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Allman et al.

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[54] **ENERGY ABSORBENT TEXTILE STRUCTURE**

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Related U.S. Application Data

[63] Continuation of Ser. No. 226,235, Feb. 14, 1972, which is a continuation of Ser. No. 881,809, Dec. 3, 1969, abandoned.

[52] **U.S. Cl.** ..... **139/383 R,** 139/426 R

[51] **Int. Cl.** **D03d 15/00**

[58] **Field of Search** ..... 139/383 R, 426 R, 420 R, 139/408–415; 297/385; 280/150 SB; 161/91

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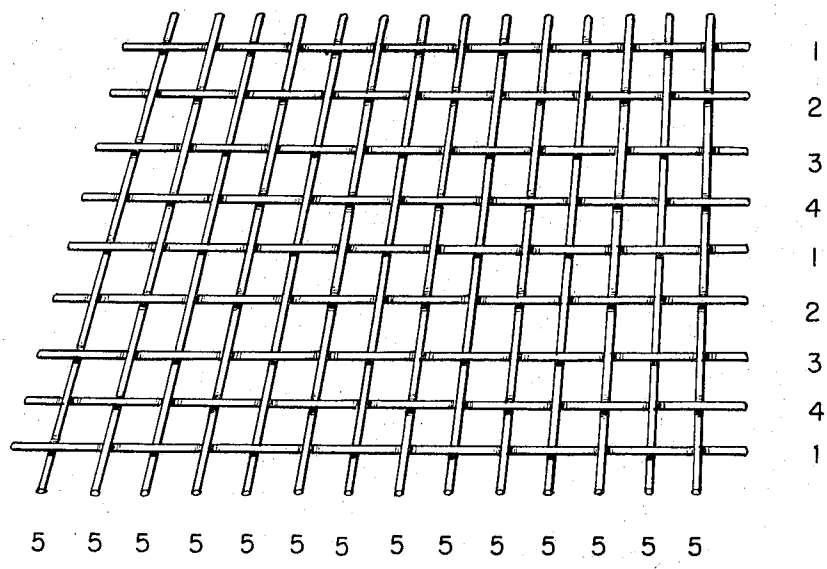
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[57] **ABSTRACT**

Impact absorbent textile structures constructed of substantially unidirectional yarns having differential elongations at the break exhibit sufficient extensibility to minimize residual recovery without impairment of strength.

