Aug. 5, 1969 H. H. HEBELER **3,459,845**

PROCESS FOR PRODUCING POLYAMIDE STAPLE FIBERS

Original Filed Sept. 16, 1965 4 Sheets-Sheet 1

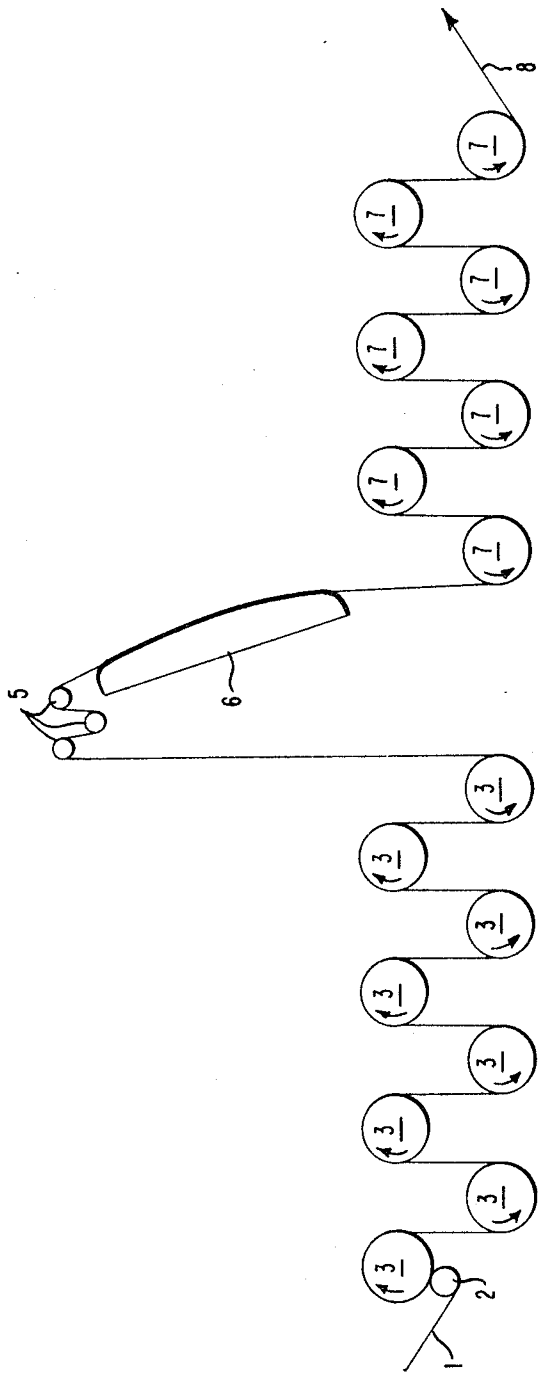

FIG. 1

TOW DRAWING MACHINE

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PROCESS