of the yarn; the tenacity of the yarn is from about 0.1 to about 10 grams per denier; the total denier of the yarn is from 30 to about 10,000, and the average denier per fibril of the fibrils comprising the yarn is from about 0.5 to about 60; the elongation of the yarn is from about 0.5 to about 75 percent; and the initial modulus of the yarn is from about 2 to about 300. The yarn of this invention has high tenacity, a soft hand, and good cover.

5 Claims, 3 Drawing Figures



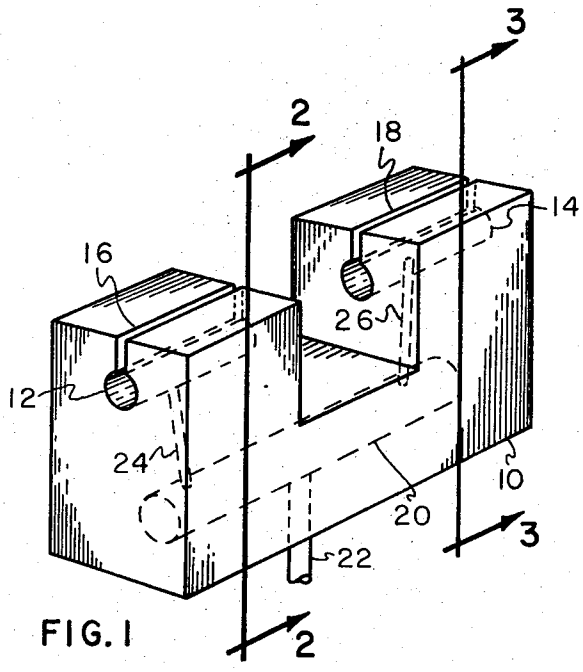


FIG. 1

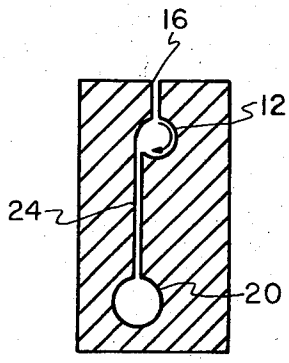


FIG. 2

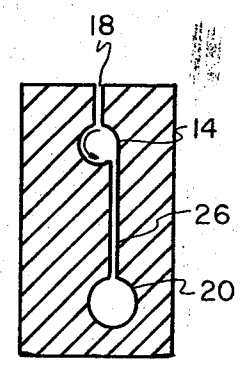


FIG. 3

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FIBRILLATED FILM YARN

This invention relates to a novel fibrillated yarn with unique properties.

Fibrillation processes, wherein filamentary articles are produced from longitudinally oriented fibrillatable synthetic polymeric tapes or films, are well known to the art. To applicant's knowledge, however, there is no prior art which describes a fibrillated yarn similar to applicant's continuous filament fibrillated yarn.

It is an object of this invention to provide an economical continuous filament fibrillated yarn with good cover, handle, and tensile properties. In accordance with this invention, there is provided a continuous filament fibrillated yarn comprised of random-length fibrils of a synthetic organic high polymer wherein: the average width/thickness ratio of cross sections of the fibrils (the "aspect ratio") is from about 2/1 to about 12/1, and the aspect ratios of the cross sections of the fibrils range from about 0.5/1 to about 20/1; the fibrils in the yarn exceeding 40 centimeters in length comprise at least 70 percent (by weight) of the yarn; the tenacity of the yarn is from about 0.1 to about 10 grams per denier; the total denier of the yarn is from about 30 to about 10,000, and the average denier per fibril of the fibrils comprising the yarn is from about 0.5 to about 60; the elongation of the yarn is from about 0.5 to about 75 percent; and the initial modulus of the yarn is from about 2 to about 300.

The yarn of applicant's invention has many unique advantages; a few of these are listed below.

1. Applicant's fibrillated yarn, for any given polymer, has a higher tenacity (particularly at zero twist) than other known fibrillated film yarns, produced from the same polymer.

2. This yarn has a softer handle than an equivalent denier per filament continuous filament yarn (which it resembles in appearance). This characteristic is particularly obvious (and advantageous) when the yarn is used as a carpet face yarn.

3. This yarn has a crisp, dry hand which is beneficial in cordage applications.

4. Fabrics produced from fibrillated polyester yarn of this invention have good cover, good "breathability", excellent wrinkle resistance (even without the use of a resin finish), and excellent printability.

5. Fabrics produced from the fibrillated yarns of this invention have a unique, desirable luster.

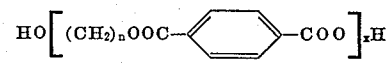
6. Fabrics produced from the fibrillated polyester yarns of this invention show excellent resistance to dry heat degradation; gas and ozone fading; mildew, moth larvae, and household insects; mineral and organic acids, alcohols, bleaching agents, dry-cleaning solvents, halogenated hydrocarbons, ketones, soap and synthetic detergents, water (including sea water), weak acids, and weak alkalies (most of these compounds have little or no effect on these fabrics); perspiration (which has no significant effect upon the strength of these fabrics); sunlight (no appreciable deterioration or discoloration occurs); and the like.

7. The durability of the folded edge of draperies produced from the fibrillated polyester yarn of this invention is very good.

8. The cover effect of the fibrillated polyester yarns of this invention is greater than the cover effect of the same denier round-cross-section filament yarn produced by the conventional process.

9. The fabrics produced from the fibrillated polyester yarn of this invention will withdraw from a flame; thus, they do not flash burn. If ignition does take place, the molten fiber tends to drop off and prevent propagation of the flame. 10. Textile processing of the fibrillated yarn of this invention (such as twisting, coning, quilling, warping, slashing, and weaving) can be carried out using standard textile equipment. Dyeing procedures for said yarn are the same as those used for regular filament yarn. Not only does applicant's fibrillated yarn have the aforementioned unique, advantageous combination of properties, but it is substantially cheaper to make than regular filament yarn.