4 Claims, 3 Drawing Figures



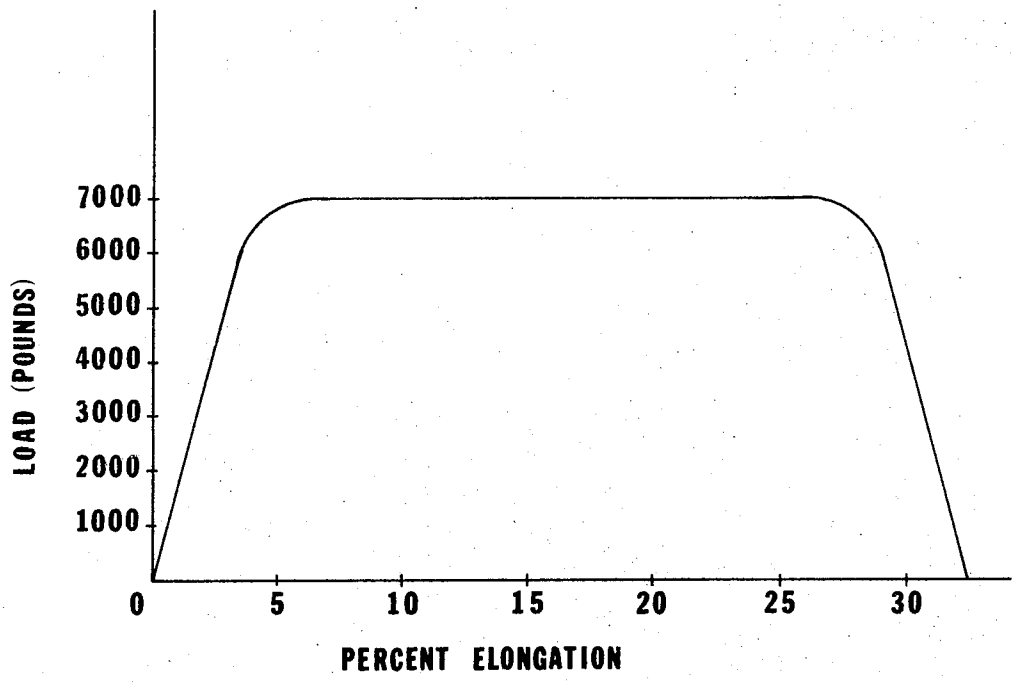


FIG. 1

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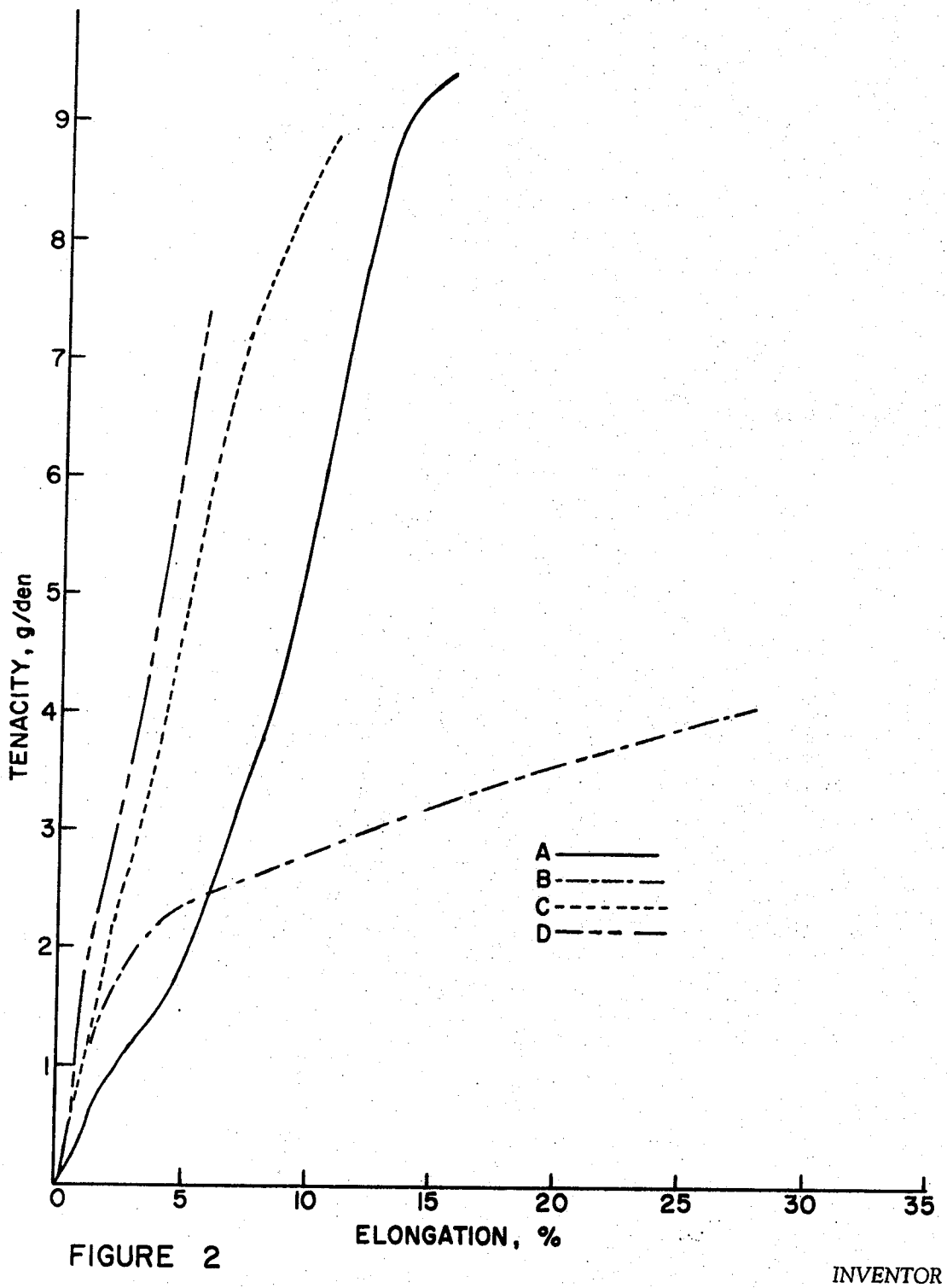


