ABSTRACT OF THE DISCLOSURE

A process is disclosed for drawing and crimping polyester filaments which have been asymmetrically quenched during melt spinning. A tow of the filaments is drawn during passage through a hot gas, passes from draw rolls into a cool air jet which cools and opens the tow, and is conveyed through a relaxation chamber. Tension is maintained on the tow until just prior to the air jet. Large unopened groups of filaments are avoided when the conditions are such that the moisture content of the opened tow is less than 2% when the tension is released.

This invention relates to the drawing of a tow of crystalizable, synthetic linear condensation polyester filaments having asymmetric birefringence to cause them to crimp spontaneously after they have been drawn. The invention is more particularly concerned with processing a tow so that it will open to form a highly bulked, uniform tow-bundle of crimped polyester filaments after release of the drawing tension.

In a recent development in the field of polyester fibers, it has been found that crimped filaments of improved properties can be formed by extruding the molten polyester in the form of filaments, quenching the extruded filaments with a fluid in an asymmetric manner so that one of the wet filaments is solidified before the other side, and orienting the extruded filament. Asymmetric cooling of the filament may be achieved, for example, by employing as the quenching medium a jet of air or other gas directed upon one side of the extruded filament a short distance from the spinneret rather than by cooling the filament over a considerable distance with a current of air, as in conventional melt spinning. Although the as-spun filaments are straight and indistinguishable by sight from ordinary as-spun filaments, they show different optical properties; i.e., an asymmetrically quenched filament exhibits an asymmetric birefringence differential across the diameter of the filament as contrasted with a symmetric differential, or lack of any differential, associated with ordinary polyester filaments. When the asymmetrically spun filaments are oriented by drawing to a length about 2 to 5 times their extruded length and the drawing tension is released, they exhibit crimp of a three-dimensional or reversing helical nature unobtainable by conventional mechanical-crimping methods.

The three-dimensionally cramped filaments are highly valuable, especially when converted to staple fibers, for many important uses including the preparation of fabrics with improved bulk, cover, and wool-like aesthetics and as stuffing materials of enhanced bulk and softness for pillows and the like. In commercial practice, it is desired to manufacture the cramped filaments in the form of tow, which consists of a large number of filaments. The tow may be shipped as such for use as a stuffing material in tow form or for direct conversion to staple yarns via the tow-to-top process; or it may be cut to staple fibers prior to shipment.

In accordance with the method employed hitherto, the asymmetrically quenched polyester filaments have been gathered together into a tow after the spinning step, oriented by drawing the tow in a bath or spray of hot water, opened by passage of air through the tow, and heat-relaxed in an oven to set the crimp to the desired extent. Unfortunately, the tows so produced are characterized by a high incidence of defects comprising large unopened groups of cramped filaments cohering firmly together substantially along their entire length. Such defects have been designated as "caterpillars." When processed to staple yarns, the non-uniform tows containing these "caterpillars" require one or more extra combing steps, and frequently it is difficult or impossible to eliminate the defects entirely. The occurrence of "caterpillars" causes particularly severe problems when the tow is processed via the tow-to-top process.

It is an object of this invention to provide an improved process for preparing oriented tows of asymmetrically quenched, cramped polyester filaments.

It has now been found that a highly fluffy tow bundle exhibiting a very desirable appearance and possessing superior fiber properties can be prepared by drawing a tow, of synthetic linear condensation polyester filaments having an asymmetric birefringence differential across the filament diameters, in a hot gas at a temperature above the second-order transition temperature of the polyester and below the melting point of the polyester, the tow being sufficiently dry to have a moisture content of less than 6% of the weight of the tow as it emerges from the hot gas and each portion of the tow being in contact with the hot gas for less than one second, maintaining the moisture content of the tow below 6% of the weight of the tow while the tow is under tension, releasing the drawing tension and passing the tow through a jet of gas at a temperature below the second-order transition temperature of the polyester to cool and open the tow while crimp develops in the filaments.

Preferably, the moisture content of the tow when the tension of drawing is released is less than 2% of the weight of the tow. The contact time of the tow in the hot gas under tension is preferably less than 0.5 second. In one embodiment of the invention, the tow is drawn in steam, the temperature and rate of flow of the steam being regulated to maintain the moisture content of the tow less than 6% (preferably less than 2%) of the weight of the tow when it is opened, i.e. when it is passed into the jet with release of the tension of drawing. In another embodiment of the invention, the tow is drawn in hot air. Any application of cooling water or aqueous finishes in connection with the drawing must be regulated to provide a moisture content of less than 6% (preferably less than 2%) by weight of the tow at the time the tension of drawing is released, of course. The hot gas may be applied to the tow in one or more stages by means of a jet or by other suitable means; although if the gas is applied in more than one stage the initial and final exposure of the gas to the tow should occur within a contact time of less than one second (preferably less than 0.5 second) to avoid loss of crimp.