The fibrillated yarn of this invention is comprised of random-length fibrils of a crystalline synthetic organic high polymer, i.e., any polymer capable of possessing an appreciable amount of crystallinity which will retain orientation on relaxation after stretching. Thus, e.g., polymers such as polyethylene; polypropylene; polybutene; polymethyl-3-butene; polystyrene; polyamides such as polyhexamehtylene adipamide, poly (ethylene sebacamide), poly(methylene bis-p-cyclohexyleneadipamide), and polycaprolactam; acrylics such as polymethyl-methacrylate and methyl methacrylate; polyethers such as polyoxymethylene; halogenated polymers such as polyvinyl chloride, polyvinylidene chloride, tetrafluoroethylene, hexafluoropropylene, and the like; polyurethanes; cellulose esters of acetic acid, propionic acid, butyric acid, and the like; polycarbonates; polyacetals; polyesters of the formula



(wherein *n* is from 2 to about 10 and preferably is 2, 3, or 4); and the like, can be used to prepare the yarn of this invention. Other materials such as delustrants, incompatible polymers, etc., may comprise the yarns of this invention. Thus the yarns of this invention are "essentially comprised" of the polymers described, i.e., at least 80 percent (by weight) of the yarn consists of one or more of said polymers.

The fibrillated yarn of applicant's invention is virtually indistinguishable in appearance from a continuous filament yarn. This is largely due to the fact that the average width/thickness ratio (the "aspect ratio") of cross sections of the fibrils comprising applicant's novel yarn is from about 2/1to about 12/2, and the aspect ratios of the cross sections of the fibrils range from about 0.5/1 to about 20/1. The preferred yarn of applicant's invention is essentially comprised of poly(ethylene terephthalate) yarn, and the average aspect ratio of the fibrils of this yarn is from about 3/1 to about 5/1, the aspect ratios of the cross sections of the fibrils ranging from about 2.5/1 to about 7/1.

The tenacity of the fibrillated yarns of applicant's invention are relatively high, ranging from about 0.1 to up to about 10 grams per denier (as determined by a modified ASTM D 2256/69 test wherein the strain rate is held at 100 percent). The most preferred embodiment, poly(ethylene terephthalate) fibrillated yarn, has a tenacity of from about 0.5 to about 7 grams per denier.

There are many long fibrils in the yarns of applicant's invention. The fibrils exceeding 40 centimeters comprise at least 70 percent (by weight) of these yarns.

The fibrillated yarns of this invention have a denier of from about 30 to about 10,000, and the average denier per fibril of the fibril comprising the yarn is from about 0.5 to about 60. The elongation of these yarns is from about 0.5 to about 75 percent, and the initial modulus of these yarns is from about 2 to about 300.

Applicant's novel fibrillated yarns do not need to be twisted as do some of the web-like "yarns" described in the prior art.

The preferred yarns of applicant's invention contain less than four free fibril ends per centimeter and thus generally are not as hairy as are the fibrillated products of the prior art; this property contributes to the continuous yarn-like appearance of the yarns of this invention. A free fibril end is a fibril which is unattached on one end, proturdes from the yarn bundles, and is visible to the naked eye.

The polymer from which the yarns of this invention are made should have a sufficiently high molecular weight so that the polymer is fiber forming. When fibrillated yarn essentially comprised of poly(ethylene terephthalate) is made via the processes of this invention, it is preferred that it be made from a polymer with an intrinsic viscosity of from about 0.4 to about 0.8. Unrelaxed poly(ethylene terephthalate) fibrillated yarns of this invention made from polymer with an intrinsic viscosity of from about 0.4 to about 0.8 preferably will have an initial modulus of from about 50 to about 120 grams per denier and a boiling water shrinkage of from about 5 to about 10 percent. The poly(ethylene terephthalate) yarns of this invention generally have an elongation of from about 1 to about 20 percent, an initial modulus of from about 30 to about 200 grams per denier and a boiling water shrinkage of up to about 20 percent; fibrils comprising the poly(ethylene terephthalate) yarn of this invention have a tenacity of from about 2 to about 6 grams per denier, an elongation at break of from about 3 to about 25 percent, and a denier per fibril of from about 0.1 to about 60.

One process that the applicant has discovered for producing the yarns of his invention (and which he believes to be patentable by itself) relates to fibrillating a fibrillatable tape at a windup speed of greater than about 500 feet per minute comprising the step of subjecting said fibrillatable tape to the action of at least two (and preferably four) fluid twisting means wherein the direction of twist imparted to the tape is completely and shraply reversed between adjacent twisting means and the tape is maintained under a tension of from about 0.05 to about 0.2 grams per denier. This process is a distinct improvement over prior art processes which suffer from the disadvantage that they generally can only be operated at relatively low "throughput speeds" and filament yarn thus cannot be produced via them which can compete in price with filament yarn produced by conventional processes. The throughput speeds used in these processes are generally about 300 feet per minute, and the maximum throughput speed which can be used in these processes is about 500 feet per minute. "Throughput speed" is often referred to as "windup speed" and is the speed at which the fibrillated yarn is taken through the last fluid twisting means and/or wound up.

In the aforementioned process it is preferred to work at throughput speeds in excess of 1000 feet per minute. A suprising advantage of this process is that the fibrillated yarn produced thereby has very good uniformity even when very high throughput speeds are used.

This process is applicable to any fibrillatable tape, i.e. any tape showing a readiness to split in the lateral direction (a tape wherein the bonds in the lateral direction are weak when compared to the bonds in the longitudinal direction). Various fibrillatable tapes are disclosed, e.g., in U. S. Pat. Nos. 2,185,789; 3,214,899; 3,242,035; 3,323,978; and the like.