FOR PRODUCING POLYAMIDE STAPLE FIBERS

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FIG. 2

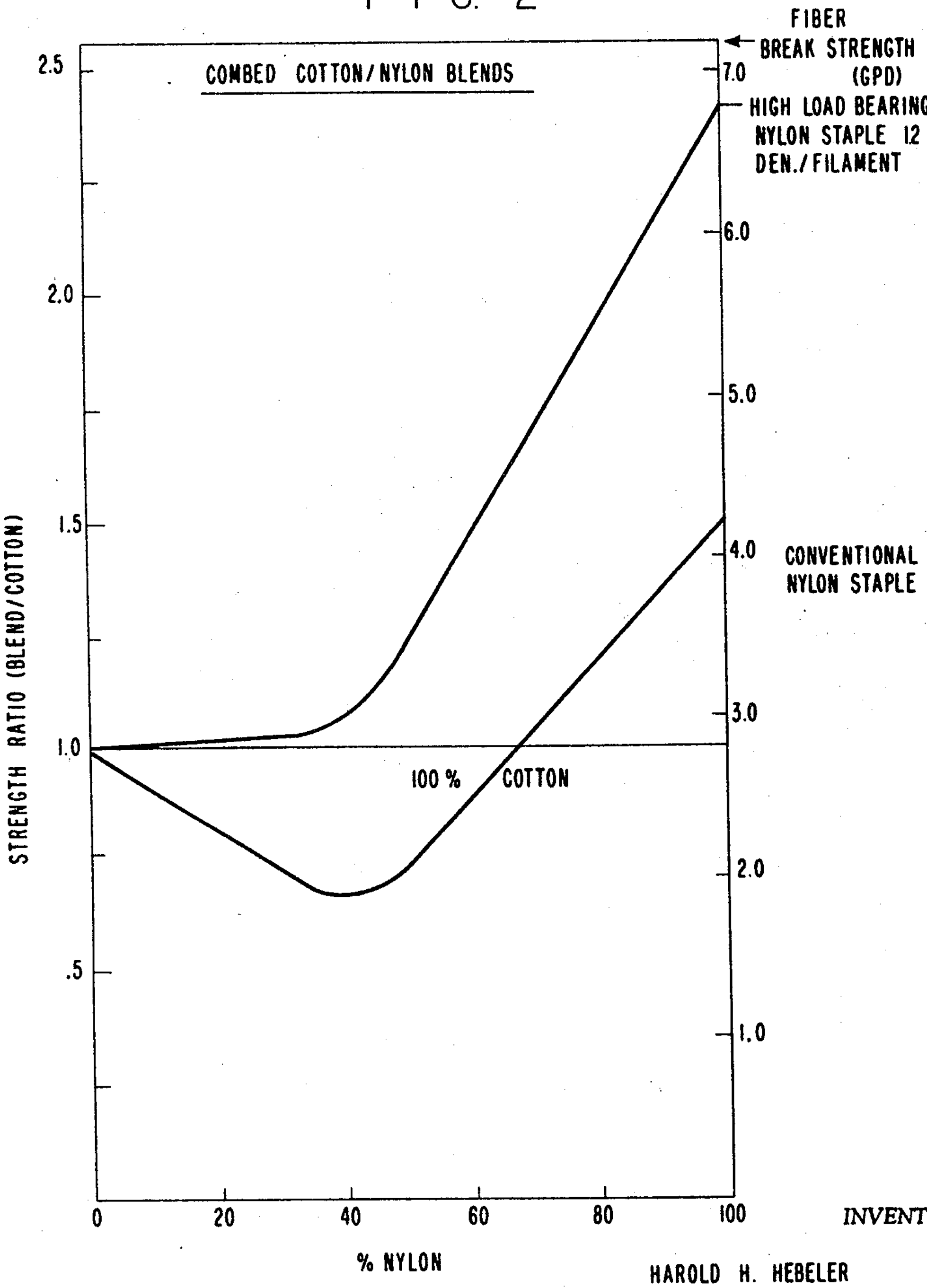

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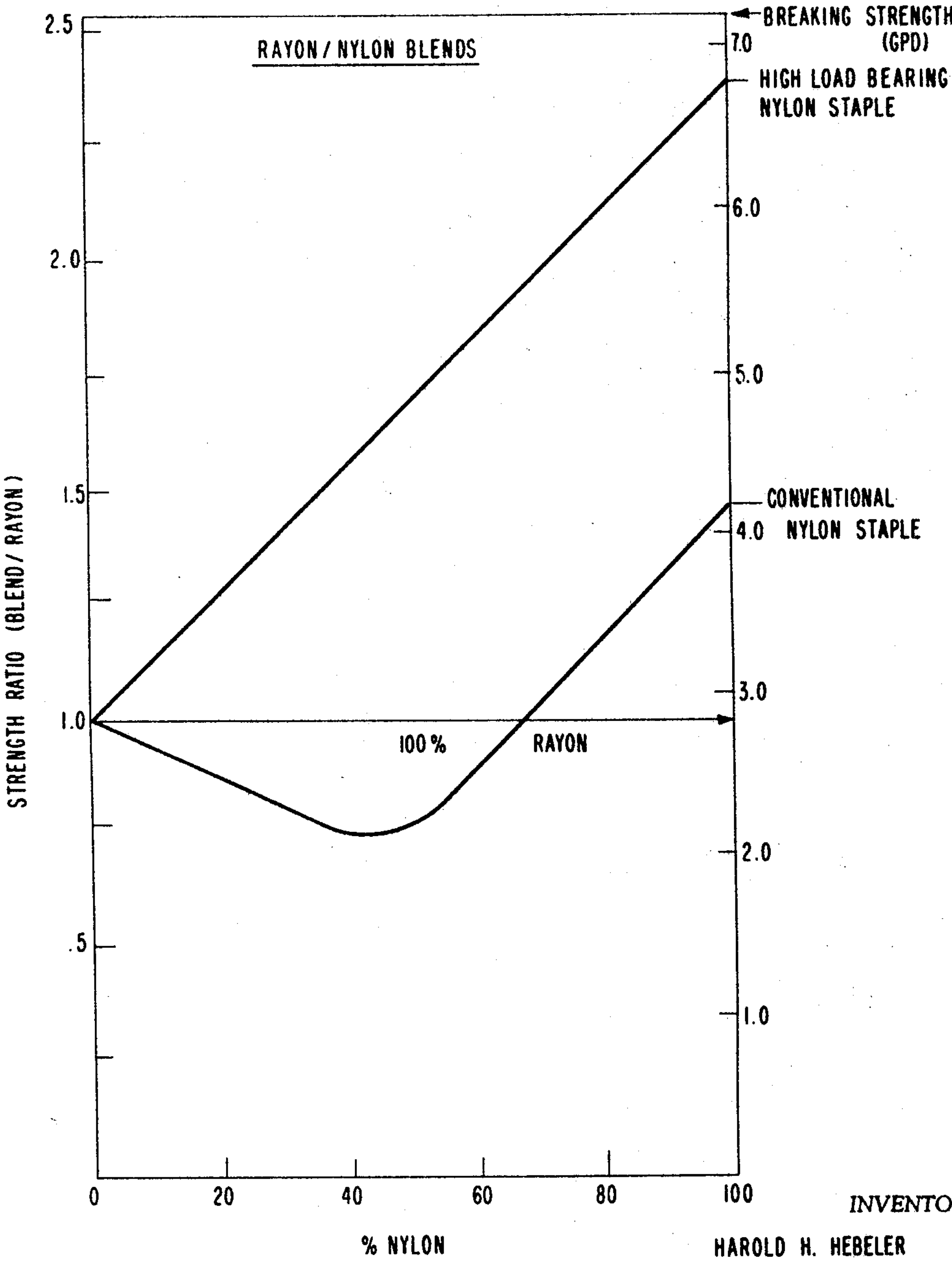
FIG. 3