FIGURE 2

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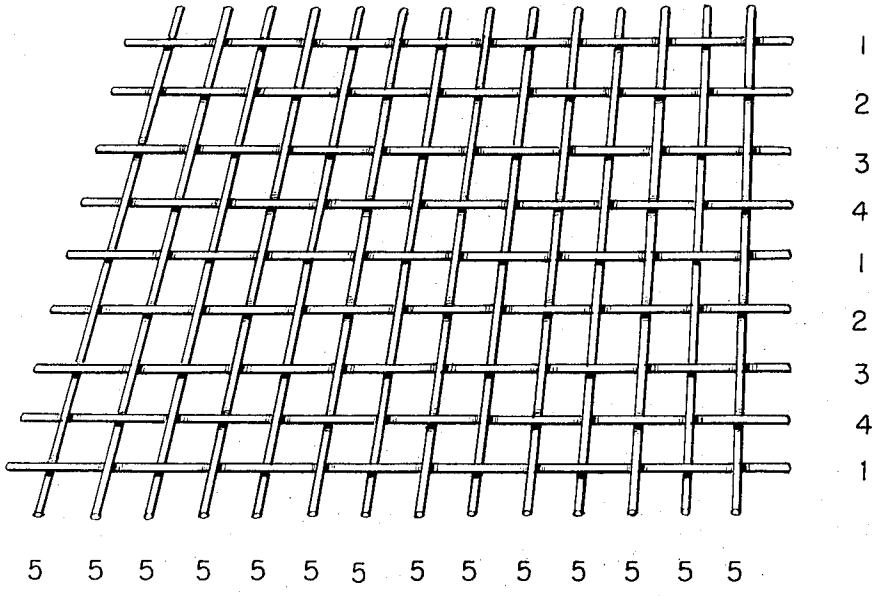


FIG. 3

ENERGY ABSORBENT TEXTILE STRUCTURE

This is a continuation, of application Ser. No. 226,235, filed Feb. 14, 1972 which is a continuation of prior application 881,809 now abandoned.

BACKGROUND OF THE INVENTION

This invention relates to energy absorbent textile structures characterized by predetermined load-elongation properties. More particularly, the invention relates to impact absorbent structures constructed from fibrous materials and having defined stress-strain characteristics minimizing the normally present inherent residual recovery of the structure to the prestressed state following high energy absorbence and where desired allowing further absorbence of additional shock forces prior to product rupture.

Impact absorbent textile structures, such as belts, webbings, nets, harnesses, ropes and the like, are used in numerous and varied applications requiring restraining structures because of their strength, i.e., toughness combined with a high degree of shape conformity and overall flexibility, in conjunction with other desired fabric properties such as dyeability, hand, lustre, abrasion resistance and the like. The above is particularly evident in applications for restraining devices which should display a pleasing, ornamental appearance as well as being capable of withstanding forces of a high magnitude, i.e., seat belts for automobiles, airplanes and other vehicles.