In this process the fibrillatable tape is subjected to the action of at least two (and preferably four) fluid twisting means so that the direction of twist imparted to the tape is completely reversed between adjacent twisting means and there is substantially no change in the longitudinal direction of movement of the tape between successive twisting means.

FIG. 1 is a view in perspective of the fluid twister used in this invention.

FIGS. 2 and 3 are views taken along lines 2--2 and 3—3 of FIG. 1.

The fluid twisting means known to the art may be used in applicant's process. Thus, e.g., the fluid twisting means disclosed in abandoned application Ser. No. 563,234 (filed July 6, 1966) may be used. Thus, e.g., the fluid twisting means disclosed in U. S. Pat. No. 2,515,299 (wherein air or water is supplied to a small, cylindrical, receptacle having a central axial passage therethrough through which the textile strand may pass freely, and twist is imparted to the strand by a vortex of whirling fluid which rotates about the axis of travel of the strand in direct contact therewith) work well in applicant's invention. Thus, e.g., the apparatus shown in FIGS. 1, 2, and 3 may be used in applicant's invention. This apparatus is comprised of two cooperating opposite rotating twisting means. Apparatus **10** is comprised to a U-shaped member with co-axial bores **12** and **14** through the legs of the "U" and slots **16** and **18** which communicate with bores **12** and **14** respectively. Fluid is supplied to manifold box **20** by connector **22** (which is supplied with a pressurized fluid such as, e.g. water or air), and this fluid then passes through fluid passageways **24** and **26** into bores **12** and **14** respectively. Said fluid passageways are essentially tangential to bores **12** and **14** with axes in planes perpendicular to the axis of bores **12** and **14**, respectively. They are thus positioned with respect to bores **12** and **14** so as to produce respectively therein fluid vortices rotating in opposite directions.

In apparatus **10** because the axes of fluid passageways **24** and **26** lie in a plane perpendicular to the axes of bores **12** and **14** the vortices generated at the intersections of said passageways **24** and **26** with bores **12** and **14** respectively are propagated equally along the axes of bores **12** and **14** from the points of vortex generation. In another useful embodiment a preferential direction and intensity of vortex propagation may be obtained by placing the axes of fluid passageways **24** and **26** in planes intersecting the axes of bores **12** and **14** at angles which are other than perpendicular. In these embodiments the twisting of the vortices not only fibrillate the tape but also tension the tape in a preferred direction. It is preferred that the planes in which the fluid passageways lie make an angle of from 15 to 70 degrees to the axis of the bores. It is

more preferred that this angle be from 30 to 60 degrees and most preferred that this angle be from 45 to 60 degrees.

In applicant's process it is preferred that the perimeter of the tape in the yarn passageway be from about 4 to about 12 millimeters, the perimeter of the yarn passageway (which, in the apparatus described above, would be bores **12** and **14**) be from about 5 to about 20 millimeters, the perimeter of the air passageway (which would be passageways **24** and **26** in the apparatus described above) be from 1.25 to about 10 millimeters, and the ratio of the tape perimeter/yarn passageway perimeter be from about 0.1 to 1.5 (and most preferably from about 0.3 to about 0.7). If the yarn passageway and air passageway are cylindrical, it is preferred that the ratio of the yarn passageway diameter/air passageway diameter be from about 0.1 to about 0.7 (and most preferably from about 0.2 to about 0.5).

Any series of at least two (and preferably four) fluid twisting means wherein the direction of twist imparted to the tape is completely reversed between adjacent twisting means and there is substantially no change in the longitudinal direction of movement of the tape between successive twisting means will work well in this process. The fluid used in said twisting means may be virtually any gas which approaches ideal gas behavior and does not react with the tape to be fibrillated. Thus, e.g., air, steam, nitrogen, oxygen, carbon dioxide, etc., may be used in the process of this invention; because it is one of the cheapest gasses, it is preferred to use air as said fluid. In said twisting means the fluid velocity should reach from about 0.5 to about 1.0 sonic velocity at the point of contact with the strand.

The direction of twist imparted to the tape is reversed between adjacent twisting means. Thus, e.g., if the fibrillatable tape is passed through the apparatus shown in FIG. **1**, it will have a clockwise twist imparted to it in bore **12** and counter-clockwise twist imparted to it in bore **14**; the tape may then be subjected to a third fluid twisting means wherein clockwise twist is imparted to it and a fourth twisting means wherein counter-clockwise twist is imparted to it.

It is preferred, for reasons of economy and efficiency, to have a pair of twisting means embodied in the same apparatus. Such apparatus are illustrated, e.g., in FIGS. **1**, **2**, and **3**.

In each apparatus which is comprised of a pair of twisting means it is preferred that the adjacent twisting means be no further than about 3 inches apart so that the direction of twist will be sharply reversed, and it is most preferred that said adjacent twisting means be no further than about 1 inch apart. When four fluid twisting means are used, the distance between each apparatus which is comprised of two twisting means may be as great as is practical; thus, e.g., two such apparatus may be from about 6 to about 1000 inches apart. It is preferred that the two adjacent apparatus, each of which are comprised of two adjacent twisting means, be from about 12 to about 500 inches apart, and it is more preferred that they be from about 15 to about 72 inches apart. In the most preferred embodiment, they are about 24 inches apart.

As the fibrillatable tape is being subjected to the action of at least two fluid twisting means, it should be maintained under a tension of from about 0.05 to about 0.2 grams per denier to insure good fibrillation of the tape, although it is preferred to maintain it at a tension of from about 0.05 to about 0.15 grams per denier, and it is most preferred to maintain it at a tension of about 0.1 grams per denier. The tape may be maintained at the prescribed tension by godet rolls or winding apparatus pulling the tape through the fluid twisting means. Alternatively, if the passageways of the twisting means are at an angle of from about 1 to about 89 degrees with respect to the axis of the passageway through which the tape travels, the tape may be maintained under the prescribed tension by the action of the fluid twisting means.