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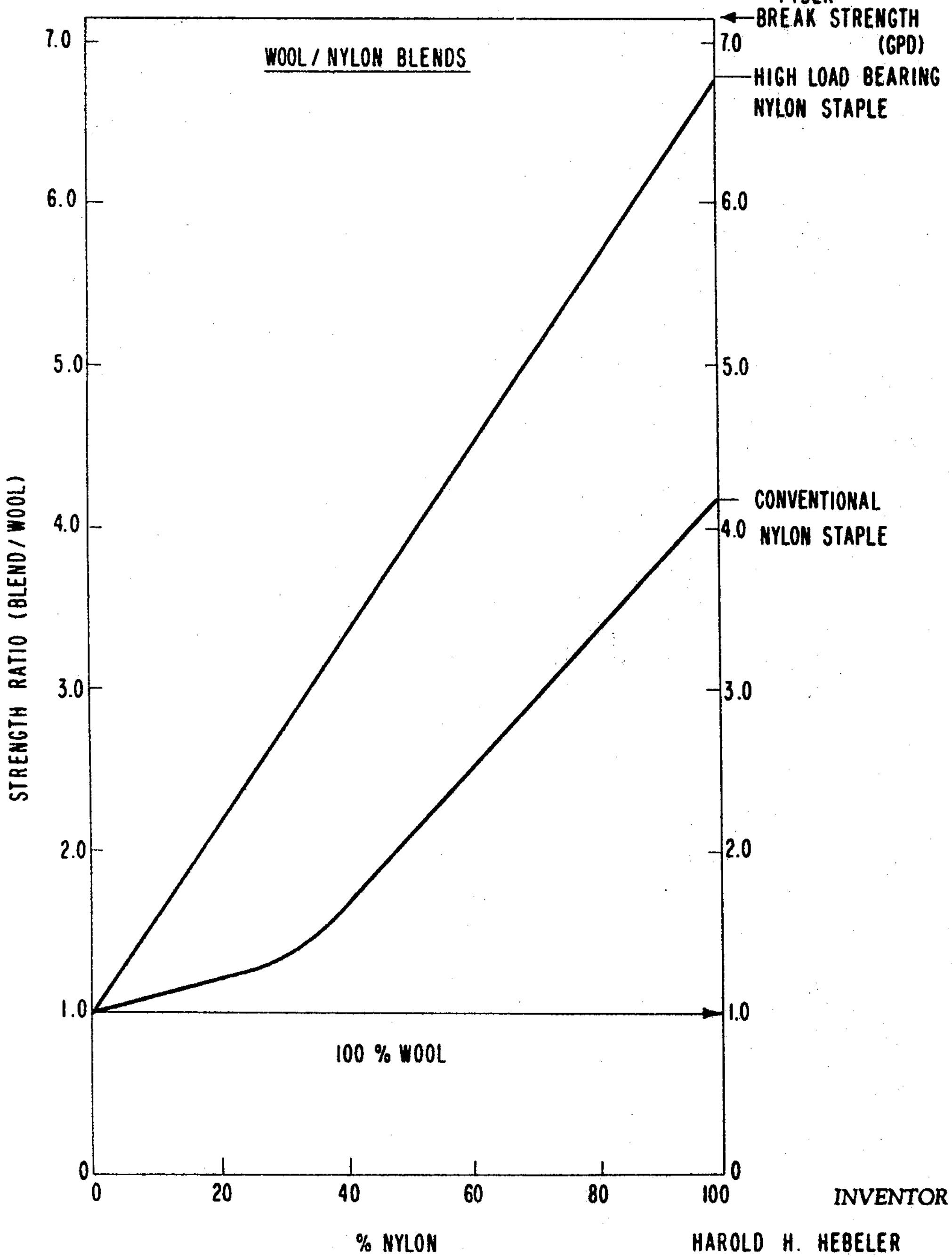
PROCESS FOR PRODUCING POLYAMIDE STAPLE FIBERS

Original Filed Sept. 16, 1965 4 Sheets-Sheet 4

FIG. 4



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3,459,845
PROCESS FOR PRODUCING POLYAMIDE STAPLE FIBERS

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Original application Sept. 16, 1965, Ser. No. 491,500, now Patent No. 3,321,448, dated May 23, 1967. Divided and this application Apr. 3, 1967, Ser. No. 628,035
Int. Cl. D01d *5/12;* D01f *7/06*
U.S. Cl. 264—168 3 Claims

ABSTRACT OF THE DISCLOSURE

In the process for producing this nylon staple, continuous filaments are drawn and heat-treated under dry conditions, using substantially the maximum operable draw ratio within the range of about 3 to 5 which can be used without excessive filament breakage. The filaments are heat-treated under drawing tension at 165° to 200° C. for a length of time which gives about 1000 to 6000 degree-seconds exposure (product of the average treatment temperature and the exposure time). The drawn and heat-treated filaments are fed directly to a staple cutter and cut to staple fibers without mechanical crimping, in order to avoid heat-relaxation of the filaments. If the staple fibers are then packed into bales under customary pressure, sufficient crimp is acquired for conventional processing into yarn and the fibers are characterized by the properties indicated above.

Cross-references to related applications

This is a division of my copending application Ser. No. 491,500, which issued as U.S. Patent No. 3,321,448 on May 23, 1967, and was filed Sept. 16, 1965, as a continuation-in-part of my application Ser. No. 152,314 (now abandoned), filed Nov. 14, 1961, as a division of my application Ser. No. 668,718, filed June 28, 1957, which issued as U.S. Patent No. 3,044,250 on July 17, 1962.

