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PROCESSABLE ULTRA LOW DENIER POLYESTER STAPLE FIBERS

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ABSTRACT OF THE DISCLOSURE

Staple polyethylene terephthalate fibers having a denier per filament of less than 1.5 and a length in inches that is numerically greater than its size in denier per filament and which are processable in a cotton system.

This invention relates to ultra low denier, rather long processable staple fibers. More particularly, this invention relates to synthetic staple fibers, which have a denier per filament of less than 1.5 and a length in inches that is numerically greater than its size in denier per filament, that are especially adapted for processing using a cotton system.

A rule that is generally accepted in the textile industry is that one cannot process on a modern cotton processing system a fiber that has a length in inches that is numerically greater than its size in denier per filament. That is, if a 1.5 denier per filament staple fiber is to be processed on a modern cotton staple yarn spinning system it must have a length of not over 1.5 inches and preferably less (i.e. 1.25 inches). The reason for this rule that the length in inches of a staple fiber must be numerically less than its denier per filament value is that heretofore known low denier per filament staple fibers could not be processed on cotton staple yarn spinning systems without undue difficulties. Processing of low denier per filament staple fibers has been particularly plagued with excessive loading and/or static in the carding, drawing, and spinning operations.

Therefore, even though it can easily be shown that the use of staple fibers smaller than 1.5 denier per filament will give, for example, a finer count, stronger, more uniform spun yarn, they have not heretofore been generally accepted in the industry because of the processing characteristics inherent therewith. Thus, it will be apparent that the development of a processable high strength, low denier per filament synthetic staple fiber of relatively long length would represent a substantial step forward in the textile art.

According to this invention it has been found that a processable low denier per filament synthetic staple fiber of relatively long length can be produced which is especially adapted for use on cotton staple yarn spinning systems. This novel ultra low denier, relatively long processable staple fiber is characterized in that it has: (1) a denier per filament of less than 1.5; (2) a length of at least 1.5 inches; (3) an intrinsic viscosity greater than 0.55; and (4) tensile properties characterized by high ultimate tenacity (>5.2 grams per denier), high tenacity at 10 percent elongation (≧4 grams per denier), low elongation (<30 percent), high elastic modulus (>45 grams per denier), and a high bending force requirement (>0.175 gram). Without these properties the ultra low denier, rather long staple synthetic fiber is normally unacceptable for use on such cotton staple yarn spinning system.

Thus, it is an object of this invention to provide ultra low denier, relatively long processable synthetic staple fiber.

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It is another object of this invention to provide a synthetic staple fiber which has a denier per filament of less than 1.5, a length in inches numerically greater than its size expressed as denier per filament, and is readily processed on a cotton staple yarn spinning system without excessive loading in the carding, drawing and spinning operations.

These and other objectives and advantages will be more apparent upon reading the following specification and appended claims.

As mentioned briefly hereinabove, synthetic staple fibers of various types have been known for a long period of time. It has also been realized that if a staple fiber of low denier per filament (i.e. 1.5 or less) and relatively long length (i.e. 1.5 inches or more) could be produced that would process on a cotton staple yarn spinning system, numerous highly useful and desirable new end products could be produced. However, it was found that once the length of the staple fiber became numerically greater than the denier per filament size of the fiber, excessive loading in the carding, drawing and spinning operations of the cotton staple yarn spinning system occurred. In an effort to find the cause for this failure of the ultra low denier relatively long staple fiber to process, a rather extensive research program was undertaken. As a result of this research effort it has been found that a synthetic staple fiber having a denier per filament less than 1.5 and a length of 1.5 inches or greater can be processed on a cotton staple yarn spinning system if it possesses the following properties:

TABLE I

Tenacity at 10% elongation	≧4.0 grams per denier.
High modulus (elastic)	>45 grams per denier.
High bending force	>0.175 gram.

It is also important, from a processing standpoint, that the synthetic staple fibers also have the following additional properties:

TABLE II

Ultimate tenacity	>5.2 grams per denier.
Ultimate elongation	<30 percent.

When these above listed terms are used in this specification or claims they are intended to have the following meanings:

(1) Tenacity at 10% elongation—The stress required to stretch the fiber 10 percent in length (elongation per se is the deformation produced by a load applied along the line of action of the load).

(2) Elastic modulus—The ratio of stress to strain at the yield point of the fiber.

(3) Bending Force (F_B)—The force in grams required to bend a fiber (of any given cross section with a moment of inertia I and equivalent diameter d^*) having a predetermined length l suspended in a cantilevered manner by one end (the force being applied at the free end) through a radius of curvature r. Thus, the bending force (F_B) in grams is calculated by using the following formula:

$$F_B=\frac{M \cdot I}{r \cdot 1}$$

where:

M=elastic modulus or stiffness of the fiber in grams per square centimeter (gm./cm.^{2});
l=free length of fiber in centimeter;
r=radius of curvature in centimeters through which the fiber is bent; and
I=moment of inertia of the fiber cross-section in centimeters to the fourth power.