In the preferred embodiment air supplied to the fluid twisting means will be under a pressure of from about 10 to about 250 p.s.i.g., although it is preferred that said pressure be from about 20 to about 100 p.s.i.g. and it is most preferred that said pressure be from about 40 to about 80 p.s.i.g. When said preferred pressure and the fluid twisting means shown in FIG. **3** are used in the process of this invention, a poly(ethylene terephthalate) tape, e.g., will have a twist of greater than 20,000 turns/minute imparted to it.

Via this process from about **5** to about 300 fibrils per tape will be produced, although it is preferred to adjust the operating conditions of this invention so that from about 25 to about 200 fibrils per tape will be produced.

This process is applicable to any fibrillatable tape such as, e.g., fibrillatable tape essentially comprised of poly (ethylene terephthalate), poly(trimethylene terephthalate), poly (tetramethylene terephthalate), polypropylene, nylon, etc. Inasmuch as a fibrillated film yarn produced from tape essentially comprised of poly(ethylene terephthalate) has the desirable properties of poly(ethylene terephthalate) yarn (such as high modulus, susceptibility to texturing, etc.) and is cheaper and has better aesthetic characteristics than yarn currently available, it is preferred to apply this process to produce fibrillated yarn comprised of poly(ethylene terephthalate).

Another process that the applicant has discovered (which may be used together with applicant's "fluid twisting means process" but can also be used with any fibrillating means), affords an especially advantageous means of fibrillating poly(ethylene terephthalate). It is very difficult to drew and fibrillate poly(ethylene terephthalate) in accordance with the procedure the art discloses for polypropylene fibrillation, for when this is done a weak, non-uniform, commercially useless yarn is usually produced. The following process solves this problem.

In this latter process a tape essentially comprised of polyester with specified properties is fibrillated. The spun tape is from about 0.0002 to about 0.0005 inches thick. The thickness of the tape may be controlled by extruding a film and slitting a tape to the required dimensions or by extruding a tape and controlling the dimensions of the die through which it is extruded and/or the quench height (the distance from the die face to the quenching medium). It is preferred to extrude the tape through a slit die which measures about 1 inch by from about 0.003 to about 0.015 inches and to have a quench height of from about 0.2 to about 2 inches, and it is most preferred to extrude the tape

through a slit die measuring about 1 inch × about 0.0006 inch and to use a quench height of about 0.5 inches. Any quenching medium can be used. The preferred quenching medium is water, and when it is used the quench temperature (i.e., the temperature of the quench medium) is about 0 to about 60 degrees centigrade, although it is preferred that it be about 30 degrees centigrade. One may, alternatively, quench on chill rollers, e.g.. The aforementioned parameters may be varied to obtain the desired tape thickness of from about 0.0002 to about 0.005 inches; any of the infinite combination of variables by which one obtains the aforementioned tape thickness is within the scope of applicant's discovery.

After said polyester tape is extruded and quenched, it may be dried to a moisture content of less than about 2 percent (by weight of tape), although when this step is employed it is preferred to dry the tape to a moisture content of less than about 1 percent. Drying should be used if a hot air drawing step is employed.

The tape used in this latter process may or may not be comprised of from about 0.1 to about 25 percent (by weight of polyester) of incompatible polymer. If incompatible polymer is used in said latter process, it must be non reactive and be dispersed finely in the polyester so that the average particle size of the dispersed incompatible polymer is less than about 8 microns. POlymer selected from the group consisting of polyethylene and polypropylene is the preferred incompatible polymer, although other polymers, which can be extruded with polyester without undergoing serious degradation of themselves which adversely affect (e.g. degrade) the polyester, may be used (e.g. nylon 6, nylon 6.6, polystyrene, etc.).

The most preferred incompatible polymer is polypropylene, and it is preferred to use at least about 0.5 weight percent of it and incorporate it into the tape. It is more preferred to use from about 1 to about 3 percent of polypropylene, and it is most preferred to use about 2 percent of polypropylene.

The mere addition of polypropylene in the latter process will not, in and of itself, promote fibrillation: the polypropylene should be finely dispersed throughout the poly(ethylene terephthalate) so that the average size of the polypropylene particles therein is less than about 8 microns, although it is preferred that they be less than about 4 microns, and best results are obtained when they are less than about 1 micron. Many methods well known to the art may be used to obtain the required degree of dispersion.

One method applicant has used to obtain the required degree of dispersion is to mix poly(ethylene terephthalate) and polypropylene and extrude the mixture at a high temperature (e.g., about 285 ° centigrade) through a slit die. It is believed that, for this method to work well, the viscosities of the poly(ethylene terephthalate) and the polypropylene should be about equal. Polypropylene is relatively nonnewtonian, i.e., its viscosity is dependent upon shear rate, whereas poly(ethylene terephthalate) is nearly newtonian; thus it is believed that, with the use of the proper conditions, at some stage during the extrusion process the apparent viscosities of the two polymers will be matched. It is believed that, in order to get good dispersion with this method, the following conditions should exist; (1) the poly(ethylene terephthalate) should have an intrinsic viscosity of from about 0.45 to about 0.75, although it is preferred that it has an intrinsic viscosity of from about 0.61 to about 0.67; (2) the polypropylene should have a melt flow index (as measured by ASTM D-1238 62T, condition E or condition L) of from about 8 to about 22, although it is preferred that it have a melt flow index of about 15; (3) a mixture comprised of from about 0.5 to about 5 percent of polypropylene (by weight of poly[ethylene terephthalate]) and poly(ethylene terephthalate) should be prepared; (4) this mixture should be extruded via a pack which imposes a shear force of from about 60 to about 150 sec^{-1} for from about 1 to about 2 seconds; and (5) the extrusion temperature should be from about 280 to about 300 degrees centigrade, it being preferred to use an extrusion temperature of about 285 degrees centigrade. Under these conditions good dispersion of polypropylene results. It is to be understood that this is merely one means of obtaining the desired degree of dispersion, and any polyester tape comprised of the desired amount of polypropylene with the desired degree of dispersion as well as the process of using said tape to produce fibrillated polyester yarn are within the scope of this invention.