It is currently believed that a primary cause of secondary injury to people and inanimate objects alike during the necessary use of shock-absorbent textile structures, that is, injury not resulting directly from the primary force against which the restraining device protects but arising as a result of the successful operation of the device in withstanding the applied stress, occurs during the residual recovery of the restraining structure to its prestressed configuration. A common example of such secondary injury is "whiplash" injury to occupants of automobiles forced to an abrupt stop. When the occupant of an automobile involved in a collision is wearing a conventional lap belt, post-collision residual belt recovery, by forcing the occupant's body in a direction opposite to that of original car motion, is believed to be a major factor contributing to "whiplash" injuries. The identical factor, abrupt change in degree or direction of body motion due to the lack of sufficient "give" in the restraining structure is also evident elsewhere as apparently contributing in a substantial manner to similar secondary injury. For instance, the inexperienced parachute jumper may not be prepared for the abrupt "yank" upon opening of the chute causing tautness of the harness. The jumper, instead of having his descent slowed without an extreme, abrupt force being applied to the body, is subjected to a sudden "jerk" as the harness reaches its fully extended position, reacts to the applied stress and recovers from the stressed condition.

Therefore, it is an object of the present invention to provide impact resistant textile structures having predetermined stress-strain characteristics.

It is another object of the invention to provide energy absorbent fibrous articles capable of withstanding high impact without recovering to the prestressed state, thereby aiding in the elimination of a primary cause of secondary injury.

It is a more specific object of the invention to provide seat belt webbing constructions having controlled stress-strain characteristics which combine desired strength with minimal residual recovery to aid in the prevention of secondary "whiplash-type" injuries.

It is a further object of the invention to provide where desired high energy absorbent, fibrous, constructions capable of withstanding repeated high impact without recovering to the prestressed state.

Still another object of the invention is to provide textile structures characterized by low residual recovery under high impact while retaining maximum designed strength prior to complete structure rupture.

Other objects of the invention will appear obvious from the detailed description of the invention hereinafter.

THE INVENTION

In accordance with the present invention there are provided strong, energy absorbent textile structures characterized by minimal residual recovery comprising a plurality of unidirectional yarns having differential elongations at the break. The structures of the invention have sufficient inherent 'give' or stretchability without impairment of impact resistance capability to essentially eliminate residual structural recovery and the accompanying hazard of secondary injury. With employment of the principles of the invention as disclosed herein, fibrous restraining constructions having any desired load-elongation curve or properties may be prepared. Maximum designed strength may be retained up to final product rupture.

In a preferred embodiment of the invention there are provided woven fabric constructions, i.e., seat belt webbings, constructed of warp yarns having differential elongations at the break to give a "flat topped" stress-strain, load-elongation curve indicating high impact resistance and energy absorbence up to complete product rupture coupled with minimal residual webbing recovery prior to such rupture. The webbing gradually elongates under applied stress instead of recovering to the prestressed state. Thus, the belt "gives" under impact eliminating to a pronounced degree what is believed to be a primary cause of secondary injury to the restrained object. Where desired the webbing is constructed to withstand repeated high impact, gradually elongating therefrom without diminution of impact resistance capability.

In another preferred embodiment of the invention, there is provided a woven textile fabric constructed of warp yarns having differential elongations at the break with at least about 80 weight percent of the warp yarns having an elongation at the break of from about 3 to 30 percent, preferably 5 to 15 percent, and more preferably, a woven fabric containing at least a significant number of warp yarns having an elongation at the break of from about 3 to 7 percent, preferably about 5–6 percent, a significant number of warp yarns having an elongation at the break of about 7 to 12 percent, preferably about 10 to 11 percent and a significant number of warp yarns having an elongation at the break of from about 13 to 20 percent, preferably about 15 to 20 percent.

FIG. 1 illustrates a load-elongation curve of the textile structure.

FIG. 2 illustrates the stress-strain curve of the individual yarns.

FIG. 3 illustrates an example of a woven fabric.

