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[54] **YARN AND INFLATABLE BAG MADE THEREFROM**

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[58] **Field of Search**.......... 57/140 R, 157 R, 157 S; 264/290 R, 290 N, 290 T; 280/150 AB; 150/1

[56] **References Cited**

UNITED STATES PATENTS

3,311,691	3/1967	Good	264/290 N
3,470,928	10/1969	Schwartz	150/1
3,610,657	10/1971	Cole	280/150 AB
3,638,755	2/1972	Sack	280/150 AB X
3,756,620	9/1973	Radke	280/150 AB
3,761,111	9/1973	Kemper	280/150 AB

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[57] **ABSTRACT**

A high elongation yarn made of poly(hexamethylene adipamide) filaments having specific values of toughness, tenacity, initial modulus and elongation are prepared by drawing spun yarn at a draw ratio of between 2.8× and 3.8×. The yarns are useful in preparing woven fabric for use in making rapidly inflatable passive restraint air bags.

5 Claims, No Drawings

YARN AND INFLATABLE BAG MADE THEREFROM

BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION

This invention relates to novel nylon yarns, and, more particularly, to synthetic multifilament yarns of poly(hexamethylene adipamide) having high toughness and high elongation, which are useful in making fabric for use in inflatable bags that are subjected to both internal and external stresses.

BACKGROUND

Passive restraint systems for the protection of the occupants of a motor vehicle in collision situations consist of rapidly inflatable bags, as shown, e.g., in U.S. Pat. Nos. 3,610,657 and 3,638,755. Many early experimental bags failed when tested for such use, and upon investigation it was determined that inertial forces on the bag must be carefully considered, as well as bag fabric permeability and stress resistance in the deployment direction. It was further determined that the fabric comprising the inflatable bags would best be made of yarn that is energy absorbing, light weight and tough in order to impart good stress relationships to the bag.

Accordingly, it was discovered that a low drawn (between 2.8× and 3.8×) yarn of poly(hexamethylene adipamide) having specific values of toughness, tenacity, initial modulus and elongation met the requirements needed for the bag. Such a yarn and a bag made from the yarn are the objects of this invention.

SUMMARY OF THE INVENTION

A synthetic, multifilament, continuous filament yarn of poly(hexamethylene adipamide) having:

a. a toughness of at least 1.5 gm. cm./den. cm.,
b. a tenacity of at least 4.0 gm./den. (gpd),
c. an initial modulus of less than 25 gpd, and
d. an elongation (at break) of at least 45 percent.

The bag of this invention is an inflatable bag made of fabric woven from poly(hexamethylene adipamide) yarn having:

a. a toughness of at least 1.5 gm. cm./den. cm.,
b. a tenacity of at least 4.0 gm./den. (gpd),
c. an initial modulus of less than 25 gpd, and
d. an elongation (at break) of at least 45 percent,

said fabric having a higher thread count in the direction of bag deployment during inflation, and a fabric modulus of less than 8 × 8.

DESCRIPTION OF THE INVENTION

The yarn of this invention is low draw-high elongation nylon yarn. Specifically the yarn is a multifilament yarn made of continuous filaments of poly(hexamethylene adipamide) which has been drawn between about 2.8× and 3.8× over the undrawn spun yarn. The yarn denier is between about 100 and 800, and preferably is between about 200 and 500.

In a preferred embodiment, the yarn will have

a. a toughness of at least 1.8 gm. cm./den. cm.,
b. a tenacity of at least 4.5 gpd,
c. an initial modulus of less than 20 gpd, and
d. an elongation (at break) of at least 50 percent.

The polymer used to prepare the yarns of this invention can be prepared and spun into yarn by well known conventional methods.

The yarn obtained from the spinning operations is substantially undrawn, i.e., it is not drawn except for normal tensioning forces needed during spinning. This undrawn yarn can then be drawn by conventional procedures under ambient conditions. For example, drawing may be carried out on the draw equipment described in U.S. Pat. No. 3,311,691 in which the undrawn yarn is fed to a friction element where the yarn is drawn by snubbing it about the element and removing it from the element at a linear speed of from about 2.8× to 3.8× times the rate the yarn is supplied to the element.