For simplicity and uniformity, all further calculation will be made for a fiber having a free length equal to

$10d^*$ and being bent through a radius of curvature equal to $2d^*$ where d^* is the equivalent diameter of the fiber which equals the diameter of a round fiber having the same cross-sectional area as the fiber being evaluated or tested. The following formula can, therefore, be used:

$$F_B=\frac{MI}{20d^{*2}}$$

Thus, for a fiber having a round cross-section, the above formula can be further simplified to

$$F_B=\frac{M\pi d^4}{64(20d^2)}$$

or

$$F_B=\frac{M\pi d^2}{1280}$$

where

$$I=\frac{\pi d^4}{64}$$

and $d^*=d$=diameter of the fiber.

(4) Ultimate tenacity=The stress required to rupture or break the fiber.

(5) Ultimate elongation=The strain at the breaking stress of the fiber.

Although the exact theory surrounding the processability of ultra low denier, relatively long, synthetic staple fibers on a cotton system is not fully understood, it has been found to involve certain of the physical characteristics of the fibers. It has been discovered that the factors relating to and affecting the bending force of the synthetic staple fabrics are especially critical and must be held above a predetermined value. That is, in accordance with the present invention, it has been found that to process properly, the bending force, and thus the physical characteristics of the fiber which affect the bending force, must be maintained at a value equal to or greater than 0.175 gram.

For example, a 1.25 denier per filament staple fiber produced using heretofore generally accepted manufacturing procedures will have an elastic modulus of about 40 grams per denier. Using the previously developed formula:

$$F_B=\frac{3.14Md^2}{1280}$$

it can be shown that the bending force (F_B) of the fiber will equal 0.158 gram. This fiber will not process satisfactorily on a cotton system. However, by raising the denier per filament to 1.5, the same 40 gram per denier staple fibers will have a bending force of 0.186 gram and the fibers will process properly in a cotton system. However, as will be appreciated, the staple fibers are now relatively larger (1.5 denier per filament or greater) and are not the size fibers (less than 1.5 denier per filament) desired.

Therefore, to achieve the critical level of at least 0.175 gram bending force, it is necessary that certain of the critical parameters of the low denier synthetic fibers be very carefully maintained within the specified limits given in Tables I and II. Surprisingly, if the parameters of the synthetic fibers are very carefully controlled then an ultra low denier relatively long synthetic staple fiber can be produced which can be processed on a cotton system.

In order to more fully illustrate this invention, the following working examples are included:

Example I

Polyethylene terephthalate fibers are melt spun from a spinnerette containing 600 circular holes (each of which is 0.4 mm. in diameter) at a spinning speed of 1050 meters per minute and a melt temperature of 300° C. The undrawn total denier is 2100 or 3.5 denier per filament, and the spinning rate is 32 pounds per hour.

The yarn is then drafted 3:1 in about 65° C. water followed by a draft of 1.17:1 in a steam tube at a temperature of about 150° C. for a total draft of 3.5:1. The drafting speed is approximately 100 meters per minute. A suitable number of polyethylene terephthalate fiber ends are then brought together to form a yarn having a total of 60,000. The yarn is then crimped in a stuffer box crimper and afterwards heatset at a temperature of about 140° C. in a free-shrink condition. The yarn is then cut into staple fibers of 1.5 inch length. Properties of this staple fiber will be as follows:

TABLE III

Denier per filament	1.3
Staple length, inches	1.5
Ultimate tenacity, grams per denier	4.1
Ultimate elongation, percent	39.3
Intrinsic viscosity	0.59
Modulus, grams per denier	38
Tenacity at 10 percent elongation, grams per denier	1.5
Bending force, grams per filament	0.16

The 1.3 denier per filament staple fibers of 1.5 inches length are then placed in a standard commercial type cotton staple yarn spinning system to be tested for processability. It will be found that these fibers cannot be processed on the cotton system due to severe card loading. Thus this example clearly illustrates the heretofore unsolvable problems that are encountered when regular 1.25 denier per filament type fibers are used on a cotton system.

Example II

Polyethylene terephthalate fibers are melt spun from a spinnerette containing 600 circular holes (each of which is 0.4 mm. in diameter) at a spinning speed of 1050 meters per minute and a melt temperature of about 300° C. The undrawn total denier is 2500, or 4.2 denier per filament, and the spinning rate is 39 pounds per hour.

The undrawn fiber is then drafted 3:1 in about 65° C. water and then 1.17:1 in a steam tube at about 150° C. The two stage drafting system gave a total draft of 3.5:1. The drafted fiber ends are then brought together to form a yarn of 60,000 total denier after which the yarn is heatset for six seconds under tension and at a constant length on hot (200° C.) rolls. The yarn is then crimped in a stuffer box type crimper at an average of 7 to 9 uniform crimps per inch and dried for approximately 5 minutes in a free-shrink condition at about 50° C. The yarn is then lubricated and cut into staple fibers of 1.5 inch length. Properties of the staple fibers will be as follows:

TABLE IV

Denier per filament	1.3
Staple length, inches	1.5
Ultimate tenacity, grams per denier	5.31
Ultimate elongation, percent	19.40
Intrinsic viscosity	0.58
Modulus, grams per denier	47.00
Tenacity at 10 percent elongation, grams per denier	4.0
Bending force, grams per filament	0.20

The 1.3 denier per filament staple fibers of 1.5 inches length are then placed in a commercial type cotton staple yarn spinning system to be tested for processability. It will be found that these fibers can be processed on the cotton system. No problems of loading of the card problems are encountered. In addition, the carding rate is unusually high, being of the order of greater than 13 pounds per hour or as high as 22 to 30 pounds per hour under some conditions.

