ABSTRACT: The elimination or reduction of broken glass cords in pneumatic tires is accomplished by using cords with tensile efficiency greater than 75 percent and a twist product within the range of zero to 0.300 turns. Tensile efficiency is a ratio of the in-rubber tensile strength of the cord to its theoretical, calculated tensile strength.
Fig. 2

Cord Structures
After Various Processing Steps

<table>
<thead>
<tr>
<th>STRAND OR END AFTER STEPS OF:</th>
<th>UNPLIED CORD</th>
<th>UNPLIED CORD</th>
<th>PLIED CORD</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPINNING AND SIZING</td>
<td>G15 (2040 Filaments)</td>
<td>G75 (408 Filaments)</td>
<td>G30 (1020 Filaments)</td>
</tr>
<tr>
<td>SPOOLING AND SLIGHT TWISTING</td>
<td>G15-1/0 (ONE STRAND)</td>
<td>G75-5/0 (FIVE STRANDS)</td>
<td>G30-1/0 (ONE STRAND)</td>
</tr>
<tr>
<td>AFTER ADDITIONAL STEPS OF:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DIPPING AND DRYING</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RESPOOLING AND TWISTING</td>
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<td>RESPOOLING</td>
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<tr>
<td>PLYING AND TWISTING</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Inventor: Paul S. Shoemaker
Walter K. Klamp

ATTORNEY.
Fig. 5

Calculated and in-rubber tensile strength per 204 "G" size filaments

\[ P = \frac{E \cdot TT^2}{1 + TT^2(2RT)^2} \text{ POUNDS PER 204 FILAMENTS} \]

- \( P \): Pounds per 204 filaments
- \( E \): Elastic modulus
- \( TT \): Twisting tendency
- \( RT \): Remarks

- **GOOD**
- **QUESTIONABLE**
- **BAD**

- **GROUP E**
- **75% P**

- **E = 10.5 \times 10^6 \text{ P.S.I. (MODULUS FOR "E" TYPE GLASS)}**
- **\( \varepsilon = 4.8\% \) (ELONGATION AT BREAK FOR "E" TYPE GLASS)**
- **R = CORD RADIUS (0.026 FOR 204 FILAMENTS)**
- **T = CORD TWIST**

**Twist Product = 2RT (Turns)**

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William H. Speaks
3,554,260

GLASS CORD REINFORCEMENT OF ELASTOMERIC ARTICLES

The foregoing abstract is not to be taken either as a complete exposition or as a limitation of the present invention, and, in order to understand the full nature and extent of the technical disclosure of this application, reference must be had to the following detailed description and the accompanying drawings as well as to the claims.

DISCLOSURE OF THE INVENTION

This invention relates to glass cord as a reinforcing element in elastomeric articles. More particularly, the invention concerns an improvement in glass cord used as a reinforcement element in pneumatic tires.

The commercially available glass cord that is presently being used as a reinforcing material for pneumatic tires and other elastomeric articles is comprised of a plurality of glass filaments. In the manufacture of the cord, a strand, or end, is formed when the glass filaments are brought together as a bundle of filaments; the strand may then be twisted to a desired amount and may itself constitute the reinforcement cord, or the strand, whether twisted or untwisted, may be twisted together with other strands to form the cord. The cord thus made is presently being used in pneumatic tires as either a carcass ply reinforcement element or as a material for use in a breather that reinforces the tread region of the tire. A breather is a layer of fabric placed under the tread of the tire and extending circumferentially therearound.

The rubber industry has encountered many problems in the use of glass cord as a reinforcement material for pneumatic tires. Fortunately, solutions have been obtained for most of these problems, but the problem of broken glass cords in tires has, until the present invention, gone unsolved.

The inventors believe that glass cord breakage is primarily the result of both compression fatigue and nonuniform tensile stress distribution among the filaments in the cord. The term “compression fatigue” as used herein has reference to the inability of glass to withstand compressive forces. Although glass possesses high tensile strength and has low elongation characteristics as compared to most other materials, it is susceptible to fatigue and fracture-type failure after having been subjected to forces of compression. As is well known by persons skilled in the art, repeated application of compressive forces to a glass cord causes a reduction in the tensile strength of the cord. Because the repeated application of compressive forces occurs with respect to the glass cords used as reinforcing elements in a rotating loaded tire, the cords ultimately fail by fracture.