This latter process, which utilizes the polyester tape described hereinabove, can make yarn with denier of from about 30 to about 10,000; this yarn is useful for knitting, weaving and tufting.

The polyester tape applicant has discovered should, prior to the time it is fibrillated, be subjected to a step which applicant has found to be important for good fibrillation: it is hot drawn to a draw ratio of from about 3.3 to about 4.2 while being subjected to a temperature of from about 80 to about 140 degrees centigrade, and thereafter it is subjected to a temperature of from about 120 to about 230 degrees centigrade for from about 0.01 to about 0.2 seconds. It is preferred that the polyester tape be hot drawn to a draw ratio of about 3.5 while it is being subjected to a temperature of from about 80 to about 140 degrees centigrade for from about 0.08 to about 0.8 seconds and that it thereafter be subjected to a temperature of from about 200 to about 230 degrees centigrade for from about 0.02 to about 0.1 seconds preferably by passing it over a hot plate or a hot air oven, the use of the hot plate being most preferred. The "residence time", the period of time during which said tape is being hot drawn and subjected to a temperature of from about 80 to about 140 degrees centigrade, is a function of, e.g., the speed at which the process is being run; it generally is from about 0.1 to about 1 second, and it most preferably is from about 0.2 to about 0.4 seconds.

The polyester tape may be drawn in hot air at a preferred hot air drawing temperature of from about 80 to about 150 degrees centigrade, it being more preferred to use a hot air drawing temperature of about 80 degrees centigrade; hot air drawing is the preferred drawing method. Alternatively the polyester tape may be drawn in hot water at a preferred hot water drawing temperature of from about 80 to 100 degrees centigrade, it being more preferred to use a hot water drawing temperature of about 90 degrees centigrade. The temperatures described hereinabove are the temperatures of the tape and not those of the drawing medium.

It is preferred that said polyester tape, after it has been subjected to the aforementioned step of hot drawing it and thereafter subjecting it to a temperature of from about 120 to about 230 degrees centigrade, have been drawn to a total draw ratio of from about 4 to about 5.5. Although the tape may be drawn to a draw ratio of from about 5.5 in one stage, it is preferred that it be so drawn in two stages. In the first stage, which corresponds to the first part of the aforementioned step, the tape may be drawn to a draw ratio of from about 3.3 to about 4.2 while being subjected to a temperature of from about 80 to about 120 degrees centigrade for from about 0.1 to about 1 second. In the second stage, which corresponds to the second part of the aforementioned step, the tape may be further drawn to increase the total draw ratio to from about 4 to about 5.5 while being subjected to a temperature of from about 120 to about 230 degrees centigrade for from about 0.02 to about 0.2 seconds.

The drawn tape can be fibrillated by any of the processes well known to the art which will provide sufficient stress to fibrillate it. Thus, e.g., the tape may be fibrillated as taught in British Pat. 1,118,912 by contacting it with a roller having on its periphery a plurality of grooves of equal pitch and cutting edges of equal pitch disposed substantially in spiral form. Thus, e.g., the tape may be fibrillated as taught in U. S. Pat. No. 3,302,501 by passing it over a stationary brush or a similar shredding means or, alternatively, by piercing the film through its thickness in a plurality of points without shredding the film by, e.g., moving the piercing means longitudinally or laterally through the film as it is pierced. Thus, e.g., the tape may be fibrillated as taught in U. S. Pat. No. 3,177,557 by passing it through a zone of high turbulence provided by a high velocity jet of stream of air or other gas.

It is preferred to fibrillate said poly(ethylene terephthalate) tape by the "four fluid twisting means" process of this invention wherein the tape is subjected to the action of at least four fluid twisting means wherein the direction of twist imparted to the tape is completely and sharply reversed between adjacent twisting means and the tape is advanced from one fluid twisting means to another while being maintained under a tension of from about 0.05 to about 0.2 grams per denier.

As was stated hereinabove, the latter process of this invention may be advantageously used to fibrillate any fibrillatable tape. Thus, e.g., it may be used to fibrillate poly(tetramethylene terephthalate). Poly(tetramethylene terephthalate) tape can be prepared in substantial accordance with the procedure described for the preparation of poly(ethylene terephthalate) tape. The addition of at least 0.5 percent of polypropylene (by weight) is not essential to produce good fibrillation with poly(tetramethylene terephthalate) tape, but said use of polypropylene is advantageous in three respects: it makes the extruded poly(tetramethylene terephthalate) film more stable and easier to process, it renders said film slightly easier to fibrillate, and the fibrillated yarn produced from said film is stronger than yarn produced from poly(tetramethylene terephthalate) film which is not comprised of polypropylene. Said poly(tetramethylene terephthalate), with or without a minor amount of polypropylene, is extruded into a film or tape which is uniaxially drawn to a draw ratio of from about 4.0 to from about 6.0, although it is preferred to use a draw ratio of about 5.0. The drawn film is then slit into the required denier, which is generally from about 150 to about 600, and fibrillated in accordance with the process of this invention. The yarn produced is very similar to the poly(ethylene terephthalate) yarn produced via the process of this invention.

In a typical process which may be used for the production of e.g., fibrillated poly(ethylene terephthalate) yarn, poly (ethylene terephthalate) polymer and the required amount of polypropylene is passed through an extruder, and through a tape die into a water quench (alternatively, a chill roll may be used). Then it is wound on a godet, passed through a hot air oven, wound over a second godet, passed over a hot plate, passed over a third godet, and subjected to the action of four fluid false twisting means in apparatus. Thereafter the fibrillated yarn is wound by tension controlled winders. Said typical process is only one of the many which may utilize applicant's invention.