This invention relates to production of a new nylon staple fiber for blending with other textile fibers, and particularly with cellulosic fibers, to increase the strength of blended yarn and to impart improved abrasion resistance to textile fabric prepared therefrom, the fiber having high flex life, low boil-off shrinkage and high load-bearing capacity in blended yarns.

The use of two or more varieties of staple fibers to create blends, and yarns and fabrics prepared therefrom, are well known in the art. Such blends have been produced to provide new and attractive fabrics having improved physical and aesthetic properties. With the advent of the newer synthetic fiber materials, there appeared to be great promise of improving the strength of the well-known and low-cost natural fiber yarns by adding small amounts of the high tenacity new materials. For example, it was expected that cotton yarns having a strength of 1–2 grams per denier (g.p.d.) could advantageously be strengthened by blending nylon staple (tenacity 4–7 g.p.d.) with the cotton.

This advantage was not, in fact, realized and considerable research has been devoted to determine the cause. The subject is well treated in an article by A. Kemp and J. D. Owen, in Textile Institute Journal, Transaction, 46, 684–698 (1955). In this article, it is shown that blends of cotton and nylon are weaker than 100% cotton yarns, until about 80% nylon fiber is present. It was recognized that this behavior was due to the much greater elasticity of the nylon fiber: thus, at low loads, the cotton was the

stress-bearing member. Due to its low break elongation (about 7%), the cotton ruptured before the nylon filaments bore any substantial proportion of the load, especially at low nylon compositions.

It has also been recognized in the art that the load-elongation (i.e., modulus) of many synthetic fibers can be increased by a hot-stretching operation. Such operations are common in the production of yarn for tire cord, for example. However, these treatments are unsuitable for improving stable fibers, in that the improvement is not stable to aging, when the filaments are free to retract (i.e., not wound upon a rigid package). This retraction results in a loss of the improved modulus, gained by hot stretching. In addition, such treatments are unstable to boil-off, a common treatment for textile fabrics, so that an excessive amount of shrinkage results in fabrics containing such fibers.

It is, therefore, a general object of this invention to provide nylon staple fiber for blending with cellulosic staple fibers in spun yarn which overcomes the above difficulties. A more specific object is to provide staple fibers of polyhexamethyleneadipamide for blending with a high modulus cotton fiber or rayon stable fiber, or other fibers derived from cellulose to increase the strength of blended staple yarn and to impart to textile fabric, prepared therefrom, improved resistance to wear and abrasion. Another specific object of the invention is to provide a process for the production of linear condensation polymer fibers especially suitable for blending with cellulosic staple fibers. Other objects will appear as the description of the invention proceeds.

These and other objects are attained by treating nylon fibers of certain synthetic linear condensation polymers so that at the break elongation characteristic of the fiber with which it is blended, the synthetic fibers will have an equal or superior load-bearing capacity in comparison to that of the other textile fiber. The synthetic linear condensation polymers which are partciularly wall adapted for the purpose of the present invention are condensation polymers selected from the class consisting of polyhexamethylene adipamide (66 nylon) and polycaproamide (6 nylon).

The synthetic condensation polymer fibers are treated to render them suitable in the present invention by (a) drawing them to the maximum operable draw ratio, and (b) subjecting them to a heat treatment under drawing tension for at least one second at the maximum operable temperature. This maximum temperature is usually about or close to the degradation point of the polymer.

The filaments so treated are characterized by having *both* a high degree of crystallinity and a high degree of crystalline orientation. This characteristic renders them stable to slack aging so that the load-bearing properties are maintained at least until the fiber is incorporated into the fabric. Yarn spun from these filaments is also free from a high and objectionable boil-off shrinkage.

It is thus apparent that the condensation polymers suitable in the present invention are those which may be highly oriented by a drawing operation, and which then may be crystallized by a sufficiently severe heat treatment to retain the high orientation. Especially suitable polymers are the linear polyamides, such as polyhexamethylene adipamide (66 nylon) and polycaproamide (6 nylon); crystallizable polyamide copolymers are also suitable when 85% or more 66 nylon or 6 nylon component is present.

The high-modulus natural or naturally-derived staple fibers for which this invention is most useful are the cellulosic-based fibers such as cotton, viscose rayon, acetate rayon and other cellulosic derivatives. In addition, fibers of lower modulus, such as for example the protein fibers (e.g., wool), and even for some synthetic fibers, such as fibers from polyacrylonitrile, may be advantageously blended with the above specified high tenacity linear condensation polymers. Likewise blends of nylon and polyester fibers may be used with any one or blend of the natural fibers.

In the drawing, FIGURE 1 shows schematically one form of a tow drawing machine suitable for preparing the high load-bearing fiber of this invention. FIGURE 2 is a self-explanatory graph which shows the improvement in strength when the high load-bearing nylon staple of this invention is added to a combed cotton. FIGURE 3 likewise is a graph which shows a similar relation for rayon and nylon blends, while FIGURE 4 similarly graphs the strength relation for blends of nylon and wool. The curves for other blends of natural fibers, such as wool with nylon, have the same general configuration.