The previously mentioned nonuniform distribution of tensile stresses among the filaments of glass cord is even more significant than compression fatigue as a factor contributing to broken glass cords. When the distribution of tensile stress is not uniform, some of the glass filaments must necessarily assume a greater proportion of the total stress on the cord than do others. Thus, some of the filaments may become overstressed and break; this, in turn, increases the stress on the remaining filaments, some of which may then fracture, and so on, until finally the cord is completely broken. Of course, it is possible to compensate to some degree for stressing of the filaments, i.e., the loss of tensile strength of the cord resulting from a nonuniform stress distribution among filaments by increasing the number of filaments, that is, by increasing the cord size. However, this solution is not completely satisfactory because it tends to decrease the stress transfer characteristics of the rubber medium that surrounds the cord, because it tends to increase the degree of nonuniform stress distribution among the cord filaments as the number of filaments increases, and because increasing cord size adds greatly to the cost of tire manufacture.

The detection of broken glass cords in pneumatic tires may be readily accomplished through X-ray examination. Such examinations have revealed that broken glass cords occur in new tires as well as in tires that have been subjected to use under load conditions. The number of broken glass cords in a given tire does, however, tend to increase with its use. Compressive forces and tensile stresses which occur during shaping and curing are believed to be responsible for broken cords in new tires.

There is some disagreement among tire engineers and others with respect to the detrimental effect of a small percentage of broken cords on tire performance; this is particularly true where the cord is used only as a breather material for a bias ply tire that has a full strength carcass structure beneath the breakers. Nevertheless, there is no doubt that broken cords do reduce overall tire strength and the number of broken cords in a localized area can lead to tire failure. Moreover, broken glass cords are of very great significance from the standpoint of the safety standards which have been recently promulgated by the United States Department of Transportation.

Motor Vehicle Safety Standard 109 defines a “ply” as a “layer of rubber-coated parallel cords,” and the word “cord” is defined as “the strand or form of the cord in the tire.” In addition, Standard 109 provides for an endurance test of tires on a test wheel of a given size and character, it being provided that “after completion of the laboratory test-wheel endurance test..., no tire shall have...broken cords.” The test procedure in Standard 109 requires that the tire to be tested be inflated to a specified pressure for the particular tire and that it be pressed against the test-wheel surface. The test wheel and tire are then rotated together at a speed of 50 miles per hour for 4 hours at one specified load, for 6 hours at a second specified load, and for 24 hours at a third specified load. Because of the low speed at which this test is conducted, it is regarded as a mild test. Nevertheless, tires having glass cord breakers or body plies generally have not been able to satisfy the requirement of no broken cords upon completion of the test.

It has now been found that broken glass cords in tires can be substantially reduced or eliminated. This is accomplished through the utilization of a glass cord which possesses a high tensile efficiency. As used herein, the term “tensile efficiency” refers to the ratio, which may be expressed as a percentage, of the in-rubber tensile strength of glass cord to its theoretically calculated tensile strength; this theoretical value being determined mathematically as hereinafter defined. It is believed that a glass cord which possesses a high tensile efficiency more uniformly distributes tensile stresses among the filaments of which it is comprised, and that failure of the cord as a result of nonuniform stress distribution is prevented thereby. Much of the commercially available glass cord has been found to possess a low tensile efficiency. Moreover the tensile efficiency is apparently randomly variable.

In addition to tensile efficiency, it has been found that the twist product of the glass cord is of some significance with respect to its failure by fracture. More specifically, it has been found that the higher the twist product of the cord, the greater is its resistance to compression fatigue, and that if the tensile efficiency of the glass cord is sufficiently high to substantially reduce broken glass cords, then even further improvement can be achieved through utilization of glass cord with a high twist product.

In connection with the above, the “twist product” is defined as the mathematical product of the diameter of the cord, expressed in units of length, and the amount of twist in the cord, expressed in units of turns per unit of length, the twist product therefore having units of turns. Where the cord is comprised of several previously twisted strands which are themselves twisted together to form the cord, the twist product is then the product of the final cord diameter and the final twist imparted to the several strands. Contrary to what is most desirable for resistance to compression fatigue, commercially available glass cord has a low twist product.

It is, therefore, an object of the present invention to provide a glass cord that is not susceptible to being broken when incorporated into a pneumatic tire as a reinforcement material.
It is another object to provide a glass cord for pneumatic tires that possesses a high tensile efficiency and adequate resistance to compression fatigue.