In order to better describe some of the preferred embodiments of applicant's invention, the below mentioned examples are presented. Unless otherwise mentioned, all parts are by weight and all temperatures are in degrees centigrade.

In examples **1–4**, a tape of the polymer under investigation was prepared by extrusion and drawing under conditions which gave favorable fibrillation at about 1000 feet per minute windup speed with the process of this invention (four fluid twisting means). This tape was then fibrillated over a range of speeds from 150 feet per minute up to 2000 feet per minute in processes wherein it was subjected to only two fluid twisting means and to four fluid twisting means. A sample for each run was cross-sectioned (five cross-sections for each sample at approximately 3 meter intervals), and the number of fils was counted. The average of the five cross-sections was then taken as the degree of fibrillation for a sample.

In analyzing the results, the speed at which one need run the "two twisting means" process with the "four twisting means" process was compared. The results were averaged to reduce the degree of uncertainty produced by the statistical variability of the fibril count. In all runs the twisting means used was essentially the same as that disclosed in FIGS. **3** and **4**, wherein the apparatus disclosed comprises **2** twisting means (and is referred to as a "jet" in these Examples). When, e.g., other fluid twisting means, such as the apparatus shown in FIGS. **1**, **2*a***, and **2*b***, are used, similar results are obtained.

EXAMPLE 1

Poly(ethylene terephthalate) with an intrinsic viscosity of 0.61 and 2 percent (by weight of polyethylene terephthalate) of polypropylene with a melt flow index of 15 were mixed and then subjected in a pack to a shear force of 120 sec^{-1} for about 1 second and extruded via a pack through a slit die (which was 1 inch × 0.0005 inch); the extrusion temperature was 280 degrees centigrade. The extruded tape was quenched in water (at a quench height of 1.25 inch) and spun. The spun tape was 10 mm wide and had a total spun denier of 3150. The spun tape was then

drawn in a first stage at a draw temperature of about 110 degrees centigrade and a draw speed of 175 feet per minute to a draw ratio of 3.5/1, and thereafter it was drawn in a second stage at a draw temperature of about 200 degrees centigrade and a draw speed of **120** feet per minute to a draw ratio of 1.4/1.

This tape was then fibrillated with one "jet" (comprising two fluid twisting means wherein the direction of twist imparted to the tape is completely reversed between adjacent twisting means) and two jets. The maximum speeds one could use to get any given degree of fibrillation with one jet and two jets operated at the same conditions (i.e., same as pressure and tension) are shown below.

Number of Fils/Tape	Maximum speed one can use with one jet to obtain the specified degree of fibrillation (feet/minute)	Maximum speed one can use with two jets to obtain the specified degree of ibrillation (feet/minute)
60	0 (i.e., at no speed could the one jet give one this degree of fibrillation)	100
50	0	170
40	70	300
35	130	410
30	230	greater 600 than
25	500	greater 600 than

EXAMPLE 2

A poly(ethylene terephthalate) tape was prepared in substantial accordance with the procedure described in Example 1, with the exception that the first stage draw ratio was 3.6/1, the first stage take up speed was 1080 feet per minute, the first stage draw temperature was 127 degrees centigrade, the second stage draw ration was 1.3/1, and the second stage take up speed was the same speed as the fibrillation speed. The tape was comprised of poly(ethylene terephthalate) with an intrinsic viscosity of 0.61 and 2 percent polypropylene with a melt flow index of **15**.

This tape was then fibrillated with one jet and two jets. The results are presented below.

Number of Fils/Tape	Maximum speed one can use with one jet to obtain the specified degree of fibrillation (feet/minute)	Maximum speed one can use with two jets to obtain the specified degree of fibrillation (feet/minute)
50	0	300
45	75	450
40	225	650
35	400	1600
30	650	greater 2000 than

This example differs from Example 1 in that the tape was prepared at much higher drawing speeds; this effect increases the fibrillation for a given speed through the jets and at the higher speeds make the fibrillation less sensitive to changes in speed.

It was observed that the use of the two jets decrease the number of large filaments, thus contributing to the uniformity of the yarn. To quantify this observation the cross sections made for Example 2 were examined and the number of fils with a breadth to thickness ratio greater than **6** were tabulated. On averaging, the following results were obtained.

Wide Fil Count (Average)

	1 jet	2 jets	
Temp. of Hot Plate, °C	1404.5	2.2	Speed effect averaged
	170—	2.2	
	200—	**0.6**	
Speed fpm	4003.8	0.6	Temperature effects average
	8004.0	1.6	
	12003.8	2.0	
	16005.0	2.2	
Overall average Total	3.7	1.5	Temp and speed effects averaged

This experiment shows that the addition of the second jet is very effective in reducing the number of wide fils. Another effective method of reducing wide fils is to increase the hot plate temperature to 200 degrees centigrade. With the use of two jets and a hot plate temperature of **200** degrees centigrade, the incidence of wide fils was almost eliminated.

EXAMPLE 3

In substantial accordance with Example 1, a nylon fibrillatable tape comprised of 2 percent of polypropylene was prepared. The nylon 6.6 had a relative viscosity of 40, and the polypropylene had a melt flow index of 15. Total spun denier of the spun tape was 2000.

The term "relative viscosity" as employed in conjunction with the nylon polymers may be defined as a measure of the ratio of the viscosity of a solution of a given strength of the polyamide in a given solvent to the viscosity of the solvent itself at the same prescribed temperature. The relative viscosity values noted herein utilize 90 percent by weight of aqueous formic acid as the solvent. The efflux time t of an 8.4 percent by weight solution of the polyamide in the formic acid solvent is determined and the ratio of said viscosity to the efflux time t of the solvent itself is the measure of relative viscosity as determined by the equation:

$$RV = t/t^{\circ}$$

The temperature employed for the determination of these viscosities is 25 degrees centigrade.