Polyester tow bundles produced in accordance with the present process have a desirable, open, fluffy appearance as contrasted with the relatively dense, stringy or ropy appearance characteristic of previously produced tows. In the previously produced tows, the unopened groups or clumps of cramped filaments ("caterpillars") characteristically comprise up to 200 or more filaments per clump, as contrasted with fewer than about 100 and usually fewer than 50 filaments per clump in tows produced in accordance with the present process. The fluffy tow bundle can be processed much more readily than dense, stringy tows; and staple fibers cut from the fluffy
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The tow are correspondingly more highly separated and less likely to lose crimp when relaxed than fibers cut from denser tows. The ease of processability of the fluffy tow carries over to the staple fibers prepared from it, which can likewise be processed with great facility. Most importantly, the bulk support afforded by the fluffy tow produced in accordance with the present process, or by staple fibers prepared from it up to 40% higher under load than the bulk support of previously produced tows or their corresponding staple fibers.

The nature of the invention will be more readily understood by reference to the following description taken in conjunction with the figures of the accompanying drawing, which is a schematic illustration of the process for drawing the tow in a jet of hot gas and then opening the tow in a jet of cool air with release of the drawing tension.

Referring now to the figure, tow 9 comprises a large number of polyester filaments which have been melt extruded and jet quenched in an asymmetric manner, e.g., employing apparatus of the type disclosed by Lees in his U.S. Patent No. 3,061,874 of Nov. 6, 1962. The tow is drawn by being passed from feed rolls 1 through 8, respectively, maintained at a given uniform peripheral speed and then around draw rolls 11 through 18, respectively, having a uniform peripheral speed considerably higher than that of the feed rolls. Between the last feed roll 8 and the first draw roll 11 the tow passes between a pair of jets 19 containing elongated slits for supplying hot gas, surrounded by enclosure 20 from which the gas may be exhausted through outlet 21. When steam is employed as the hot gas, the temperature and rate at which the steam is supplied should be adjusted such that the moisture content of the tow upon release of tension of drawing is less than 0.6%. It is preferable to keep the moisture level below 2% and desirable to keep the tow as dry as possible.

After leaving the draw roll 18 at the end of the draw section, the tow is passed around puller rolls 22. The tow is then passed through an air jet traversing funnel 23 which lays the tow down on a conveyor 24, upon which the tow is passed through relaxing chamber 25. At the end of the relaxing chamber, the tow is deposited in container 26, preferably with a traversing means (not shown). The three-dimensional or reversing helical crimp becomes apparent in the filaments as they are released from the jet, and is passing out of the funnel 23. The tow may be cut to staple fibers after relaxation or, if desired, may be collected in an intermediate step and cut to staple fibers prior to relaxation.

The term "tow," as used herein, refers to a large number of continuous, substantially parallel, synthetic filaments collected in a loose, ribbon-like or rope-like form without definite twist. The tow may be in the form of a web. Generally speaking, the minimum number of filaments to which the term "tow" is considered applicable is on the order of about five hundred, and normally there are at least 10,000 filaments. A tow may be quite large. Tows containing on the order of 1,000,000 filaments are frequently encountered, and there may be occasional to employ tows of 10,000,000 filaments, or even more. The filaments may be of round cross-section, or of trilobal or other nonround cross section.

In general, the invention is applicable to any crystallizable, linear condensation polyester. These comprise linear polymers containing in the polymer chain carboxyloxy linking radicals,

\[ \text{O} - \text{C(OH)} - \text{O} - \]