A further object is to provide a glass cord that has improved resistance to fracture when used as a breaker reinforcement material.

Still another object is to establish the relationship of tensile efficiency and twist produced by a glass cord to the performance of that cord as a reinforcement element in a pneumatic tire.

These and other objects of the invention are more readily understood and become more apparent upon reading of the specification which follows and by reference to the drawings, in which:

FIG. 1 is a partial cross-sectional view of a bias ply tire having incorporated therein a breaker structure comprised of two layers of parallel glass cords;

FIG. 1A is an enlarged view of the tread surface of the tire of FIG. 1, parts of the tread surface being broken away to reveal the underlying breaker and ply structures and to show broken glass cords in the breaker structure as they might ordinarily occur;

FIG. 2 is a chart which illustrates typical glass cord constructions and numerical designations therefor;

FIG. 3 is a pictorial view showing the method for constructing samples of rubber reinforced with glass cord to be tested for in-rubber tensile strength;

FIG. 4 is an enlarged view of the three-cord test sample that is placed in a tensile-testing machine in order to determine the in-rubber tensile strength of the glass cord, the three-cord test sample being a portion cut from the samples constructed in accordance with FIG. 3;

FIG. 5 is a graph of glass cord tensile strength per 204 G-size filaments versus twist product of the glass cord;

FIG. 6 is a plot of data points showing the percent of broken cords in new tires as against their respective glass cord tensile efficiencies, and

FIG. 7 is a plot of data points for the same tires as in FIG. 6, but here the data points represent the percent of broken cords in the tires after stepped up high-speed (SUHS) wheel testing, as against their respective glass cord tensile efficiencies.

With reference to FIG. 1, the partial cross-sectional view of the tire shows a tread portion 1 and a body or carcass portion consisting of reinforcing plies 2 and 3. The crown or tread region of the tire is reinforced by breaker plies 4 and 5 which are comprised of parallel glass cords coated with rubber as shown in FIG. 1A, and as is the usual case, the cords of the respective breaker plies are oppositely directed. In FIG. 1A, a number of the cords in breaker plies 4 and 5 are depicted with breaks therein, and it may be noticed that the breaks are shown as occurring in clusters. This is intended to be illustrative of the fact that broken glass cords frequently occur in localized regions of the breaker structure. In FIGS. 1A and 1A, it is assumed that the carcass plies 2 and 3 are comprised of parallel cords made of a material other than glass, and, thus, no broken cords are shown.

The chart of FIG. 2 illustrates typical unplied and plied glass cord constructions, the numerical designations used to describe the various constructions, and the processing steps in the manufacture of the cord structures. The cord cross sections shown are labeled G15, G15-110, G75, G75-5/0, G30, G30-1/0, and G30-1/3. In these numerical designations, the G designates the diameter of the individual filaments of glass from which the cord is made; a G-size filament has a diameter of 0.00036 of an inch. The number which immediately follows the filament size designation indicates the number of hundreds of yards of strand required to obtain a weight of one pound; thus, 1,500 yards of a G15 strand will weigh one pound and the strand will consist of 2040 filaments. Similarly, 7,500 yards of a G75 strand will weigh one pound and the strand will consist of 408 filaments of a G30 strand will weigh one pound and the strand will consist of 1,020 filaments. It should be noted that the number of filaments in each of the above strands is a multiple of 204.

When a number of strands are twisted together to form a cord, the cord is then given a numerical designation. For example, a G75-5/0 cord is an unplied cord and is one which is made from five G75 strands which are twisted together in a single direction; on the other hand, a G30-1/3 cord is one which is made from three strands that are separately twisted in one direction and which are then plied together and twisted in the opposite direction to form a plied cord.

The manufacture of glass tire cord comprises a number of distinct steps as is illustrated by the chart of FIG. 2. First, the strand is formed by spinning the appropriate number of G-size filaments. The spinning is accomplished by causing molten glass to flow through a number of equally sized holes in a bushing, the number of holes corresponding to the number of filaments in the strand. If, for example, a G75 strand were being made, the bushing would contain 408 holes to make the necessary 408 filaments. As the filaments leave the bushing, they solidify and a sizing composition is then applied to them, after which they are brought together and given a very slight twist during the process of being wound on a spool in the form of a stand. Typically, the strand is then caused to undergo a dipping and drying process wherein the strand is coated with a composition designed to promote the adhesion of the glass to the rubber in which it is eventually embedded. Following this, the strand is respooled and is twisted alone or with other strands. In the case of unplied cord, this completes the cord manufacturing process. However, in the case of plied cord, the strand must be respooled, plied with other strands, and twisted together in a direction opposite to the initial twist direction in order to complete the cord manufacturing process.