The nylon tape was then fibrillated with one and two jets; the results are shown below.

Number of Fils/Tape	Maximum speed (f.p.m., one jet)	Maximum speed (f.p.m., two jets)
50	75	250
45	150	325
28	750	1600
26	950	2500

EXAMPLE 4

In substantial accordance with Example 1, a tape comprised of poly(tetramethylene terephthalate) with an intrinsic viscosity of 0.67 and 2 weight percent of polypropylene (with a melt flow index of 15) was prepared. The term "intrinsic viscosity" as used with reference to polyester polymers may be defined as the limit of the ratio of solution viscosity to solvent viscosity taken from one 1 divided by the concentration of the polymer in solution as the concentration approaches zero

$$\left(\eta = \lim_{c \to 0} \frac{\eta - \eta_s}{c\eta_s}\right)$$

units are in deciliters/gram. Measurements may be made of relative viscosity (on an 8 percent solution polyester in orthochlorophenol) and converted to intrinsic viscosity by an empirical formula. The tape was 8 mm wide and had a total spun denier of 400. The draw ration used was 5/1 and the draw speed was 1500 feet per minute. The tape was fibrillated with one jet and two jets, and the results are shown below.

Number of Fils/Tape	Maximum speed one can use with one jet to obtain the specified degree of fibrillation (feet/minute)	Maximum speed one can use with two jets to obtain the specified degree of fibrillation (feet/minute)
90	0	375
80	200	550
60	550	1200
58	625	1500
56	700	2500

EXAMPLE 5

In substantial accordance with Example 1, a tape 9 mm wide of total denier 3000 was extruded from a polymer mix of 2 percent polypropylene (M. F. I. 15) and 98 percent poly (ethylene terephthalate) (0.61 intrinsic viscosity). This tape was drawn into hot air in two stages to a total draw ratio of 4.9/1. The drawn tape was then fibrillated by passing it through one of the "jets" disclosed in FIGS. **1**, **2***a*, and **2***b* at a rate of 50 **feet per minute with an applied air pressure of** 60 p.s.i.g. and a yarn tension of 75 grams. A fibrillated yarn with an average of 45 filaments was obtained. The yarn was then passed through another such jet at a rate of 200 feet per minute with an applied air pressure of 60 p.s.i.g. and a yarn tension of 50 grams. The yarn obtained had an average of about 100 filaments per tape (as determined by a fibril count of microscopically prepared cross-sections of the yarn). The length/breadth distribution of the yarn, estimated from this cross-section, was as follows:

Length/Breadth Ratio	Percent Frequency
0–1	1
1–2	22
2–3	27
3–4	21
4–5	16
5–6	10
6–7	3

The average length/breadth ratio is 3.2. The yarn, has a total denier of 600 and an average denier per filament of about 6, has a tenacity of 2.4 grams per denier, and an elongation of 12.5 percent. This yarn, as well as the other yarns described herein, are useful in polyester shaped articles; more particularly, said yarns are useful in textile fabrics and garments.

EXAMPLE 6

In substantial accordance with Example 5, an 800 denier drawn tape was prepared and fibrillated through two of said jets at a rate of 100 feet per minute with a yarn tension of 50 grams and an air pressure of 60 p.s.i.g. The yarn has an average of 68 filaments, with an average length/breadth ratio of 4.3.

EXAMPLE 7

In substantial accordance with Example 5, a poly(ethylene terephthalate) tape was drawn uniaxially in two stages to a total draw ratio of 4.9; the dimensions of the drawn tape were approximately 15 microns thick and 4.5 mm wide. The tape was subjected to the action of two of the aforementioned jets at a rate of 280 feet per minute with a yarn tension of 55 grams and an air pressure of 40 p.s.i.g. The resulting fibrillated yarn had a tenacity of 2.45 grams per denier, an elongation of 4.7 percent, and an initial modulus of 84 grams per denier. On average, about 51 filaments could be counted at a cross-section of the yarn. From microscopic examination the cross-section of an average filament could be described as essentially rectangular and had an average aspect ratio of 4.7/1. The total denier of the yarn was 684,with an average denier per filament of 13.4. The yarn was very slightly hairy in appearance.

This yarn was 4 ply twisted into a thick yarn and tufted, as a face yarn, into a carpet. Tufting performance was exceptionally good and, except for a pleasant sheen, performed similarly to continuous filament carpets from which it was difficult to distinguish. It was judged far superior to commercially available carpets of fibrillated polypropylene.

EXAMPLE 8

In substantial accordance with Example 7, a poly(ethylene terephthalate) tape was drawn to a draw ratio of 5.4; the tape was 4.5 mm wide and 16.5 microns thick. This tape was fibrillated by passing it through **3** of the aforementioned jets at a speed of **232** feet per minute under a yarn tension of 60 grams with an applied air pressure of 80 p.s.i.g. A fibrillated yarn was obtained with a tenacity of 3.2 grams per denier, an elongation of 4.5 percent, and initial modulus of 106 grams per denier. The yarn had an average of 71 filaments per tape. The average cross-section ratio was 3.1.

The continuous filament yarn was woven as filling yarn into a warp of 70 denier polyester to give a fabric which would be suitable in upholstery and drapery. After dyeing and heat setting, the fabric had a soft and pleasant handle and exhibited good drape and a pleasing and unusual surface sparkle.

