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3,055,167

ROPE

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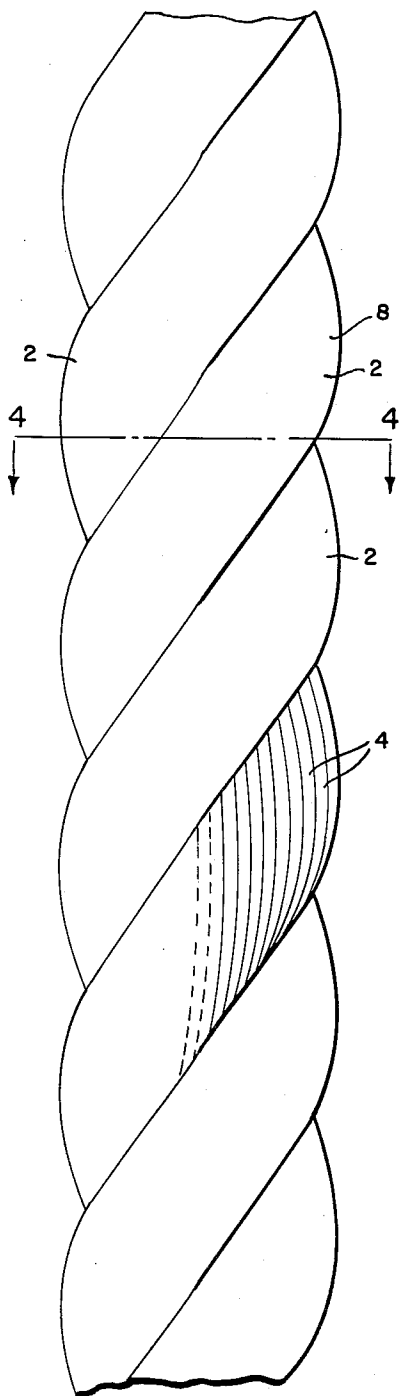


FIG. 3.

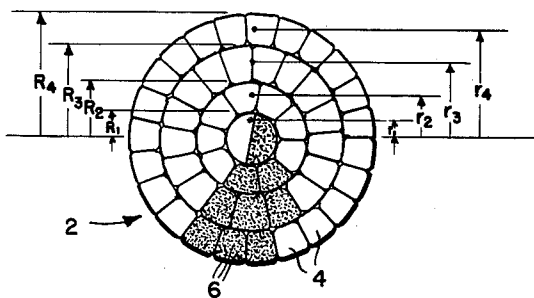


FIG. 1.

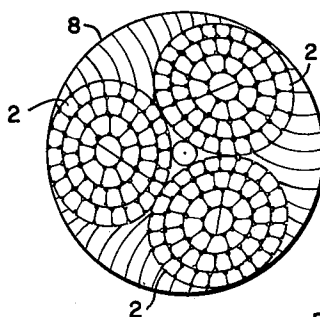


FIG. 4.

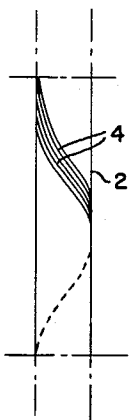


FIG. 2.

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3,055,167  
ROPE

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This invention relates to rope and methods of making the same and has particular reference to the making of strands to be formed into rope.

The objects of the invention are to improve the strength and durability of rope. The invention has particular reference to ropes made of synthetic filaments the properties of which may be altered or selected.

Ropes are made of strands, each strand consisting of twisted yarns which are in turn composed of filaments. While the principles of the invention may be carried into the formation of yarns, its practical aspects relate to the formation of strands.

Assuming that a yarn entering into the composition of a strand is homogeneous and may be regarded as a unit, an assumption justified in practice by reason of the customary low degree of twist of the component filaments of a yarn and its small diameter, the problem solved in accordance with the invention may be stated as follows:

As heretofore constituted, strands have been made up of yarns of the same materials and characteristics twisted together in concentric layers with each layer of the same helical pitch, this condition arising as an incident of the mechanism used for its formation and resulting in maximum concentration of yarns for a given cross-section of the strand. The result of this is that central yarns in a given length of a strand are appreciably shorter than the peripheral yarns. Since the percentage elongation of a yarn to its breaking point is a constant for a given material, it will be evident that, for progressive application of stress to a strand, central yarns will reach their ultimate elongation before peripheral yarns and will ordinarily fail first under tension, failure then progressing to the outer layers. Even within the elastic limit there will be greater stresses on the inner yarns for a given strain and since the number of yarns per layer considerably increases with radius, the loads will be borne unduly by the inner yarns.