With the discussion above, that portion of the disclosure which follows may be more readily understood.

As was previously stated, the tensile efficiency of a glass cord for use as a reinforcement element in a pneumatic tire is defined by the inventors as the ratio, which may be expressed as a percentage, of the actual in-rubber tensile strength of the cord divided by its theoretical, calculated tensile strength, on, expressed mathematically,

\[ \text{TE} = \left( \frac{T_{SR}}{T_{SG}} \right) \times 100\% \]

where \( \text{TE} \) is the tensile efficiency expressed as a percentage, \( T_{SR} \) is the in-rubber tensile strength of the particular cord, and \( T_{SG} \) is its theoretical, calculated tensile strength.

In order to determine the tensile efficiency of a particular glass cord and to obtain meaningful and repetitive results, it is necessary that the in-rubber tensile strength of the cord be measured in a prescribed manner. The following test procedure accomplishes this and avoids erroneous results caused by damage to glass cords from the clamping means in the tensile-testing machine used to hold the test sample.

The test sample that is ultimately pulled in the tensile-testing machine to determine the in-rubber tensile strength of the glass cord contained therein consists of three parallel glass cords cured in a sufficient amount of rubber to insure that each cord is surrounded completely by rubber at least equal in thickness to the cord diameter. It is essential that the test sample be prepared in a manner that will assure that the cords are parallel, evenly spaced, under equal tension during cure of the surrounding rubber medium, and surrounded by sufficient rubber. The rubber compound used is not critical, provided however that the compound must be of the type normally used to coat reinforcement cords of pneumatic tires and must contain such ingredients as will provide reasonable rubber to glass cord adhesion. Such rubber compounds are known and are believed by the inventors to be within the skill of the art.

Illustrated in FIG. 3 is the method for constructing samples of rubber reinforced with glass cord to be tested for in-rubber tensile strength. The rubber compound to be used is calibrated, at a thickness of at least one and one-half times the...
diameter of the cord to be tested, on holland cloth. A metal plate 10 is provided on which are placed, on opposite sides thereof, two layers 11 and 12 of the calendared rubber from which the holland cloth has been stripped. Rubber layers 11 and 12 may be caused to adhere to plate 10 by application of slight pressure. Plate 10 is provided with V-shaped grooves 13 which serve to maintain the position of the continuous glass cord 14 that is helically wound around plate 10, and thus, over rubber layers 11 and 12. During winding of the glass cord 14, it is maintained at a constant tension and the respective turns are kept evenly spaced. Upon completion of the winding process, the ends of glass cord 14 are secured to plate 10, and rubber layers 15 and 16 are placed over the wound cord. The resulting assembly is then placed in an unheated press for a period of time and at such pressure as will cause the rubber layers to adhere to one another and to surround the glass cord without the presence of voids. Following this, the cord windings are cut at both ends of plate 10 at or near the V-shaped grooves 13, thereby forming two samples of rubber-coated parallel glass cords which are carefully removed from plate 10 to prevent distortion or damage to the cords embedded in the rubber. Each of the samples is then cured (vulcanized) in a suitable mold, care being taken to be sure that curing pressure is uniformly distributed over the sample surface area. After the sample has been removed from its curing mold, its ends are cut off. A three-cord test sample is then made as illustrated in FIG. 4. The two outer cords 20 and 21 of the three-cord test sample are cut through at the midpoint of their length, leaving the center cord for tensile determination.

To determine the in-rubber tensile strength of the glass cord, the three-cord test sample is placed in a tensile-testing machine and the sample pulled up to a load of 2 inches per minute until the center cord breaks; the tensile force at break is recorded. Throughout the process of preparing and testing the glass cord test samples, care must be taken to prevent it from being flexed, bent or twisted.