Example III

Another fiber sample is spun under the same conditions of Example II except that it is drafted at an over-all draw ratio of 4.15:1. This staple fiber will have the following properties:

TABLE V

Denier per filament	1.3
Staple length, inches	1.5
Ultimate tenacity, grams per denier	6.6
Ultimate elongation, percent	18.00
Intrinsic viscosity	0.59
Modulus, grams per denier	46.00
Tenacity at 10 percent elongation, grams per denier	4.4
Bending force, grams per filament	0.19

This fiber will be found to easily process on a cotton staple yarn spinning system without undue difficulties.

Example IV

Polyethylene terephthalate fibers are spun from a spinnerette containing 670 holes (each of which is 0.45 mm. in diameter) at a spinning speed of 1100 meters per minute and a melt tempearture of about 300° C. The undrawn denier is 3200.

The undrawn fibers are drafted 3:1 in a 68° C. water bath and then are drafted 1.33:1 in a 150° C. steam tube. The ends of the drawn fibers are gathered together to form a yarn of 400,000 total denier and are heatset for about 25 seconds in a dryer using hot air at 220° C. The yarn is then crimped and dried in a free-shrink condition for about 5 minutes at a temperature of less than 90° C. After being lubricated the yarn is cut to give a staple fiber. The staple fibers will have the following properties:

TABLE VI

Denier per filament	1.3
Staple length, inches	1.5
Ultimate tenacity, grams per denier	6.2
Ultimate elongation, percent	19.4
Intrinsic viscosity	0.59
Modulus, grams per denier	50.00
Tenacity at 10 percent elongation, grams per denier	4.20
Bending force, grams per filament	0.21

This fiber will be found to easily process on a cotton staple yarn spinning system without undue difficulties.

Example V

Another fiber sample is spun under the same conditions as Example IV.

The drafting condition is also the same as Example IV except that a two stage draw of 3:1 in hot water and 1.36:1 in steam is used and the total denier of the yarn is 600,000. The yarn is heatset for 20 seconds at constant length in a hot air dryer at 220° C. The staple fibers will have the following properties:

TABLE VII

Denier per filament	1.3
Staple length, inches	1.5
Ultimate tenacity, grams per denier	7.1
Ultimate elongation, percent	24.1
Intrinsic viscosity	0.59
Modulus, grams per denier	65.00
Tenacity at 10 percent elongation, grams per denier	5.4
Bending force, grams per filament	0.27

This fiber will be found to easily process on a cotton staple yarn spinning system without undue difficulties.

From the foregoing it can be seen that a totally new low denier per filament, relatively long processable fiber has been produced. This fiber, due to its bending force of at least 0.175 gram, and other related physical characteristics, can be easily handled on a modern cotton staple yarn spinning system without undue difficulty. This permits a wide variety of new products to be produced at a cost below that which would otherwise be incurred. Furthermore, the solution to the long standing problem surrounding why low denier per filament, rather long fibers could not be made to process in cotton systems will undoubtedly open the way for the development of a totally new line of synthetic staple fibers.

The invention has been described in detail with particular reference to certain preferred embodiments thereof, but it will be understood that variations and modifications can be effected within the spirit and scope of the invention as described hereinabove.

We claim:

1. As an article of manufacture, a drawn polyester textile fiber in staple form which can be processed using a cotton system, said fiber having a denier per filament of less than 1.5 a length in inches that is numerically greater than its size in denier per filament, an ultimate tenacity of at least 5.2 grams per denier with a tenacity of at least 4 grams per denier at 10 percent elongation, and said fiber having a bending force of at least 0.175 gram calculated by

$$F_B = \frac{MI}{20d^{*2}}$$

where:

F_B=bending force in grams;

M=modulus (elastic) of fibers in grams per square centimeter;

I=moment of inertia of the fiber cross-section in centimeters to the fourth power; and

d^*=equivalent diameter of fiber in centimeters.

2. The article of claim 1 wherein the fiber has an elastic modulus of greater than 45 grams per denier.

3. The article of claim 2 wherein the fiber has an ultimate elongation of less than 30 percent.

4. The article of claim 3 wherein the fiber is comprised of ester linking units of a synthetic fiber-forming linear condensation polymer of ethylene glycol and terephthalic acid.

5. The article of claim 4 wherein the intrinsic viscosity of the polyester fiber is greater than 0.55.

6. The article of claim 4 wherein the fiber has a denier of less than 1.31 denier per filament.

7. The article of claim 5 wherein the length of the fiber is substantially 1.5 inches.

8. The article of claim 1 wherein said polyester is polyethylene terephthalate.

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