Using natural fibers of practically unchangeable properties, the conditions just indicated cannot be satisfactorily cured. But in accordance with the present invention by selective choices of properties of synthetic yarns, it is possible to provide strands in which the component yarns contribute approximately equally to the stress-strain characteristics and ultimate strength of the strands. In brief, this is accomplished by choosing yarns for the individual layers of a strand so that in a finished rope under load the yarns of every layer reach their ultimate elongation approximately simultaneously.

As will become evident hereafter, the invention is not only applicable to twisted ropes and cables but to ropes composed of braided strands as well. For uniformity and simplicity of description, however, the invention will be primarily described with reference to the formation of ropes by twisting strands.

The various objects of the invention and their attainment will become more apparent from the following description, read in conjunction with the accompanying drawing, in which:

FIGURE 1 is a diagrammatic showing of a cross-section of a strand illustrating the arrangement of the component yarns;

FIGURE 2 is an elevation showing a single pitch length of a strand;

FIGURE 3 is a fragmentary elevation of a rope provided in accordance with the invention; and

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FIGURE 4 is a cross-section of the rope taken on the plane indicated at 4-4 in FIGURE 3.

From the standpoint of geometry, rope provided in accordance with the present invention is essentially conventional and the figures will merely serve to clarify the various terms used. A strand 2 is composed of units 4 which are either single yarns or ply yarns, both being herein called yarns, which are in turn composed of filaments 6. The filaments 6 are twisted to only a relatively slight extent in the formation of the yarns, and the internal construction of the yarn as to its geometrical aspects is not here considered, the yarn being regarded as a unit of the structure, each of the yarns being assumed homogeneous throughout its cross-section. A strand is formed by a conventional twisting of yarns in layers as indicated in FIGURE 1. In the assembly of the yarns into a strand the yarns which may originally be approximately cylindrical are distorted into trapezoidal shapes providing a compact strand structure. The final strands are twisted into rope following conventional practices to which more detailed reference will be made hereafter, the rope being indicated at 8. In FIGURES 3 and 4 a three strand rope is illustrated, but it will become obvious hereafter that the rope or cable in which the improved strands are used may be of any conventional type.

For calculation purposes, consider a strand of (effectively) circular cross-section, as shown in FIGURE 1, having an outer radius  $R_n$  with  $n$  layers of yarns and with  $X_i$  yarns in a layer  $i$ , the layers being numbered from the innermost to the outermost. The radii of the bounding cylinders of each layer may be best effectively determined as follows, remembering that the yarns do not themselves have circular sections but are flattened as illustrated in FIGURE 1.

The total cross-sectional area of the strand being  $A = \pi R_n^2$ , the area of each yarn (assuming all yarns to be of the same size) may be determined as:

$$a = \frac{A}{\sum_{i=1}^n X_i}$$

The radius  $R_i$  of the cylinder externally bounding the layer  $i$  is then determinable as:

$$R_i = \sqrt{\frac{a}{\pi} \sum_{k=1}^i X_k}$$

wherein the summation is the cumulative number of yarns in all layers from the innermost to and including layer  $i$ .

FIGURE 1 shows the  $R_i$ 's as  $R_1$ ,  $R_2$ ,  $R_3$  and  $R_4$  for a four layer strand in which  $X_1=2$ ,  $X_2=9$ ,  $X_3=17$  and  $X_4=23$ .

All of the yarns of a given layer  $i$  are similarly disposed and each may be considered wound about the inner bounding cylinder of its layer, following a helix which may be best assumed to have a radius  $r_i$  such that the cylinder in which the helix lies divides the layer into equal inner and outer areas. Geometry then gives the helix radius ascribable to a yarn in layer  $i$  as:

$$r_i = 0.7071 \sqrt{R_i^2 + R_{i-1}^2 - 1}$$

0.7071 being

$$\frac{\sqrt{2}}{2}$$

to a better than required approximation.