Although not necessary, it is sometimes beneficial to heat-set the yarn at constant length. This can be readily carried out on the equipment shown in the aforesaid U.S. Pat. No. 3,311,691 by employing the annealing chest of the equipment as the heat-setting zone.

In another conventional drawing procedure, the undrawn yarn is drawn on a conventional draw twister in which the yarn, after being drawn, is wound into a package while some twist is imparted to it. The presence of the twist has no effect on the properties of the yarn of this invention.

The procedure may be a continuous one where the polymer is supplied directly to a spinning machine and drawing takes place immediately, or it may be a split procedure where the spun yarn is collected and is later drawn after a time interval.

Since the freshly spun yarn is substantially undrawn, the filaments in it will be substantially unoriented except for any draw due to spinning tension (which will be minimal). One skilled in the art of nylon spinning can easily determine the birefringence and spinning orientation of the yarn and from that estimate the draw ratio needed, which will normally be between 2.8 × and 3.8×.

Upon weaving yarn of this invention into an inflatable bag and testing for use in automobile passive restraint systems, in which the bag is inflated by nitrogen within about 20–40 milliseconds to restrain occupants, the bag was found to maintain its integrity whereas bags woven from conventional high strength, high toughness, low elongation poly(hexamethylene adipamide) yarns such as the ones described in U.S. Pat. No. 3,311,691, frequently failed. The reason for the superior performance of the yarns of this invention in such use is not entirely clear, but is believed to be due to the unique external stresses that occur upon the rapid inflation of an air bag and to the particular energy absorbing properties imparted to the bag by the yarn of this invention. Thus, the high toughness, high elongation, and low modulus of the yarns of this invention are apparently of greater importance to the successful development of a rapidly inflatable bag which is subjected to internal and external stresses than are the properties of breaking strength, tenacity and high modulus, which are the properties usually most closely associated with conventional high strength industrial yarns of poly(hexamethylene adipamide).

The woven fabric used in the bags of this invention preferably has an air permeability of between about 2 and 15 CFM/sq. ft., and most preferably between about 3 and 10 CFM/sq. ft.

TEST METHODS

Breaking strength (lbs.), elongation (%), initial modulus (modulus at 1 percent elongation), work-to-break, and toughness data are obtained on 10-inch samples having 3 tpi twist added, elongated on an Instron Tensile Tester at a constant rate of 60 percent per minute. Breaking strength (lbs.) is converted to yarn tenacity (grams per denier), initial modulus is expressed in grams per denier, and toughness (area under stress-strain curve) is determined in gram-cm. per denier-cm. units, all by dividing the respective measurements by the yarn denier. Yarn packages are conditioned at 74° ± 2°F. dry bulb and 72 ± 2 percent relative humidity for a minimum of 2 hours before testing.

EXAMPLES

EXAMPLE 1

A. This example illustrates the careful selection of draw ratio which must be exercised in achieving the yarns of this invention.

In a coupled spin-draw procedure, yarns of poly(hexamethylene adipamide) containing 140 filaments are spun continuously from hexamethylene adipamide polymer having a relative viscosity of 70 as determined in an 8.4 percent by weight solution of polymer in 90 percent by weight formic acid at 25°C. The yarns are drawn in an apparatus of the type described in U.S. Pat. No. 3,311,691. Drawing for yarn samples A and B, described below, was carried out in the first stage of the apparatus by snubbing them around the friction element and removing them from the element at a faster linear speed. These two yarn samples were heat set at constant length at 220°C. by using the hot pipe and the annealing chest of the apparatus. Yarns C and D, also described below, were drawn a second time using the hot pipe as described in said patent. All yarns were subsequently relaxed 5 percent in a tension relaxing zone prior to winding.