Polymers containing oxycarboxyloxy radicals are comprehended within this group. The polymers should be of molecular weight; usually, this implies a relative viscosity of about 10 or higher as conventionally measured in solution in a solvent for the polymers. A good solvent for most of the linear condensation polymers is a mixture of 58.8 parts of phenol and 41.2 parts of tri-chlorophenol. Copolymers, teropolymers, and the like are intended to be comprehended within the term "polymer." Examples of crystallizable, linear condensation polymers include polyethylene terephthalate, polyethylene terephthalate/sulfite ester (5%/95), polyethylene terephthalate/S - (sodium sulfite)isophthalate (97/3), poly-(p-hexahydroxyethylene terephthalate), poly (deca-hydronaphthalene - 2,6 - dimethylene 4,4' - bibenzoate), polyethylene 2,6 - or 2,7-naphthalenedicarboxylate, and poly(bicyclohexyl - 4,4'-dimethylene 4,4'-biphenylate), as well as many others. Preferably, the polyester of which the tow and staple fibers of the invention are formed is a linear glycol terephthalate polyester. By this is meant a linear condensation polyester derived from a glycol and an organic acid in which the glycol component is comprised substantially of a dihydroyx compound of a divalent saturated hydrocarbon radical containing from 2 to 10 carbon atoms and the acid component is at least about 75 mol percent terephthalic acid.

The expression "second-order transition temperature," also designated herein by the symbol \( T^\alpha \), is defined as the temperature at which a discontinuity occurs in the curve of a first derivative thermodynamic quantity with temperature. It is correlated with yield temperature and polymer fluidity and can be observed from a plot of density, specific volume, specific heat, sonic modulus or index of refraction against temperature. \( T^\alpha \) is sometimes also known as the "glass transition temperature" because it is the temperature below which the polymer exhibits glass-like behavior; above \( T^\alpha \) the polymer is somewhat more rubber-like. A convenient method for determining \( T^\alpha \) for a given sample of a polymer is given by Pace in U.S. Patent No. 2,556,295 of June 12, 1951 (column 3, line 24, to column 4, line 19). The crystallinity of the polymer sample selected for measurement of \( T^\alpha \) should be comparable with the crystallinity of the drawn filaments of the polymer.

To observe the degree of symmetry of birefringence of a fiber, the Hecks method for refractive index is employed, with the fiber immersed in a liquid having a refractive index close to the refractive index of the fiber. The immersed fiber is observed under a polarization microscope with the analyzer in place and the polarizer removed. For best observance the jet 23 the drawing axis should be parallel to the fiber axis. When the fiber is in focus, halos are observed on either side of the fiber. When the focus of the microscope is changed slightly, the halos are observed to move in a symmetrical fashion towards or away from the fiber axis when the fiber has symmetrical birefringence. For jet-quenched fibers or other fibers having unsymmetrical birefringence, the halos move at different rates or times when the focus of the microscope is changed. If the fiber at first appears symmetrical, it should be turned approximately 90° to make sure that by chance the line of sight was not in the plane of asymmetry of the fiber in its initial position.

The following examples will serve to illustrate the invention, although they are not intended to be limitative. The "bulk support test" referred to in the examples is a measure of the compressional properties of the crimped fibers. In carrying out this test, samples are prepared by processing quantities of the staple fibers through a worsted card which is equipped with a 10 cm. by 6.4 mm. (4 inches by 24 inch) doffing trumpet. The flat silver so produced is cut into 15.2 cm. (6-inch) rolls. The flat card is used to prepare all samples tested, and the settings of the card are maintained rigidly constant, in order to produce silver having a constant degree of openness. Since the absolute values of the bulk support measurement are dependent on this, the silver, maintenance of constant worsted card settings this permits correlation sample values obtained at different times.
A stack of the squares of card sliver weighing 20 grams ±1 gram is prepared by piling the squares cross-wise. The weight of the stack is determined to the nearest 0.1 gram, after which the stack is placed on the compression cell platform of a tensile tester equipped with a 10 cm. (4 inch) diameter plunger (commercially available from Instron Engineering Corporation, Quincy, Massachusetts) to determine the relationship of pressure applied to the height of the card sliver stack. The compression plates of the tensile tester are 20.3 cm. (8.0 inches) apart. The stack is compressed to a maximum load of 22.7 kilograms (50 pounds), allowed to recover, and compressed again. The height of the batt at a pressure of 0.014 kg/cm² (0.2 p.s.i.) is measured and reported. If the weight of the card sliver stack is not exactly 20.0 grams, the value obtained for the height under pressure is corrected to that of a standard 20.0 gram stack, using a calibration curve plotted by using data from a number of stacks of a uniform sample of card sliver weighing from 19 to 21 grams. In this test, batt heights greater than 2.5 cm. (1.0 inch) are considered good and batt heights of 3.0 cm. (1.2 inch) or higher are considered excellent.