In a strand of the type being considered the pitch, i.e., the distance along the longitudinal axis of a strand in which a yarn makes a complete turn, is the same for all layers, and considering the pitch of the unstressed strand to be  $P_0$ , it will be evident that the helical length of a

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yarn in layer  $i$  will be given for the pitch length  $P_o$  by:

$$h_{i0} = \sqrt{P_o^2 + (2\pi r_1)^2}$$

In determining the final helical length of a yarn in layer  $i$ , there must be taken into account the change of shape of the strand. For this purpose it is valid to assume that under stress the volume of a given portion of the strand remains constant with increase of length being accompanied by reduction of effective radius of the outermost layer and proportional reductions of radii of the other layers. Constancy of volume leads to:

$$2\pi r_n^2 L_o = 2\pi r_{nf}^2 L_f$$

wherein:

$L_o$  is the original length of a given portion of a strand;

$L_f$  is the final length of the same portion, which may be expressed for all practical purposes as  $L_o$  times unity plus a decimal corresponding to the percent elongation of the basic material which is a property of the material determinable from a simple load v. elongation test; and  $r_{nf}$  is the final radius to the center of mass of the layer  $n$ .

Then writing  $k$  for

$$\sqrt{\frac{L_o}{L_f}}$$

the final effective radius of a layer to which the radius  $r_1$  is reduced becomes  $r_{1f} = kr_1$ .

The final pitch increases to

$$P_f = \frac{P_o L_f}{L_o}$$

so that the final helical length of a yarn in layer  $i$  becomes, at rupture:

$$h_{if} = \sqrt{P_f^2 + (2\pi r_{1f})^2}$$

The foregoing matters apply to a strand as it is formed preparatory to being twisted into a rope.

In the final step of rope manufacture the turns inserted in the rope will automatically increase or decrease the twist in the strand by the same number depending on the directions of twists. Ordinarily, the twist in the rope is in a direction opposite to the twist in the strand, and the effect upon each individual strand is to remove one turn for each turn of rope twist inserted. In the foregoing analysis of the geometry of a strand it was shown that upon the insertion of twist the lengths of yarns in successive layers moving outwardly from the center became progressively longer because of the helical length thereof. If a length of twisted strand is untwisted to any degree, excessive lengths of yarns become evident in successive layers with the greatest excess length appearing in the outside layer. It can, therefore, be seen that unless the original turns in the strand can be maintained as it lays in the rope, any turns less than the original will automatically introduce excessive lengths and therefore decrease the effectiveness of the strand in supporting load.

To minimize the excessive lengths in the manufacture of rope, foreturns are inserted into the strands at the same time that they are being twisted into a rope. The foreturns are generally described in terms of a foreturn ratio, the foreturn ratio being the number of turns inserted in the rope to the turns inserted in the strand in a given length. If the foreturn ratio is unity, the twist or pitch of the strand as it lies in the rope will be the same as in the original strand. When the foreturn ratio is less than unity, the twist of the strand as it lies in the rope is something less than the original twist of the strand so that excessive yarn lengths will then exist in the layers of the strand. In order to keep within the limits of practical rope making, normal practices use a foreturn ratio of somewhat less than unity, for example, 0.90.

Considering the foreturn ratio  $F$ , the new pitch  $P_n$  is related to the original pitch  $P_o$  by

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$$P_n = \frac{P_o}{F}$$

The theoretical length  $L_1$  of a yarn in layer  $i$  as the strand lies in the rope is then given by

$$L_1 = \sqrt{P_n^2 + (2\pi r_1)^2}$$

(The radius  $r_1$  will vary slightly for different pitches, but the variation is so small that the original  $r_1$  may be here used.)