The drawing ratios and the effect of the drawing conditions on the properties of yarns A, B, C and D are shown in Table I following.

TABLE 1

Item	A	B	C	D
1st Zone Draw Ratio	2.5	3.0	3.1	3.1
Total Draw Ratio	2.5	3.0	3.5	4.0
Denier	839	906	831	834
Breaking Strength, lbs. (kg)	7.44 (3.38)	9.72 (4.41)	11.0 (4.99)	12.9 (5.86)
Tenacity, gpd	3.83	4.65	5.99	7.02
Modulus, gpd	19.5	22.9	28.6	30.6
Work-to-Break, gm.-cm./cm.	1724	1692	1483	1604
Break Elongation, %	71.4	57.0	43.7	41.6
Toughness, gm. cm./den. cm.	2.05	1.88	1.78	1.92

As shown in Table 1, only yarn B, which was drawn in a single-stage at 3.0X resulted in a yarn having properties within the scope of the yarns of this invention.

B. A conventional commercial industrial yarn of poly(hexamethylene adipamide) drawn about 5.0 having a denier of 855, a tenacity of 8.6 gpd, a break elongation of 19 percent, a toughness of 0.78 gm. cm./den. cm., and a modulus of 44 gpd, is woven into a fabric. Yarn of Item B above is also woven into a fabric. The two fabrics are woven with a loom thread count of 24 ends/inch × 24 picks/inch. The two fabrics are scoured, heat set, and coated with about two oz./sq. yd. of an elastomeric impermeable coating. The properties of the fabrics are as follows:

	Item B	Conventional
Weight (oz./sq. yd.)	7.8	7.9
Grab Break Strength-WxF-(lbs./in.)	361×329	368×299
Grab Break Elongation-WxF-(%)	56×63	29×38

It is seen that the fabric made of the yarn of item B, a yarn of this invention, has a strength equal to that of the fabric made of the commercial yarn, even though the item B yarn has a tenacity almost half that of the commercial yarn.

EXAMPLE 2

Two yarns, A and B, are melt-spun from poly(hexamethylene adipamide) flake having a relative viscosity of 39 using a conventional grid-melt spinning machine. The unoriented yarn is wound up and subsequently drawn 3.64X using a ⅝ inch diameter draw pin on a conventional draw twister.

The properties of yarns A and B are shown in Table 2 following, as are the properties of a conventional high tenacity poly(hexamethylene adipamide) yarn (Yarn C) which was prepared under conditions similar to those for preparing the conventional commercial yarn used in Example 1 except that denier was lower.

TABLE 2

Item	Yarn Den./Fil.	Breaking Strength lbs. (kg.)	Tenacity, gpd	Initial Modulus, gpd	Elongation, %	Toughness gm. cm./den. cm.
A	407/68	4.36 (1.98)	4.85	16.1	58.2	1.90
B	208/34	1.99 (0.90)	4.34	17.7	63.7	1.98
C	420/68	7.17 (3.26)	7.74	47.2	18.7	0.71

The data represent average properties from 10 bobbins of each item.

Fabrics are woven of yarns A and C, and Table 3 lists their properties:

TABLE 3

	Item A	Item C
Weight (oz./sq. yd.)	7.1	7.8
Thread Count (warp × fill)	74×41	89×39
Tongue Tear Strength (lbs./in.)	48×33	58×40
Grab Break Strength (lbs./in.)	495×312	622×332
Grab Break Elongation (%)	74×55	38×27
Air Permeability (CFM/sq. ft.)	6.9	5.6
Fabric Modulus (lbs./in.)/(%)	6.7×5.7	16.4×12.3

The gray, unscoured, fabrics of Item A and Item C are fabricated as identical inflatable cylindrical bags (closed at both ends) 39 inches tall with a cross section in the shape of a tear-drop 35 inches long, 22 inches at the widest part of the drop. The narrow end of the drop is small enough to contain a 2 inch diameter cylindrical pipe-manifold around which the bag is secured. The bags are inflated with nitrogen pouring through slots in the manifold, and this nitrogen entered the pipe from a pressure bottle at 3500 psi pressure. The rate of nitrogen release is such that the bag made of the yarn of Item A is fully inflated in less than 30 milliseconds and then (because of the permeability of the fabric) is deflated in less than 60 milliseconds after the first triggering of nitrogen release. However, the bag made of the conventional yarn failed to inflate completely because of a rip under the same conditions.