EXAMPLE 9

In substantial accordance with Example 5, a poly(ethylene terephthalate) tape was prepared which had a denier of 680 and a film thickness of 15 microns. This tape was fibrillated by passing it through two of the aforementioned jets at 285 feet per minute under yarn tension of 55 grams with air pressure of 40 p.s.i.g. being supplied to the jets. The tape fibrillated into a yarn composed of an average 51 filaments, corresponding to an average denier per filament of 13.4. The yarn had only three ends per centimeter and a tenacity of 2.5 grams per denier. To produce fibrillation of this quality with only one jet (comprised of only two twisting means), it was necessary to lower the fibrillation speed to 70 feet per minute.

EXAMPLE 10

In substantial accordance with Example 5, a poly(ethylene terephthalate) tape was prepared and fibrillated through two of said jets at a speed of 532 feet per minute under a yarn tension of 60 grams and with 80 p.s.i.g. of air pressure being furnished the jets. The yarn produced was 393 denier, had 48 filaments and a tenacity of 4.4 grams per denier, was comprised of very few broken ends, and had an elongation of 6 percent and an initial modulus of 80 grams per denier.

This yarn was woven into a drapery fabric which had good drape, soft hand, dyed uniformly, and had a pleasant, sparkly surface effect. This yarn was also woven into a fabric suitable for awnings, tents, etc., in which the fabric properties match or surpass a similar fabric made from cotton.

EXAMPLE 11

Poly(tetramethylene terephthalate) polymer with a relative viscosity of 37.5 was extruded at a temperature of 255 degrees centigrade into a water quench to give a film 4.5 mm wide with a denier of 1520. This tape was then drawn in hot air at a temperature in excess of 80 degrees centigrade in two stages to a total draw ratio of 5/1. The drawn tape was then fibrillated through two jets similar to those shown in FIGS. **1**, **2***a*, and **2***b* at a speed of 50 feet per minute under a yarn tension of 50 grams with an applied air pressure of 60 p.s.i.g. A fibrillated product was obtained with an average filament count of 34 and an average dpf of 8.9. The filament cross-section is rectangular with the thin dimension about 17 microns and the cross section range between 1/1 and 4.5/1 with about 70 percent of the filaments being in the 2.5/1 to 3/1 range. The yarn had an elongation of 12.6 percent, a tenacity of 0.87 grams per denier, and an initial modulus of 12.0 grams per denier at 60 percent strain rate.

EXAMPLE 12

Poly(tetramethylene terephthalate) polymer with a relative viscosity of 37.5 was blended with 3 weight/percent of polypropylene (melt flow index 12) and extruded to give a film 7.5 mm wide with a denier of 4250 and a birefringence of 3.6.

The tape was drawn and fibrillated under the same conditions used in Example 11. A fibrillated yarn was obtained with an average filament count of 26, average denier per filament of 33, and very few broken ends. The filament cross section was rectangular with the thin dimension being 38 microns. The aspect ratio range is from 2/1 to 7/1. The surface of the filament was very smooth and in appearance very like similarly processed poly(ethylene terephthalate) yarns. The yarn had a tenacity of 2.0 grams per denier, an elongation of 12 percent, and an initial modulus of 30 grams per denier at 60 percent strain rate.

It is preferred that the yarns of this invention be comprised of at least 90 percent (by weight of yarn) of polymer selected from the group consisting of poly(ethylene terephthalate), poly(trimethylene terephthalate), poly(tetramethylene terephthalate), nylon, and mixtures thereof. This invention comprehends combination yarns wherein, e.g., one or more tapes are simultaneously fed to the false twisting means and combined or where, e.g., fibrillated yarn is combined with conventional filament or semicontinuous yarn. The yarn of this invention may contain additional additives such as dyes or colorants; delustrants such as titanium dioxide; or particulate materials such as talc, china clay, or glass.

The tapes described in this invention have utility for, e.g., the preparation of carpet backing materials. Furthermore, they can be used as tufting materials for artificial grass constructions.

Although the above examples and descriptions of this invention have been very specifically illustrated, many other modifications will suggest themselves to those skilled in the art upon a reading of this disclosure. These are intended to be comprehended within the scope of this invention.

WHAT IS CLAIMED IS:

1. A continuous filament fibrillated yarn comprised of random-length fibrils of a synthetic organic high polymer wherein: the aspect ratio of cross sections of the fibrils is from about 2/1 to about 12/1, and the aspect ratios of the cross sections of the fibrils range from about 0.5/1 to about 20/1, the fibrils in the yarn exceeding 40 centimeters in length comprise at least 70 percent (by weight) of the yarn; the tenacity of the yarn is from about 0.1 to about 10 grams per denier; the total denier of the yarn is from about 30 to about 10,000, and the average denier per fibril of the fibrils comprising the yarn is from about 0.5 to about 60; the elongation of the yarn is from about 0.5 to about 75 percent; and the initial modulus of the yarn is from about 2 to about 300.

2. The yarn of claim **1**, wherein said yarn is essentially comprised of polymer selected from the group consisting of poly(ethylene terephthalate) polymer, poly(trimethylene terephthalate) polymer, and poly(tetramethylene terephthalate) polymer; said yarn contains less than **4** free fibril ends per centimeter.

3. The yarn of claim **2**, wherein said polymer is poly(ethylene terephthalate).

4. The yarn of claim **3**, wherein said polymer has an intrinsic viscosity of from about 0.4 to about 0.8; the average aspect ratio of the yarn is from about 2.5 to about 7.0 and the average aspect ratio of fibrils comprising the yarn is from about 3/1 to about 5/1; the tenacity of the yarn is from about 0.5 to about 7 grams per denier; the elongation of the yarn is from about 1 to about 20 percent; the initial modulus of the yarn is from about 30 to about 200 grams per denier; the fibrils comprising the yarn have a tenacity of from about 2 to abOut 6 grams per denier and an elongation at break of from about 2 to about 25 percent; and the boiling water shrinkage of said yarn is up to about 20 percent.

5. The yarn of claim **4**, wherein said initial modulus is from about 50 to about 120 grams per denier and said boiling water shrinkage is from about 5 to about 10 percent.

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