DETAILED DESCRIPTION

One example of woven fabric that may be with the instant invention is shown in FIG. 3. The warp yarns **1, 2, 3** and **4.** The weft yarns are shown by the yarn **5.** Other weaving configurations may of course be employed with the instant invention particularly those as are hereinafter described.

As an aid in understanding the invention FIG. 1 of the drawing is an ideal Instron stress-strain, load-elongation curve of a textile structure constructed in accordance with the invention wherein percent elongation is plotted along the horizontal (x) axis against load expressed in pounds plotted along the vertical (y) axis. The coordinate points plotted on a geometrical graph give a horizontally-extending stress-strain curve approximately parallel to the x axis until the percent elongation at the break of the textile structure is reached. The geometrical curve shows the gradual elongation of the textile structure under high stress. Residual structure recovery is virtually eliminated without loss of impact resistance by the progressive breaking of the yarns prior to the obtainment of maximum percent elongation at the break of the most highly extensible yarns.

As disclosed in certain of the preferred embodiments of the invention, a relatively small weight proportion, generally between about 5 and 10 percent of the warp yarns of a woven impact absorbent structure will have a maximum elongation at the break up to about 7 percent and preferably between about 4 to 6 percent. In this manner, some of the low elongation value fibers will be broken or deformed during impact, thereby preventing the structure from recovering to its prestressed condition. By the construction of webbings with yarns having a plurality of progressively increasing elongations at the break, while maintaining desired strength in the structure as described hereinafter, a woven impact resistance structure is produced which gradually stretches or gives under impact and where desired repeated impact due to the continual deforming or breaking of yarn, without impairment of strength.

The following example illustrates one embodiment of the invention in the construction of a seat belt webbing exhibiting a stress-strain curve geometrically similar to that of the drawing.

EXAMPLE 1

A seat belt webbing is constructed according to the invention using a combination of rayon, nylon and polyester yarns in a particular webbing warp yarn layout. The yarns, designated A, B, C and D have the following physical characteristics.

YARN PHYSICAL PROPERTIES

Yarn	Fiber	Yarn Characteristics	Breaking Strength (lbs)	Yarn Denier	Breaking Elongation (%)	Yarn Tenacity*
A	polyester	250/48/1/4Z	2.2	250	29.1	4.0
B	polyester	840/74/1/4Z	16.2	840	10.4	8.7
C	nylon	840/140/1/4Z	15.8	840	18.2	8.5
D	saponified rayon	270/350/1/4Z	4.6	270	5.9	7.7

*grams per denier

The warp yarns formed from yarns A and D are **6** ply with an additional 2 twists in the z direction while warp yarns formed from yarns B and C are 2 ply with an additional 2 twists in the Z direction to give a total webbing warp yarn composition as follows:

WARP YARN

Type A	6 ply/2Z/76 ends
Type B	2 ply/2Z/5 ends
Type C	2 ply/2Z/5 ends
Type D	6 ply/2Z/10 ends
TOTAL ENDS = 96	

The webbing is woven using the above-described warp yarns according to the following transverse warp yarn end arrangement, the number preceding the warp yarn "letter designation" being the number of ends of that particular warp yarn used at a corresponding place along a transverse section of the webbing; that is, the transverse warp yarn layout is given as extending from one side edge of the webbing across to the opposite side edge.

Transverse warp layout (side edge to side edge): **11A, 2B, 3D, 2C, 27A, 1B, 4D, 1C, 27A, 2C, 3D, 2B, 11A** Total ends = 96.

The webbing has the following physical characteristics:

Total denier	147,000
Weight (ounces/yard)	21.01
Thickness (inches)	0.035
Breaking Strength (pounds)	843
Initial Breaking Elongation, %	8.0
Final Breaking Elongation, %	13.0
Width (inches)	1.125

The Instron load-elongation curve of the webbing curves abruptly forming a sharp angle when the breaking elongation of the most extensible yarns is reached under load.