However, since the strand was formed with an original pitch of  $P_o$ , it actually contains

$$\frac{P_n}{P_o} \text{ or } \frac{1}{F}$$

pitch lengths of yarn so that each yarn in layer  $i$  will now have an actual length  $L_{ai}$  given by:

$$L_{ai} = \frac{h_{i0}}{F}$$

giving an excess length percentage  $E_1$  given by

$$E_1 = \frac{L_{ai} - L_i}{L_i} \times 100$$

Defining a percent elongation  $S_1$  for each layer  $i$  by

$$S_1 = \frac{h_{i1} - h_{i0}}{h_{i0}} \times 100$$

and using  $Z$  to represent the ultimate elongation ratio of the fiber used, either natural or synthetic, this being a physical property determined by test and commonly supplied by manufacturers of synthetic fibers, a correction factor  $C_1$  may be determined by

$$C_1 = Z_1 - S_1 + E_1$$

From these values of  $C_1$  for the various layers, it is then possible to correct for strain inequalities in rope structures so that the ultimate strains of the yarns in the successive layers going outward from the strand center may be either increased or decreased to the ultimate end that failure of all of the layers may be expected simultaneously.

Assuming the same material for all yarns in a strand, various methods of yarn treatments may be employed.

Preshrinking may be employed, applied to the yarns forming the layers inwardly of the outermost, in which case, for example, the innermost layer would have its ultimate elongation increased by the amount  $C_n - C_1$ , the second layer having its elongation increased by the amount  $C_n - C_2$ , etc. When preshrinking is involved, the total elongation is approximately equal to the shrinkage plus the elongation which the filament would have without shrinking. In other words, with the application of tension, the amount of preshrinking is first absorbed and then the filament will elongate to substantially its original extent before breaking. As examples, two well known types of nylon have elongations as ordinarily supplied in the amounts of 17% and 24%, while with shrinkage these figures may be respectively increased to 27% and 39%. The particular amount of shrinkage which should be effected may be determined from the foregoing considerations. The shrinking may be effected by steaming without tension or with tension at various temperatures and at various times which are known or may be readily ascertained for the particular fibers which are used. The extent of desired shrinkage being known from considerations given above, the factors of time, temperature and tension which must be involved may be controlled. In general, the shrinkage will be effected below the critical temperature and below critical tension in a steam atmosphere at atmospheric pressure, though these factors may be widely varied depending upon the results desired.

Alternatively, hot stretching may be used, in such case the stretching being carried out to reduce the ultimate elongation of the yarns to form the outer layers. Hot

stretching of nylon may be carried out at temperatures in the range of 400° to 420° F. in an oxygen-excluding atmosphere or medium. For example, the nylon mentioned above having originally an elongation of 17% may have its elongation reduced to 10% by hot stretching, carried out in molten wax, in eutectic alloys, or in inert gas. It may be here noted that the ultimate strength of rope may be increased in accordance with the invention even though weakening may occur so far as the innermost yarns of the strands are concerned. This is due to the fact that, as pointed out above, the stresses are in conventional rope sustained primarily by the relatively few innermost yarns rather than the much greater number of outer yarns, the latter, under ordinary conditions, being stretched to a relatively slight extent at the time that the innermost yarns reach their ultimate elongation and break. It will be evident that selective shrinking and stretching may be carried out on the different yarns forming a single strand.

While nylon has been particularly mentioned above, the same results may be secured by the selective shrinking and stretching of yarns of Dacron, polyethylene, or the like.

Shrinking and/or stretching may also be accomplished with various synthetic fibers by the use of known chemical treatments.

Effective changes in elongation may also be produced by crimping of the fibers composing the yarns. Crimping will provide a greater elongation, applicable to the inner layers of yarns in view of the fact that increased ultimate length is attained. While crimping will not generally produce a yarn which offers a high ratio of stress to strain initially, it may be used particularly in the case of yarns of the central layer or layers which then initially may take a negligible proportion of the load. The term crimping is here used in a broad sense to include not only a zig-zag formation of the fibers but also the effective shrinking attained by twisting and setting.

The invention may also be applied by using different types of yarns in the various layers without treatment beyond that which has been involved in producing commercial yarns. In this case, advantage may be taken of the different properties of yarns made from different materials. For example, nylon yarns of different characteristics may be used in the various layers, these being disposed to secure the desired results of having the elongations such that the yarns could be expected to fail simultaneously. Layers may also be made of quite different materials, such as various grades of nylon, Dacron and other synthetic fiber yarns.