As is apparent from the preceding discussion, it is necessary in order to determine the tensile efficiency of a given glass cord that its calculated tensile strength be determined. To make this determination, the following equation is employed:

\[
P = \frac{\pi R^2}{1 + \pi (2RT)^2}
\]

where \(P\) is the total axial force carried by the cord at break, \(E\) is the modulus of elasticity for the type of glass from which the cord is made, where \(R\) is the breaking strain, or percent elongation at break, for the glass cord filaments, where \(R\) is the radius of the cord, and where \(T\) is the twist (turns per unit of length) in the cord. It should be noted here that the product \(2RT\) in the above equation is, in accordance with the definition previously given, the twist product of the cord. Thus, it appears that the total axial force on the cord is a function of its twist product.

The above equation is believed to be fairly well known in the textile art, and as written, is only applicable to perfectly elastic filaments, glass being considered to be one of such filaments. The derivation of the equation is based on certain assumptions. They are: (1) that the cord is uniform along its length and has a circular cross section; (2) that all the filaments in the cord also have circular cross sections and possess equal, uniform properties; (3) that each filament forms a circular helix the center of which coincides with the axis of the cord; (4) that the filaments fall in a rotationally symmetric array in the cross-sectional view; (5) that the diameter of the cord is large compared with the filament diameters; (6) that the filaments are very long relative to their diameters; and (7) that the filaments are incapable of supporting bending moments, torsional moments, and shear, and that they can therefore carry only axial tensile loads. Of course, it is realistically impossible to manufacture glass cord in conformity with these assumptions, but they permit an equation to be developed which is indicative of the maximum tensile strength of glass cord of given character. Moreover, when the tensile-efficiency of a particular cord is determined from its actual in-rubber tensile strength and its tensile strength calculated from the equation, a measure of its susceptibility to fracture when used as a reinforcement element in a pneumatic tire is thereby provided.

<table>
<thead>
<tr>
<th>Breaker glass cord</th>
<th>Twist product (turns)</th>
<th>No. of filaments in cord</th>
<th>In-rubber tensile strength (lbs.)</th>
<th>In-rubber tensile strength (lbs. per 204 &quot;O&quot; filaments)</th>
<th>Calcd. tensile strength (lbs. per 204 &quot;O&quot; filaments)</th>
<th>Percent tensile efficiency</th>
<th>New tire (SUS/JIS wheel test)</th>
<th>After SUS/JIS wheel test</th>
<th>Cord quality</th>
</tr>
</thead>
<tbody>
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<td>A</td>
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</table>

Reference is now made to the table of data contained herein. The table summarizes the result of a complete tire test program for glass cord of various constructions and twist products. For each variation in construction or twist product, the in-rubber tensile strength for the cord was determined by the method hereinafter described. In addition, two tires were built and cured for each glass cord variation, and the data for each particular cord contained in the table is the average of measurements made on each of the two tires. The glass cord in all of the tires was used as a reinforcement material for a two-ply breaker structure, the carcass plies of the tires being reinforced with polyester cord and being of normal full strength for bias-type passenger car tires without a breaker. After the tires were cured and before they were placed on the test wheel, that is, when they were new, the tires were X-rayed to determine the percent broken glass cords.
Two X-ray photographs of different portions of each tire were made, the number of broken cords shown in the photographs were counted, and the result extrapolated to cover the entire breaker structure so that the percent broken cords could be determined. The X-ray photographs were sufficiently clear and distinct to permit detection of the broken cords in each of the breaker plies. After the percent broken cords had been determined for the tires while in their new condition, each of the tires was subjected to a stepped up high-speed test on a standard test wheel. In the stepped up high-speed (SUHS) test, the tire is tested to be mounted on the axle of the test wheel, inflated to its normal air pressure, and pressed against the axis of the test wheel with a load force equal to 75 percent of its rated load at such normal air pressure. The tire is then rotated at a speed of 60 miles per hour. At the end of one hour, the speed is stepped up to 70 m.p.h. At the end of another hour, the speed is increased to 80 m.p.h. and then to 90 m.p.h., and, finally, to 95 m.p.h. Upon completion of the SUHS test on each tire, the percent broken glass cords was again determined in the manner described above. Based on the high speeds involved in the SUHS test, it is considered to be a much more severe test than the tire endurance test as specified in Standard 109.