Although the webbing does not fully conform to the calculated theoretical physical property values, i.e., final breaking elongation should be 30 percent, it is believed that this is because of a variety of factors associated with yarn property variables, yarn crimpiness and tension exerted during the manufacturing process. However, the webbing functions according to the theoretical load-elongation curve of the drawing with a gradual stretching occurring under applied stress. The virtually complete elimination of residual recovery coupled with maintenance of maximum strength prior to final break in the structure results in the construction of a highly desirable restraining device, particularly for use as a vehicle seat belt. Where desired, the seat belt is constructed to withstand repeated maximum load by proper selection of yarns having particular breaking strengths.

EXAMPLE II

A harness belt is constructed in accordance with the present invention using the following yarns:

TABLE I

Yarn	Fiber	Yarn Characteristics	Breaking Strength (lbs)	Breaking Elongation (%)	Yarn Tenacity*
A	saponified rayon	270/350/1/4Z	4.6	5.9	7.7
B	polyester	840/74/1/4Z	16.2	10.4	8.7
C	polyester	840/74/1/4Z	14.0	16.0	7.6
D	polyester	840/74/1/4Z	12.0	20.0	6.5
E	polyester	840/74/1/4Z	10.6	25.0	5.7

*grams per denier

The warp yarns are all 2 ply, with the exception of the warp yarn formed from yarn A which is 3 ply, and are twisted 2 ½ turns in the *Z* direction.

The belt is constructed using a transverse warp layout as follows repeated 46 times; A, A, B, C, D, E.

The belt, having a calculated breaking strength of slightly over 700 pounds and a total denier of over 2 thousand is excellent for use as a parachute harness and exhibits the characteristic stress-strain, load-elongation curve of the drawing.

It has been determined that a textile structure theoretically conforming to pre-select load and elongation values may be constructed through a perusal of individual yarn stressstrain curves. For example, the primary yarn component should have a theoretical elongation at the break equal to that desired in the fabricated structure. This yarn is then plied as desired with the number of ends necessary for a given structural breaking strength at the selected elongation at the break employed in the construction of the impact resistant article.

Additional yarns, which may be one or more up to 100 to 1000 different yarn types, are selected having elongations at the break lower than the maximum, and preferably when two or more additional yarns are used, having elongations at the break which regress by a constant percentage, that is, if the maximum elongation at the break is 25 percent, 4 additional yarns may be selected having elongations at the break of 20, 15, 10 and 5 percent. As the yarns of lower extensibilities break, the webbing is prevented from returning to the prestressed state.

In order to determine the number of ends and type of yarn for the construction of the impact absorbent article, the stress-strain curves of each yarn type are plotted on a sin graph. Once the number of ends of the yarn having the greatest percentage elongation at the break required for a specified breaking strength is determined, the load sustainable by that yarn at the elongation at which the yarn having the next lowest percentage elongation value breaks is calculated. This numerical value is subtracted from the total breaking strength requirement, the number of ends of the second yarn being used to supply the balance of such requirement. The above procedure is repeated for each yarn at its particular percent elongation at the break, working backwards to the next lowest value and subtracting the total load sustainable by all previously considered yarns from the desired structural breaking strength at such elongation value to determine the number of ends of that particular yarn to be incorporated into the structure. Obviously, it is, therefore, possible to construct webbings capable of sustaining a desired number, as well as a single, high impact, with gradual elongation thereof.

This above-disclosed method of constructing the energy absorbent structures of the invention is illustrated by FIG. 2 of the Drawing.

The individual curves of FIG. 2 represent the stress-strain curves of 4 individual yarns to be used in the construction of a seat belt webbing. In addition to the yarn characteristics set forth in FIG. 2 of the Drawing, the individual yarns have the following deniers:

Yarn A	840 denier
Yarn B	250 denier
Yarn C	840 denier
Yarn D	270 denier

Using the principles described, a seat belt webbing is constructed from the following number of yarn ends.