In the operation of the apparatus shown in FIGURE 1, multiple ends of undrawn filaments from a bank of spinning machines, from a creel or the like, are combined into a heavy denier tow (source of supply not shown) and enter the draw machine as a band of filaments at **1**. The band of filaments is pressed against the first of a series of feed rolls **3, 3, 3**, by means of pinch roll **2**, thus preventing the tow from slipping. The feed rolls **3** are all driven at the same constant peripheral speed, and serve to meter the tow to the drawing pins **5**. In the drawing zone, the tow passes in a zig-zag path about the three fixed stainless steel drawing pins **5**, thus producing a snubbing effect, which localizes the draw point. The band of filaments then travels in contact with a heated plate **6** (heating means not shown) to the draw rolls, **7, 7, 7**. The draw rolls, all operating at the same speed, rotate at a higher peripheral velocity than that of the food rolls, **3, 3, 3** so that the yarn is thereby drawn. The relative peripheral speed of the two sets of rolls determines the draw ratio. The drawn tow leaves the machine at **8**, and may pass thence to a crimping device, a cutting device, to storage or to a tow packaging device. It should be mentioned that hot plate **6** is relatively long, e.g., 9 feet, and may suitably be heated electrically, or by hot oil, high pressure steam, or the like, as is conventional. It is desirable that the tow passing through this machine be spread out into a wide flat band of filaments of uniform but small thickness. When staple finishes are added to the tow prior to drawing, this usually takes place before the filaments reach pinch roll **2**.

The apparatus of FIGURE 1 is merely illustrative of one suitable embodiment for tow-drawing; other designs may have especial advantages. For example, it may be desirable to use feed or draw rolls operating at different peripheral speeds, thus minimizing slippage. Greater or fewer draw pins, in a wide variety of known abrasion-resistant materials may be employed. The drawing may be accomplished in two or more stages. An initial drawing may be accomplished by a conventional "cold" draw process, and subsequent hot drawing with heat treatment may then be used as described herein to produce the high load-bearing nylon fiber of this invention.

Production of the fiber of this invention will be described in terms of its application to cotton-nylon blends, because of their great utility and importance in commerce. Application to other fiber blends will be discussed subsequently.

The break elongation of middlings cotton is about 7%, and the break strength is about 2.1 grams per denier. At this elongation, conventionally processed nylon from polyhexamethylene adipamide has a load-bearing capacity of about 0.5 to 1.0 g.p.d. For convenience and brevity in this specification, the load-bearing capacity of a filament at a given elongation will be referred to as $T_{elong.}$; for example, the load-bearing capacity (T_7) of the nylon fiber of this invention should be at least 2.0 grams per denier at 7% elongation, corresponding to the break elongation of cotton, which is about 7%, and has a strength of about 2 g.p.d.

EXAMPLE I

Conventionally spun nylon yarn from polyhexamethylene adipamide flake is combined into a bundle of about 16,700 filaments, to form a 63,000 denier rope. The rope (without addition of aqueous finishes) is drawn in a machine schematically shown in FIGURE 1. The machine is furnished with a 9 foot long hot plate, and the draw ratio, drawing speed, and the time of contact with the plate as well as the plate temperature are varied. The band of filaments is snubbed by a 420° wrap around three snubbing pins, preceding the heated plate. The temperature of the yarn during its passage over the hot plate is determined by means of a contact thermocouple. Average values are given in Table 1. The extent of heat treatment is calculated by multiplying the average yarn temperature by the time the yarn remains at that temperature. The product thus has the dimensions of degree-seconds.

Samples of yarn produced under these conditions are aged for nine days in relaxed condition at 78° F., 72% R.H., before determining their stress-strain characteristics. The preparation conditions for each sample are shown in Table 1.

TABLE I.—OPERATING CONDITIONS

Sample	Draw ratio	Heat treatment		Degree-sec.
		Sec.	Temp., ° C.	
A	3.01	2.0	30	60
B	3.01	0.15	190	29
C	3.01	1.8	180	320
D	3.01	12	175	2100
E	3.01	30	170	5100
F	3.62	2.0	30	60
G	3.62	0.15	180	27
H	3.62	1.8	175	320
I	3.62	12	170	2000
J	3.62	30	180	5400
K	3.62	45	170	7700
L	3.62	60	160	9600
M	3.87	2.0	30	60
N	3.87	0.15	180	27
O [1]	4.07	2.0	30	60
P	4.07	12.0	170	2000
Q [1]	4.14	2.0	30	60
R [1]	4.14	0.15	180	27
S	4.14	1.2	180	220
T	4.14	6	195	1200
U	4.14	30	175	5300
V	4.14	45	170	7700
W	4.14	60	165	9900

[1] Draw ratio too high to be operable; yarn broke down. No sample obtained.

The properties of the samples obtained under the conditions shown in Table 1 are listed in Table 2. The T_7 for each sample is determined from the stress-strain curve using a conventional Instron Tester. Values are calculated on a gram per denier basis. Boil-off shrinkage is determined on a skein of the test yarn; the length of the skein is measured before and after the 60 minute boil-off treatment and the percent change (based on length before boil-off) is calculated.

The birefringence of the yarn is determined according to methods of Heyn, Textile Research Journal, 22, 513 (1952) and is a measure of crystalline orientation. The density is measured using density gradient tubes, according to the method of Boyer, Spencer and Wiley, Journal Polymer Science, 1, 249 (1946). The dnesity is proportional to the degree of crystallinity of the fiber.