In the table of data, the first column contains a letter designation for two-tire sample groups. The second column describes the glass cord construction used as a reinforcement element in the breakers of the tires of the respective groups. The third and fourth columns indicate, respectively, the twist product and the number of glass filaments in each of the various cord constructions. In the fifth column of data, the actual in-rubber tensile strength of the various cords is shown; the values shown in the sixth column are calculated from those in fifth column and are the actual in-rubber tensile strength for the cords as expressed in terms of pounds per 204 G-size glass filaments. Theoretical tensile strengths for the various cords, as calculated from equation (2), are contained in the seventh column of the table. The percent tensile efficiency for the various cords is expressed in the eighth column and is the ratio of the respective values in the sixth column to those in the seventh column, multiplied by 100 percent. In the ninth column, the percent broken cords both before and after the SUHS test are given. The tenth column contains designations of cord quality based on test wheel performance; those tires which had 0, or almost 0, percent broken cords before the SUHS test and a very low percentage of broken cords after the test are labeled "good," and those tires with higher broken cord percentages are labeled "bad." Group E tires were considered to be questionable because of the 7.9 percent broken cords after the SUHS test, notwithstanding 0 percent broken cords before the test. It is readily apparent from the table of data that only tires having tensile efficiencies greater than 75 percent had no broken cords before the SUHS test, and very low percentages of broken cords thereafter. Furthermore, this is true for glass cord constructions having twist products varying from zero to and including 0.300 turns. It should also be noted that the group of tires containing glass cord with the highest twist product (0.300 turns) was the only tire group to have 0 percent broken cords both before and after the SUHS test.

With reference now to FIG. 5, there is shown a graph of the theoretical, calculated glass cord tensile strength per 204 G-size filaments versus cord twist product. More specifically, the curve drawn as a solid line is a graph of equation (2) with the axial force $P$ on the cord being calculated in terms of tensile strength per 204 filaments. The independent variable plotted along the abscissa of the graph is taken to be the twist product 2RT of the cord. A cord having 204 G-size filaments is known to have a radius $R$ of 0.0026 of an inch; since $P$ is to be expressed as a tensile strength, in pounds, per 204 filaments, it is necessary that $R$ be fixed at this value. Moreover, the glass filaments are assumed to be made from an electrical-type (E-type) glass which has a known modulus of elasticity $E$ of 10.5 x 10^6 pounds per in. and a known elongation at break of 0.48 percent. The factor $T$ is the cord twist in turns per inch. As may be seen from the graph of equation (2), the tensile strength of the cord decreases rapidly as twist product increases. Practically speaking, this means that the higher the twist product of the glass cord used as a reinforcing element in a pneumatic tire, the greater must be the number of such elements used in order to obtain a given overall tire strength.

The broken line in the graph of FIG. 5 is a curve of 75 percent of $P$, that is, every point on the broken line curve corresponds to a particular twist product equal to 75 percent of the calculated tensile strength for that particular cord twist product. Furthermore, if the ordinate of the graph is the in-rubber tensile strength per 204 G-size filaments, then the broken line curve is one for 75 percent tensile efficiency. This means that glass cords with tensile efficiencies greater than 75 percent will fail within the region above the broken line curve, and those with tensile efficiencies less than 75 percent will fall within the region below the broken line curve.

In addition to the two curves described above, FIG. 5 contains a plot of points obtained from the table of data. The data points are determined by the in-rubber tensile strength (pounds per 204 G-size filaments) and the twist product for each of the two-tire sample groups. Those data points which reflect tire groups having "good" glass cord construction are shown as unfilled circles, and those which reflect tire groups having "bad" glass cord quality are shown as filled circles. The data point for the questionable group E is indicated by a partially filled circle. From FIG. 5, it may be seen that all of the data points for tires having "good" glass cord quality are located above the 75 percent tensile efficiency curve, as is the questionable data point. Furthermore, all of the data points for tires having "bad" glass cord quality are located on or below the 75 percent tensile efficiency curve. Furthermore, this may be seen to be true for a range of twist products from zero to and including 0.300 turns. The conclusion to be drawn is that if glass cord having a tensile efficiency greater than 75 percent is used as a reinforcing element in a pneumatic tire, rather than glass cord having a lesser tensile efficiency, then the possibility of fracture-type failure of the cord is substantially reduced or eliminated.