Yarn A	10 ends
Yarn B	456 ends
Yarn C	10 ends
Yarn D	60 ends

Thus, theoretically the webbing should withstand a peak load of about 950 to 1000 pounds. The load of the webbing at any given elongation can be easily calculated by the following formula:

$$\frac{Le = \sum_{A}^{N} lend}{453.6}$$

wherein

A...N are types of yarn in the warp.

l_e is load (g/den) required to extend yarn *e* percent.

n is the number of ends of a yarn in a warp.

d is denier of a yarn in the webbing warp.

For example, the L_5 of the webbing constructed as described using the yarns of FIG. 2 is calculated as follows: $L_5 = 1/\mathbf{453.6}$ [(456)(250)(2 4) + (10)(840)(4.8) + (10)(840)(1.9) + (60)(270)(6.4)]

This webbing contained **456** ends of **250** denier polyester, **10** ends of **840** denier polyester, **10** ends of **840** denier nylon and **60** ends of **270** denier Fortisan. The $\mathbf{l_5}$ were taken from the stress-strain curves of FIG. 2 of the Drawing. The calculation of various L_e gives the following results:

$L_{2.5} = 635$

$L_5 = 956$

$L_{7.5} = 852$

$L_{10} = 949$

$L_{12.5} = 902$

$L_{15} = 962$

Thus, it can be seen that this would predict a flat topped peak breaking load of around 950 pounds. No attempt was made to take into account warp crimp which will affect webbing elongation, or yarn to fabric strength conversion efficiencies. This webbing has been found to have an actual breaking load peak around 850 pounds. This 90 percent efficiency of strength translation is surprisingly good since 100 percent polyester in

seat belt webbings has typically shown 80 percent conversion efficiency. The correlation of load with elongation is not as good since the significant factor of crimp has not been taken into account.

From the aforegoing it is readily apparent that nearly any type of yarn may be employed in the practice of the present invention as long as its specific stress-strain curve is considered as described above in determining the yarn composition of the impact absorbent structure. As examples of fibers which may be used, there may be mentioned natural fibers such as cotton and wool and man-made fibers such as acetate, both secondary and triacetate, rayon, acrylic, modarcylic nylon, olefin, polyester and polyvinylhalide.

At times, it may be desirable to include an undrawn or partially drawn yarn in the restraining article's construction. These yarns, having not been drawn to their maximum tenacity for a preselected elongation before being employed in the manufacturing operation, will be drawn during elongation of the impact resistant structure to a stronger tenacity. For example, underdrawn or undrawn yarns could be used when, for aesthetic or other reasons, the number of ends of yarn having the greatest percent elongation at the break required for the pre-determined final breaking strength is undesirable. As long as the yarn's particular stress-strain curve is correctly considered in the calculation of the breaking strength of the article, it can be used in the construction thereof. Further, yarns applicable in the present invention may be of any structural type as long as they are continuous strands of material suitable for intertwining, i.e., knitting and weaving processes, and exhibiting distinguishable stress-strain curves. For example, the yarn employed in the invention may be spun yarn, monofilament with or without twist, multifilament with or without twist or other narrow strip material such as paper, cellophane and metal foil, also with or without twist. Similarly, the yarn may be employed to construct various structural types of impact resistant articles depending upon the usual type of yarn intertwining used in the manufacture of comparable articles not having the defined stress-strain characteristics imparted by perusal of the present invention. For example, conventional woven and knitted impact resistant structures, as well as nonwoven, i.e., continuous filament tows, and other types of intertwined structure such as braided ropes, may be constructed with either limited or complete elimination of residual recovery after stress. Preferably, the invention is employed in woven constructions of relatively narrow width, i.e., seat belts, with the warp yarns having incrementally increased differential elongations.