It is well known, of course, that nylon filaments consist of crystalline and amorphous regions. The density of the amorphous regions has been estimated to be about 1.069, while that of the crystalline regions has been estimated to be about 1.220 by use of infrared techniques. This is described by Starkweather & Moynihan in Journal Polymer Science, 22, 363 (1956). From these data, a value can be calculated which is proportional to the fraction of crystalline volume using the formula:

$$\frac{(\text{avg. density of yarn}) - (\text{density of amorphous yarn}) \times 100}{(\text{density of 100\% crystalline yarn}) - \text{density of 100\% amorphous yarn}} = \text{percent}$$

this gives a number which is proportional to the percent crystallinity.

An examination of the data in Table 2 shows that acceptable T_7 values are obtained when *two* criteria are met: (a) the density is higher than about 1.139, and (b) the birefringence is simultaneously above about 0.0590. Both of these parameters characterize the polyamide product of this invention, and are a minimum for acceptable cotton blending. It is obvious, of course, that at higher draw ratios, higher heating temperatures, and longer contact times, higher T_7 values and correspondingly greater strength contributions to the blended yarn are obtained.

TABLE 2.—TEST RESULTS

Sample	Tenacity, g.p.d.[1]	T_7, g.p.d.[2]	Birefringence	Density	Shrinkage, percent[3]
A	3.7	0.98	0.0521	1.136	9.1
B	3.6	1.04	0.0528	1.135	9.0
C	3.9	1.35	0.0527	1.136	8.5
D	4.0	1.45	0.0564	1.141	5.1
E	3.9	1.47	0.0567	1.142	5.6
F	5.0	1.44	0.0573	1.137	8.1
G	5.3	1.54	0.0583	1.138	8.2
H	5.7	1.81	0.0584	1.138	7.0
I	5.9	2.19	0.0594	1.142	4.2
J	5.5	2.11	0.0586	1.140	5.2
K	5.8	2.18	0.0589	1.141	4.6
L	5.6	2.16	0.0602	1.143	4.4
M	6.0	1.61	0.0547	1.139	7.5
N	6.9	1.72	0.0568	1.139	8.1
P	7.3	2.68	0.0612	1.143	4.7
S	6.7	2.50	0.0602	1.140	5.6
T	7.3	2.68	0.0622	1.142	4.9
U	6.5	2.58	0.0606	1.141	6.0
V	6.5	2.61	0.0606	1.142	4.6
W	6.4	2.59	0.0594	1.142	4.9

[1] Tenacity after aging in relaxed condition, 9 days at 78° F., 72% R.H.
[2] Load at 7% elong., aged relaxed for 9 days.
[3] Shrinkage determined by boiling a previously measured skein in water for 60 minutes.

It is apparent from an inspection of the data in Tables 1 and 2, that satisfactory results are obtained at draw ratios above about 4.0 with high plate temperatures, a heating time of at least 1 second and a yarn exposure of at least 200 degree-seconds. Better results are obtained, especially at lower draw ratios, when yarn is exposed to at least about 1000 degree-seconds. Higher values of T_7 and lower boil-off shrinkage are usually obtained at higher heat exposure.

It should be noted, however, that draw ratios causing excessive breakage and treating temperatures causing yarn discoloration should be avoided. For polyamide without added antioxidant, some slight discoloration becomes noticeable at exposures somewhat above about 5000 degree-seconds which may be unacceptable for use in white fabrics.

As far as can be ascertained, high load-bearing nylon staple having the physical properties of the fiber of this invention has not been previously known. Some of the conditions exemplified in Table 1 are illustrative of those used in the current processing of nylon yarns. For example, the conventional drawing process in which yarn is drawn over a snubbing pin substantially as described by Babcock in U.S. Patent 2,289,232, is illustrated by samples A, F and M, for draw ratios of 3.01 to 3.87. No heat, other than that produced by friction with the drawing pins, is supplied to the yarn. None of these samples have a T_7 above 2.0 grams per denier. A T_7 of at least 2.1 and preferably 2.5 g.p.d. is highly desirable. Sample M has the minimum density of 1.139 but it does not have the minimum birefringence of 0.0590. Higher orientation (via increased draw ratio) is not obtainable under these test conditions, as shown by test condition O, which was not operable at a draw ratio of 4.07. It is also worthy of note that these unacceptable yarns are further characterized by having a boil-off shrinkage above about 6.0%.

Conventional drawing techniques in which the yarn contacts a heated pin or plate during the drawing operation are characterized by samples B, G, N and R. None of these samples (see Table 2) have an acceptable T_7 value, nor do they show birefringence or density above the prescribed minima. Test condition R shows that it is impossible to draw to higher ratios (4.14) at short heating times, since the yarn breaks down.

It should be recognized that the high load-bearing staple of this invention is not merely a product of higher tenacity obtained by routine increase in draw ratio and/or drawing temperature. This point is illustrated by samples M and N (Tables 1 and 2) which have a higher tenacity (due to higher draw ratio) than samples I through L, but have unacceptable T_7 values. Samples I through L are acceptable.

EXAMPLE II

The process of Example I is repeated with filaments spun from vacuum-finished, low monomer (3 to 4%) 6-nylon (polymer from caprolactam). The draw ratio in this case is 4.00, and the filaments are held at a temperature of 165° C. for a period of 30 seconds under drawing tension. The yarn produced, following slack aging for a period of 9 days, had a tenacity of 6.3 g.p.d., a break elongation of 19.1%, and a T_7 of 2.3 g.p.d. The yarn sample had a density above 1.139, and a birefringence higher than 0.0590.