In order to further illustrate the benefits obtained from glass cord having a tensile efficiency greater than 75 percent, another plot of data points is shown in FIG. 6. These data points reflect the percent of broken cords in new tires, as against their respective tensile efficiencies, for each two-tire group listed in the table of data. A vertical broken line is drawn at 75 percent tensile efficiency. All of the two-tire groups having glass cord with a tensile efficiency greater than 75 percent may be seen to have zero percent broken cords. In addition, none of the two-tire groups having tensile efficiencies less than 75 percent had 0 percent broken cords, but rather, the percent broken cords was generally much higher for these groups.

FIG. 5 further illustrates the benefits derived from glass cord having a tensile efficiency greater than 75 percent. FIG. 7 is similar to FIG. 6, except that the data points reflect percent broken cords after the SUHS test as against tensile efficiency. It is apparent that the percent broken cords for two-tire groups having glass cord tensile efficiencies greater than 75 percent is substantially less than that for the other tire groups. Furthermore, of the tire groups having glass cord tensile efficiencies greater than 75 percent, the worst from the standpoint of percent broken cords after the SUHS test was the questionable group E.

From the preceding, it is evident that glass cord glass cords in pneumatic tires can be substantially reduced or eliminated if the tensile efficiency of the cord is greater than 75 percent, and, of course, the higher the in-rubber tensile strength of the cord the higher is its tensile efficiency.

There are numerous factors which affect the in-rubber tensile strength of glass cord. Filament length uniformity is known to have a significant effect on the stress distribution among the filaments, the stress distribution affecting in-rubber
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tensile strength. Where the glass cord is of plied construction, ply length uniformity is also of importance. From the standpoint of stress transfer among the cord filaments, the type and quality of the sizing application, the type of dip and dip penetration, the spacing of the cords in the surrounding rubber medium, and the rubber quality may all have an effect on the in-rubber tensile strength. In addition, moisture is also known to affect the in-rubber tensile strength of glass cord.

It will be understood that the foregoing description of preferred aspects of the present invention is for purposes of illustration only, and that the various structural and operational features herein disclosed are susceptible to a number of modifications and changes none of which entails any departure from the spirit and scope of the present invention as defined in the hereto appended claims.

We claim:

1. A glass cord for use as a reinforcement element in a pneumatic tire, said cord being comprised of a plurality of glass filaments, said cord having a twist product within the range from zero to and including 0.300 turns, and said cord having a tensile efficiency greater than 75 percent.

2. The glass cord of claim 1, wherein said cord is used as a reinforcement element in the breaker structure of a pneumatic tire.

3. A glass cord for use as a reinforcement element in a pneumatic tire, said cord being comprised of a plurality of glass filaments, said cord having a twist product within the range from zero to and including 0.300 turns, and the ratio, expressed as a percentage, of the in-rubber tensile strength of said cord to its theoretical tensile strength being at least 75 percent, the in-rubber tensile strength being the tensile strength at break of the center cord of a test sample consisting of three parallel glass cords embedded in vulcanized rubber, the test sample being pulled at the rate of two inches per minute in a tensile-testing machine, and the theoretical tensile strength of said cord being calculated from the equation

$$P = \frac{E \pi R^3}{1 + \pi^2 (2RT)^2}$$

where $P$ is the total axial force carried by the cord at break, where $E$ is the modulus of elasticity for the type of glass from which the cord is made, where $E$ is the breaking strain, or percent elongation at break for the glass cord filaments, where $R$ is the radius of the cord, and where $T$ is the twist in the cord.

4. The glass cord of claim 3, wherein said cord is used as a reinforcement element in the breaker structure of a pneumatic tire.

5. A pneumatic tire containing a glass cord comprised of a plurality of filaments, said cord having a twist product within the range from zero to and including 0.300 turns, and said cord having a tensile efficiency greater than 75 percent.

6. A breaker reinforced with glass cord comprised of a plurality of filaments, said cord having a twist product within the range from zero to and including 0.300 turns, and said cord having a tensile efficiency greater than 75 percent.

7. A pneumatic tire containing a breaker reinforced with glass cord comprised of a plurality of filaments, said cord having a twist product within the range from zero to and including 0.300 turns, and said cord having a tensile efficiency greater than 75 percent.

8. A bias ply tire containing a breaker reinforced with glass cord comprised of a plurality of filaments, said breaker being comprised of at least two layers of parallel glass cords and the cords in alternate layers being directed at opposite bias angles, said cord having a twist product within the range from zero to and including 0.300 turns, and said cord having a tensile efficiency of at least 75 percent.