**EXAMPLE I**

Polyethylene terephthalate containing 0.3% TiO₂ and having a relative viscosity of 27.5 is extruded from a spinneret block maintained at 304° C. and jet quenched, using a quenching apparatus of the type exemplified by Lees in his U.S. Patent No. 3,061,874, at a spinning speed of 438 meters per minute (480 yards per minute). The quench air velocity at the threadline is 987 meters per minute (1080 yards per minute), and 16.9 cubic meters of air are employed per kilogram of polymer (270 cubic feet per pound). Several thousand of the filaments are combined to form a tow bundle which is then piddled into a large cylindrical container. Tₐ for this polymer is 79° C.

When examined under the polarizing microscope, the individual spun filaments exhibit an asymmetrical birefringence difference across the filament diameter.

The tow bundle is then drawn at a draw ratio of 2.70 through an atmosphere of dry steam at 118° C. as shown in the figure. The residence time in the draw-jet enclosure is 0.3 second and the speed of the tow in the draw-roll section is 90.1 meters per minute (98.6 yards per minute). The steam is supplied and exhausted at such a rate that the drawn tow contains 1.16% moisture, measured after the release of drawing tension. From the draw-roll section the tow is passed around the puller rolls, fed into the air-jet opener, and collected in a container. Upon release of the tension of drawing, spontaneous crimping of the filaments is observed with excellent separation of the filaments to form a uniform, fluffy tow bundle containing only a relatively low number of filaments per "caterpillar," averaging only 42 filaments.

The opened tow is cut to 6.3 cm. (2.5 inch) staple fibers which are placed on a shiver-moving conveyor belt which carries them through an oven maintained at 160° C. The residence time of the fibers in the oven is 1.5 minutes, after which the fibers are deposited in a large container. The product comprises highly crimped fibers averaging 3.6 crimps per centimeter of the extended fiber length (9.2 crimps per inch). The denier is 4.35 per filament, the tenacity is 2.32 g.p.d., and the elongation is 19.2%. The fiber bulk support is measured by a batt height of 3.10 cm. (1.22 inch) at a pressure of 0.014 kg/cm² (0.2 p.s.i.) on the second cycle in the bulk support test described above.

A series of experiments is performed with increasing tow moisture content (measured on the opened tow). The results are shown in the table below.

<table>
<thead>
<tr>
<th>Moisture content of tow, percent</th>
<th>Filaments per &quot;Caterpillar&quot;</th>
<th>Crimp per cm. (inch)</th>
<th>Bulk support batt height, cm. (inch)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.46</td>
<td>42</td>
<td>3.6 (0.23)</td>
<td>3.10 (1.22)</td>
</tr>
<tr>
<td>2.0</td>
<td>43</td>
<td>3.7 (0.24)</td>
<td>2.97 (1.17)</td>
</tr>
<tr>
<td>2.5</td>
<td>42</td>
<td>3.8 (0.25)</td>
<td>3.02 (1.19)</td>
</tr>
<tr>
<td>3.0</td>
<td>138</td>
<td>3.6 (0.21)</td>
<td>3.10 (1.22)</td>
</tr>
<tr>
<td>3.5</td>
<td>225</td>
<td>3.7 (0.26)</td>
<td>2.89 (1.14)</td>
</tr>
</tbody>
</table>

As shown in the table, "caterpillar" size is minimized when the tow moisture content is 2% or lower. Between about 2% and about 6% the "caterpillar" size is acceptable, although higher than desired. When the tow moisture content during opening exceeds about 6%, the size of the "caterpillars" becomes unacceptable, and loss of crimp in the relaxed fibers as well as a reduced level of bulk support is observed.

By comparison, a similar polyethylene terephthalate tow passed from a feed bath at 25° C. and drawn 3.14x at 238 meters per minute (260 y.p.m.) in a spray of water at 95° C. with subsequent application of a spray of 25° C. water, in accordance with the method shown by Ciporin and Latour in FIGURE 2 of their U.S. Patent No. 3,134,833 of May 26, 1964, yields a poorly opened, relatively stringy tow containing numerous large "caterpillars," averaging 571 filaments per "caterpillar." The wet tow is dried at 50° C. Fibers cut from the tow and relaxed 1.5 minutes at 165° C. exhibit a batt height of only 2.51 cm. (0.99 inch) at a pressure of 0.014 kg/cm² (0.2 p.s.i.) on the second cycle in the bulk support test described above. The fibers have a crimp averaging 2.95 crimps per centimeter of extended fiber length (7.5 crimps per inch). The tenacity is 2.49 g.p.d. and the elongation is 32.5%.