The increased strength of yarns prepared from the high load-bearing nylon staple of this invention in blends with combed cotton are shown in FIGURE 2, in comparison with conventionally prepared nylon staple. The graph shows that 70% or more conventional nylon staple must be added to combed cotton yarns to equal the strength of the original 100% cotton yarn. In contrast, the blended cotton-nylon yarn of this invention yields increased strengths when even small amounts of nylon are added.

The high load-bearing nylon staple of this invention is also advantageously used for blending with rayon staple yarns, as shown in FIGURE 3. In this case, the critical parameter is the break elongation of the rayon yarn, which is typically 14%. Thus, the nylon staple should have a high T_{14} value for blending with such rayon. The nylon staple of this invention, as previously defined, is suitable for this purpose when it has a break elongation above 14%. The nylon staple of this invention shows substantial improvement in this respect over conventional nylon staple; the curve in FIGURE 3 shows that initial additions of conventional nylon, up to about 50%, result in a strength decrease, and the original strength of the rayon is only attained when over about 65% of nylon is added thereto. In contrast, the nylon staple of this invention shows a strength increase with the initial additions.

The high load-bearing nylon staple of this invention may also be advantageously added to low modulus natural fibers such as wool, as shown in FIGURE 4. For equivalent compositions, the staple of this invention provides a stronger yarn than that when conventional nylon staple is used for wool-blending purposes.

A further measure of the improvement in strength and uniformity of yarns prepared from the blended fiber of this invention is obtained from the lea product (skein break), as shown in Table 3, for blends with cotton, rayon and wool. Lea products show consistant improvement in strength with increasing additions of the staple of this invention as compared to a decrease in strength or a lesser degree of improvement for conventionally prepared nylon staple.

TABLE 3.—LEA PRODUCT VALUES FOR SPUN YARNS OF NYLON AND OTHER FIBERS

[Nylon, 1½"; length, 3 den./filament]

Blending fiber	Middlings cotton		Rayon		Wool	
Yarn count	20/1s		15/1s		8/1s	
Nylon staple type	T_7[1]	C[2]	T_7	C	T_7	C
Lea product, nylon added, (percent):						
0	2,040	2,040	1,700	1,700	1,148	1,148
20	2,150	1,730	2,200	1,580	2,240	2,490
30	2,220	1,610	2,750	1,540	2,840	1,830
100	4,300	3,000				

[1] High T_7 nylon staple.
[2] Conventional nylon staple.

In addition to improving the strength of cotton yarns made from blends containing the high load-bearing staple of this invention, there is a substantial improvement in abrasion resistance, as shown by the data in Table 4. High load-bearing 2.2 denier per filament, 1½ inch nylon staple was blended in the amount shown, with 1⅛ inch middlings cotton, and spun to 20/1's cotton-count yarn which was then knitted into fabric and subjected to a Stoll flat abrasion test, carried out in agreement with A.S.T.M. D–1175–55T. Fabrics were tested after boil-off.

Table 4.—Effect of nylon on abrasion resistance

	Stoll flat abrasion [1] cycles
Cotton, 1⅛" middlings	425
15% high T_7 nylon added	1025
30% high T_7 nylon added	1433
50% high T_7 nylon added	1928

[1] Carried out in agreement with A.S.T.M. D–1175–55T.

The high load-bearing staple of this invention also has outstanding resistance to pilling, either as a blend in admixture with other staple fiber, or as a 100% nylon fabric. "Pilling" is a defect commonly observed when woven fabrics from high strength synthetic fibers are subjected to abrasion. The fibers on the surface become entangled into unsightly fibrous balls described as "pills."

What may be termed a "drawing-heat treating process," whereby the high load-bearing nylon staple of this invention is prepared, must be critically controlled. It is desirable to draw the nylon filaments in the absence of added moisture; that is, if antistatic finishes are applied to the yarn prior to drawing, they should be of the non-aqueous variety or, alternatively, the tow may be dried prior to subjecting to the drawing operations. If aqueous finishes are required, the heating step must also provide for sufficient time and heat capacity to flash off water in excess of that in equilibrium with the polymer at room temperature, as well as for subjecting the filaments to the required degree-seconds of heat treatment. It is important to avoid exposing the treated filaments to moist conditions (i.e., to liquid water, steam, high humidity or high humidity-high temperature conditions) following the drawing-heat treating step.

It is obvious, that if an antistatic or other type staple finish is to be added to the tow, prior to heat treating and drawing, that such finish must be stable at the hot plate temperatures which the filaments will encounter.

As mentioned hereinabove, the maximum operable draw ratio should be used, subject only to the requirement that excessive filament breakage be avoided. The tow may suitably be heated by contact with a hot plate, wherein the shape is not critical, as long as good contact is obtained. It has been found that the yarn reaches plate temperature in ½ to 1 second; during the balance of the plate contact time, the filaments have been found to be substantially at plate temperature. An alternative which may sometimes be preferable is to use radiant heat, or to use an oven supplied with heated air. Combinations of these are often useful, since the hot plate heats the tow rapidly, while the oven provides a very uniform heat treatment and avoids yarn friction and formation of carbonized deposits of yarn finish on heated contact surfaces.