As will be evident from what has been discussed the overall properties of the rope may also be modified. For example, in certain cases it may be desirable to provide a rope having relatively little elongation when subjected to working loads to insure less internal work in the applications of the loads. In other cases greater elongation may be desired so that loads may be taken up gradually and in such cases the stress-strain characteristics of the yarns will be modified accordingly.

It will be evident that the invention is also applicable to the formation of braided ropes involving superimposed cylindrical braids with or without a central core. The strands making up the various braid layers may be treated in accordance with the foregoing to secure the same desirable end result of having all of the strands reach their ultimate elongations substantially simultaneously under load. In the case of braided ropes an aspect of crimping is involved due to the over and under alternate passes of each strand and this may be taken into account in determining the elongations and the treatments which must be applied to the yarns.

It will be evident that various details may be modified without departing from the invention as defined in the following claims.

What is claimed is:

1. A strand for the formation of rope by association with similar strands, said strand comprising concentric-

ly arranged continuous layers of twisted yarns with contiguous yarns in each layer in tight engagement with each other, the yarns in the respective layers having different ultimate elongations so as to reach their ultimate elongations approximately simultaneously when loaded in a rope, at least some of the yarns being preshrunk synthetic yarns.

2. A strand for the formation of rope by association with other similar strands, said strand comprising concentrically arranged continuous layers of twisted yarns with contiguous yarns in each layer in tight engagement with each other, the yarns in the respective layers having different ultimate elongations with the ultimate elongations of the yarns of each layer being less than the ultimate elongations of the yarns of the next inner layer, at least some of the yarns being preshrunk synthetic yarns.

3. A strand for the formation of rope by association with other similar strands, said strand comprising concentrically arranged continuous layers of twisted yarns with contiguous yarns in each layer in tight engagement with each other, the yarns in the respective layers having different ultimate elongations so as to reach their ultimate elongations approximately simultaneously when loaded in a rope, at least some of the yarns being hot stretched synthetic yarns.

4. A strand for the formation of rope by association with other similar strands, said strand comprising concentrically arranged continuous layers of twisted yarns with contiguous yarns in each layer in tight engagement with each other, the yarns in the respective layers having different ultimate elongations with the ultimate elongations of the yarns of each layer being less than the ultimate elongations of the yarns of the next inner layer, at least some of the yarns being hot stretched synthetic yarns.

5. A strand for the formation of rope by association with other similar strands, said strand comprising a plurality of concentrically arranged continuous layers of twisted yarns with continuous yarns in each layer in tight engagement with each other, the yarns in each of the respective layers having different ultimate elongations, said elongations being such that the yarns in each layer reach their ultimate elongations approximately simultaneously when loaded in a rope.

6. A rope composed of strands having the characteristics of claim 5.

7. A strand for the formation of rope by association with other similar strands, said strand comprising a plurality of concentrically arranged continuous layers of twisted yarns with continuous yarns in each layer in tight engagement with each other, the yarns in the different layers being of different materials, the yarns in each of the respective layers having different ultimate elongations, said elongations being such that the yarns in each layer reach their ultimate elongations approximately simultaneously when loaded in a rope.

8. A strand for the formation of rope by association with other similar strands, said strand comprising concentrically arranged continuous layers of twisted yarns with continuous yarns in each layer in tight engagement with each other, the yarns in the different layers being of different materials, the yarns in each of the respective layers having different ultimate elongations with the ultimate elongations of each layer being less than the ultimate elongations of the yarns of the next inner layer, the length of said elongations being such that said yarns in each layer reach their ultimate elongations approximately simultaneously under load.

9. A strand for the formation of rope by association with other similar strands, said strand comprising a plurality of concentrically arranged continuous layers of twisted yarns with continuous yarns in each layer in tight engagement with each other, said tightness of engagement being substantially uniform throughout the stand, the yarns in each of the respective layers having different ultimate

elongations, said elongations being such that the yarns in each layer reach their ultimate elongations approximately simultaneously when loaded in a rope.

References Cited in the file of this patent

UNITED STATES PATENTS

1,930,661 Rochester Oct. 17, 1933

2,400,181  
2,438,864  
2,477,652  
2,591,628  
2,880,568

5

Warren May 14, 1946  
Reed Mar. 30, 1948  
Robbins Aug. 2, 1949  
Snyder Apr. 1, 1952  
Starr Apr. 7, 1959