**EXAMPLE II**

Polyethylene terephthalate filaments are spun, formed into a tow bundle, and drawn in general accordance with the procedure described in Example I, except that the draw ratio is 2.94, the speed of the tow in the draw-roll section is 288 meters per minute (315 y.p.m.) and the residence time of the tow in the draw-jet enclosure is 0.1 second. The tow moisture content of this tow upon opening is extremely low, estimated as considerably less than 1%. Upon release of the tension of drawing in the air-jet opener, spontaneous crimping of the filaments is observed with excellent separation of the filaments to form a uniform, fluffy tow bundle containing only a relatively low number of filaments per "caterpillar," averaging only 47 filaments. The tow is relaxed at 160° C. for 5 minutes and is then cut into staple fibers. The product comprises filaments of exceptionally high crimp, averaging 5.4 crimps per centimeter of extended fiber length (13.7 crimps per inch). The denier is 4.3% per filament, the tenacity is 2.3 g.p.d. and the elongation is 20.5%. The fibers exhibit a very high level of bulk support as shown by a batt height of 3.85 cm. (1.32 inch) at a pressure of 0.014 kg/cm² (0.2 p.s.i.) on the second cycle in the bulk support test described above, 35% higher than the level of bulk support obtained with the control fibers prepared in accordance with the method of Ciporin and Latour as described in Example I.

**EXAMPLE III**

Polyethylene terephthalate filaments are spun and formed into a tow bundle as described in Example I, except that the tow is dried directly at a draw ratio of 2.80 through an atmosphere of dry steam at 275° C. The residence time in the draw-jet enclosure is 0.019 second and the speed of the tow in the draw-roll section is 1151 meters per minute (1260 y.p.m.). The drawn tow is substantially moisture free. Upon release of the tension of drawing in the air-jet opener, spontaneous crimping of the filaments is observed with excellent separation of the filaments to form a fluffy, open tow bundle. Examination of the tow bundle reveals that the "caterpillars" are small and in-
conspicuous. Individual filaments separated from the relaxed tow bundle average 3.5 crimps per centimeter of extended fiber length (9.0 crimps per inch).

EXAMPLE IV

Polyethylene terephthalate containing 0.3% TiO₂ is spun and quenched in general accordance with the procedure of Example I. A 4-inch ribbon is formed from 720 of the filaments and the ribbon is drawn at a draw ratio of 1.91 to draw rolls operating at a peripheral speed of 2440 meters per minute (2667 yards per minute) through a rectangular-slot jet with air at 145° C. passed through the jet at approximately the same speed as the ribbon. The residence time of the ribbon in the jet is approximately 0.008 second. The drawn ribbon, which is dry, is passed through an air-jet opener and laid on a moving belt. The product is a uniform, fluffy 16-inch web of highly crimped filaments which is extremely well opened and without "caterpillars." Individual filaments separated from the web have a denier of 1.4 and average 3.3 crimps per centimeter of extended fiber length (8.4 crimps per inch). They have a tenacity of 3.4 g.p.d. and an elongation of 26%.

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

I claim:

1. In the process for drawing and crimping a tow of synthetic linear condensation polyester filaments, having an asymmetric birefringence differential across the filament diameters, by drawing the tow while the tow passes directly from feed to draw rolls in a free path at a temperature above the second-order transition temperature and below the melting point of the polyester to orient the filaments, cooling the tow and releasing the drawing tension to develop crimp in the filaments, the improvement for preparing a highly fluffy tow of three-dimensionally crimped filaments having superior properties which comprises conducting said drawing in a hot gas with the tow sufficiently dry to have a moisture content of less than 6% of the weight of the tow as the tow emerges from the hot gas, each portion of the tow being in contact with the hot gas for less than 0.5 second, forwarding the emerging tow under tension directly to the next specified treatment, releasing the drawing tension and passing the tow through a jet of gas at a temperature below the second-order transition temperature of the polyester to cool and open the tow while crimp develops in the filaments, the moisture content measured on the opened tow being less than 2% of the weight of the tow when the drawing tension is released.

2. A process as defined in claim 1 wherein the hot gas is steam.

3. A process as defined in claim 1 wherein the hot gas is air.

4. A process as defined in claim 1 wherein the polyester is a linear glycol terephthalate polymer.

5. A process as defined in claim 1 wherein the polyester is polyethylene terephthalate.

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JULIUS FROME, Primary Examiner.
A. H. KOECKERT, Assistant Examiner.