The 66 nylon tow may be heated to temperatures of 140 to 225° C., and preferably to 165 to 200° C. The time at this temperature may vary from 1 second to 40 seconds, shorter times requiring higher temperature, as disclosed hereinbefore. Very satisfactory results are obtained when the yarn is heated by contact with the plate at 195° C., followed by an oven at 185° C., for a period of 20 seconds. Under these conditions, the yarn is subjected to about 3800 degree-seconds, which is a very suitable exposure; a draw ratio of 3.7 may be used for 2.2 denier filaments. As a guide, draw ratios, satisfactory for different filament deniers, are listed.

Denier:	x draw
1.2	3.2
2.2	3.7
4.3	4.5
10	5

The heat-treatment ranges apply to a wide range of deniers (e.g., from 1.2 to 15 denier and over per filament). It may prove desirable to increase the treating temperatures by about 5° C. for filaments of 10 to 15 denier, but treating times should not be altered. In general, the heat exposure under drawing tension should be about 1000 to 6000 degree-seconds, with 2000 to 5000 degree-seconds preferred.

Following the heat treating step, it is desirable to let the filaments cool somewhat before the drawing tension is released. Preferably the tow should cool to 90° C. or less.

After drawing, nylon intended for staple use is customarily crimped in some type of stuffer crimper (for example, that disclosed by Hitt in U.S. Patent 2,311,174), It has been found that this treatment leads to a certain amount of relaxation of the yarn, especially when done in the presence of moisture. This relaxation results in a significant loss in T_7, and hence is undesirable. For example, nylon is readily processed, without crimping, to a T_7 of 2.5 g.p.d. Under the same processing conditions, but followed by a crimping step giving a crimp index of 10%, the T_7 is only 1.9 g.p.d.; with increased crimping to give a crimp index of 20.5% (normal for standard 3 denier/filament nylon staple), the T_7 falls to 1.57 g.p.d.

Crimp index is determined on individual filaments by (a) straightening a fiber to remove crimp without substantial elongation of the fiber, (b) measuring the straightened length, (c) allowing the fiber to retract freely and again measuring; the crimp index is calculated as follows:

$$\frac{\text{length(a)}-\text{length(c)}}{\text{length(a)}}\times 100\% = \text{crimp index}$$

Thus, for highest values of T_7, mechanical crimping is to be avoided. More satisfactory results are obtained by passing the tow directly to a suitable staple cutter. A suitable cutter is disclosed by Hull in U.S. Patent 2,694,447. The staple is thereafter preferably passed through an opener, such as for example the Davis Furber Synthetic Fiber Opener. The opened staple may then be packed into bales under customary baling pressure, whereby it acquires sufficient crimp so that it can be satisfactorily blended with cotton or processed on conventional cotton spinning equipment. Maximum retention of the high load-bearing properties of the staple of this invention is attained if the staple is cut and baled as soon as possible after the drawing operation.

The high load-bearing staple of this invention is suitable for stock blending, sliver blending, or for the preparation of 100% synthetic fiber spun yarns.

The above examples are given by way of illustration since it will be apparent that variations may be made in the nature of the staple, time, temperature, drawing, etc., to obtain desired properties in the finished yarn or ultimate fabric. It is also to be understood that substitution of cotton staple by wool, or by other cellulosic fibers may be made where conditions permit.

The high load-bearing staple of this invention may contain conventional delusterants, dye modifiers, antistatic agents, antioxidants, heat stabilizers and the like. Suitable staple finishes may be added before, during or after the drawing and heat-treating step, subject to the requirements of heat-stability, and, for polyamides, freedom from hygroscopic effects tending to increase the fiber moisture content above the equilibrium value (e.g., about 4.1% at 76% R.H., 74° F.).

The present invention offers many advantages over the prior art. It permits the use of relatively cheap natural fibers or those derived from natural cellulosic materials with even small percentages of synthetic fibers to produce a yarn which may be fashioned into wearing apparel having improved wear and abrasion resistance. Another advantage is that apparel made from such blended fibers such as sweaters and socks have improved properties such as less pilling and stretching, softer hand, better shape retention, and greater comfort. It will be apparent, therefore, that the yarns herein disclosed offer a great economic improvement over the prior art.

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. An improvement in the conventional process for producing nylon staple fiber of about 1 to 15 denier per filament by melt-spinning nylon into continuous filaments, drawing the filaments, mechanically crimping the drawn filaments and feeding the crimped filaments to a staple cutter for cutting to staple; wherein the improvement comprises drawing and heat-treating the filaments under drawing tension at 165° to 200° C. for a length of time which provides 1000 to 6000 degree-seconds exposure, the filaments being drawn and heat-treated under dry conditions at substantially the maximum operable draw ratio within the range of about 3 to 5 which can be used without excessive filament breakage, feeding the drawn filaments to the staple cutter without crimping, and cutting the uncrimped filaments into staple fiber.

2. The process defined in claim **1** wherein the filaments

are of nylon selected from the group consisting of polyhexamethyleneadipamide and polycaprolactam, and are drawn and heat treated to provide a product characterized by a birefringence of at least 0.0590, an average density of at least 1.140, a break elongation above 14%, a boil-off shrinkage below 6.0%, and a load bearing capacity of at least 2.1 grams per denier at 7% elongation, measured after slack aging for nine days at 78° F. and 72% relative humidity.

3. The process defined in claim **1** wherein the staple fiber is crimped by packing the fiber into bales under pressure.

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