The inflation-deflation sequence is a static simulation of a head-on collision with an immovable object of an automobile traveling 30 mph. In actual use the impact would trigger release of stored nitrogen and the bag would be inflated within 40 milliseconds after impact to prevent the automobile passenger from hitting the windshield. The passenger is projected into the bag, and does not rebound because of the deflation. The bag design places significantly more warp ends in the direction of bag travel than fill picks.

EXAMPLE 3

Yarn of poly(hexamethylene adipamide) having a relative viscosity of 54, a spun denier of 1260 and a spinning birefringence of 0.0090 equivalent to a spinning draw ratio of 1.20 is drawn in a single stage using a draw twister.

Average properties of four short doffs drawn under conditions as in Example 2 show a yarn denier 403, a breaking strength of 4.53 lbs. (2.06 kg.), a tenacity of 5.1, an initial modulus of 18.1, an elongation-at-break at 67.2 percent and a toughness of 2.30 gm. cm./den. cm.

TABLE 4

	Item D	Item C
Weight (oz./sq. yd.)	7.0	7.0
Thread Count (warp × fill)	77×44	73×41
Tongue Tear Strength (lbs./in.)	58×57	53×34
Grab Break Strength (lbs./in.)	647×369	653×371
Grab Break Elongation (%)	88×71	45×28
Air Permeability (CFM/sq. ft.)	3.5	3.7
Fabric Modulus (lbs./in.)/(%)	7.3×5.2	14.5×13.2

Fabrics are woven of this yarn (Item D) as well as of the yarn of the conventional yarn of Item C of Table 2. Table 4 specifies fabric properties of these two fabrics:

It is seen that Item D has substantially the same tongue tear strength and grab break strength as the fabric of Item C although the yarn of Item D has significantly less tenacity than that of Item C. It is to be noted that the fabrics made of the yarns of this invention have a modulus of less than 8 where fabric modulus is defined by

(Grab Break Strength/Grab Break Elongation). Grab break strength and elongation as well as tongue tear strength in the foregoing examples were measured with the methods of ASTM D39-59, while air permeability was measured with the method of ASTM D737-46.

The foregoing detailed description has been given for clearness of understanding only and no unnecessary limitations are to be understood therefrom. The invention is not limited to the exact details shown and described for obvious modifications will occur to those skilled in the art.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A synthetic, multifilament, continuous filament yarn of poly(hexamethylene adipamide) having

a. a toughness of at least 1.5 gm. cm./den. cm.,
b. a tenacity of at least 4.0 gm./den. (gpd),
c. an initial modulus of less than 25 gpd, and
d. an elongation (at break) of at least 45 percent.

2. The yarn of claim **1** wherein the yarn has:

a. a toughness of at least 1.8 gm. cm./den. cm.,
b. a tenacity of at least 4.5 gpd,
c. an initial modulus of less than 20 gpd, and
d. an elongation (at break) of at least 50 percent.

3. The yarn of claim **2** wherein the yarn has a denier of between about 100 and 500.

4. An inflatable bag made of fabric woven from poly(hexamethylene adipamide) yarn having:

9. 9 toughness of at least 1.5 gm. cm./den. cm.,
b. a tenacity of at least 4.0 gm./den. (gpd),
c. an initial modulus of less than 25 gpd, and
d. an elongation (at break) of at least 45 percent,

said fabric having a higher thread count in the direction of bag deployment during inflation, and a fabric modulus of less than 8 × 8.

5. The bag of claim **4** wherein the air permeability of the fabric is between about 2 and 15 CFM/sq. ft.

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