Although ideal stress-strain curves for specific impact resistant structures are not known at the present time, it has been found that woven textile structures to be used in applications requiring minimal residual recovery coupled with high-speed impact absorbence of stresses of the order of 700 pounds load and higher, i.e., seat belt constructions for use in automobiles and airplanes, in addition to being constructed from warp yarns having differential elongations at the break, may be constructed so that at least about **20** weight percent of the warp yarns have an elongation at the break of from about 5 to 20 percent. Preferably, as illustrated by Example I hereinbefore, seat belt constructions are manufactured so that at least 70 weight percent of the warp yarns have an elongation at the break of from about **28** percent to 30 percent and less than about 30 weight percent of the warp yarns have an elongation at the break of from 5 to 20 percent. Most preferably, about 75 to 80 weight percent of the warp yarns will have an elongation at the break of at least 28 percent, about 6 weight percent of the warp yarns will have an elongation at the break of about 20 percent, about 6 weight percent of the warp yarns will have an elongation at the break of about **10** percent and about 12 weight percent of the warp yarns will have an elongation at the break of about 5 per cent.

The warp layout may vary but it is preferable that the yarn of highest concentration, generally corresponding to the yarn of highest elongation at the break value, be arranged in three or more fields equally spaced across the width of the fabric, that is, the yarn of highest elongation could be along both edges and, preferably, in two rather wide yarn fields spaced across the internal fabric area, with the remaining yarns arranged in narrow bands thereinbetween, again with fields of the yarns of different elongations being nearly evenly-spaced across the width of the fabric. This type of fabric construction, particularly with woven structures, assures uniformity of energy absorbence across the width of the structure throughout its normally expected life span and prevents premature structurally apparent rupture of the fabric, i.e., splitting off yarns along the edges prior to a complete transverse break at maximum elongation.

Although FIG. **1** of the Drawing depicts an idealized Instron stress-strain curve, it will be appreciated by those of skill in the art that the Instron curve, because of the gradual increase in applied load per unit time (2 inches/minute) would not precisely coincide with a high speed/high impact stress-strain curve of a comparable structure. However, the essential feature of the curve, a horizontally extending line substantially parallel to the ordinate under peak load until break would be preserved. Of course, impact absorbent structures of any desired stress-strain curve may be construction by application of the principles discussed herein with respect to webbing construction.

Numerous modifications within the spirit of the invention will appear obvious to those of ordinary skill in the art.

What is claimed is:

1. An improved woven fabric capable of energy absorption in at least one direction, said woven fabric having warp yarns interwoven with weft yarns and said warp yarns being a plurality of yarns having differential elongations at the break so that loading causes successive breakage of said different types of warp yarns, and said fabric being capable of peak loads of up to about 9000 lbs. and final breaking elongations of from 25 to 35 percent, said fabric comprising at least four groups of warp yarns with said first group of warp yarns having an elongation at break of from 3 to 7 percent; with said second group of warp yarns having an elongation at the break of from 7 to 12 percent; with said third group of warp yarns having an elongation at break of from 13 to 20 percent; and said fourth group of warp yarns having an elongation at break from 21 to 35 percent; each said group of warp yarns being present in an amount of at least 5 percent by weight of all said warp yarns; so that said fabric is essentially capable of a load of from 5000 to 9000 lbs. at an elongation of 5 percent, a load of from 5000 to 8000 lbs. at an elongation of 10 percent,

a load of from 2000 to 7000 lbs at elongations from 15 to 30 percent; whereby under high impact loading the total energy absorbing ability of said warp yarns is increased without increasing the whiplash.

2. The structure of claim **1** wherein at least 70 weight percent of said warp yarns have an elongation at the break of from about 28 to 30 percent and less than about 30 weight percent of said warp yarns have an elongation at the break of from about 5 to 20 percent.

3. The fabric of claim **1** wherein about 75 to 80 weight percent of said warp yarns have an elongation at break of at least 28 percent, about 6 weight percent of said warp yarns have an elongation at break of about 20 percent, about 6 percent of said warp yarns have an elongation at break of about 10 percent and about 12 weight percent of said warp yarns have an elongation at break of about 5 percent.

4. The structure of claim **1** wherein said warp yarns having the highest percentage elongation at the break are in fields along the edges and in at least one centrally positioned area of said fabric.

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