April 23, 1968 J. A. ROBERTS ET AL 3,378,999

METALLIC YARN STRUCTURE

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Fig. 1.

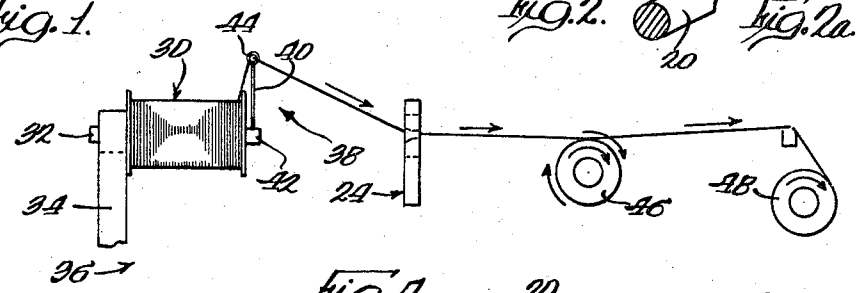


Fig. 2.

Fig. 2a.



Fig. 3.

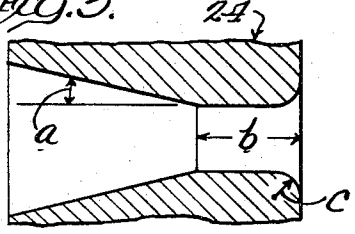


Fig. 4.

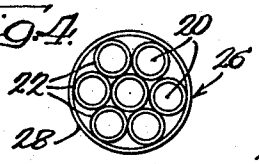


Fig. 5.

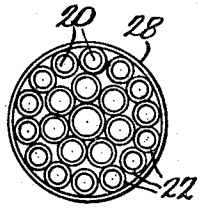


Fig. 6.

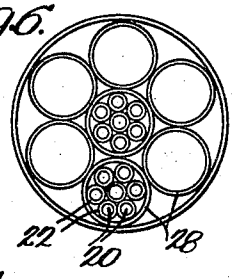


Fig. 7.

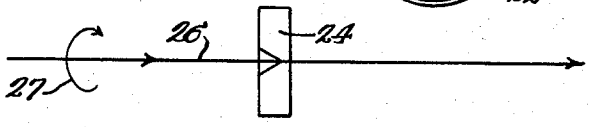


Fig. 8.

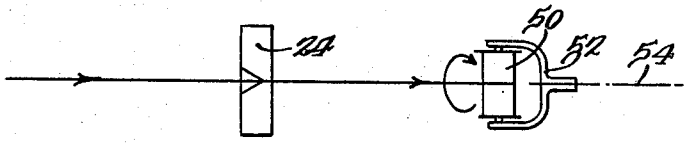


Fig. 9.

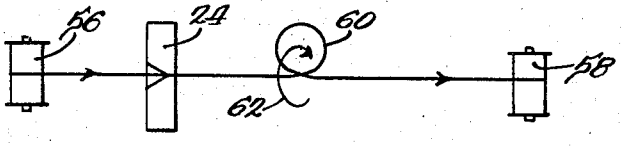


Fig. 10.

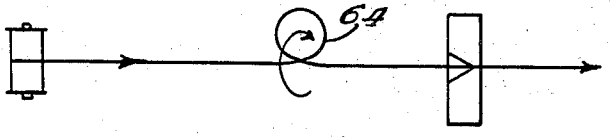
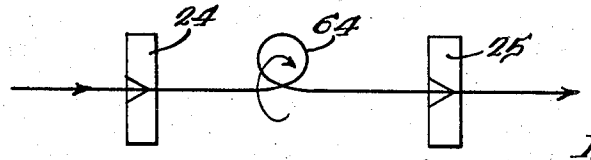


Fig. 11.



Inventors:
John A. Roberts
Joseph R. Quirk
By Hofgren, Wegner,
Allen, Stellman & McCord Attys

Fig. 12.

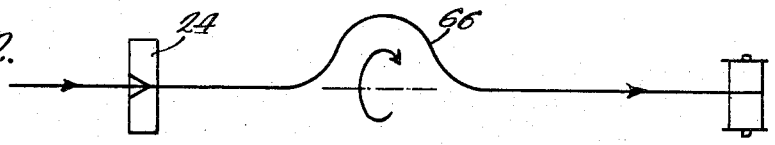


Fig. 13.

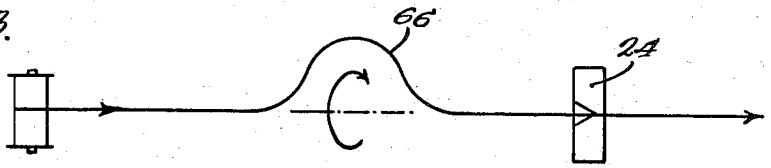


Fig. 14.

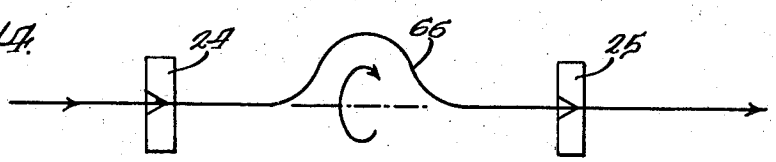


Fig. 15.

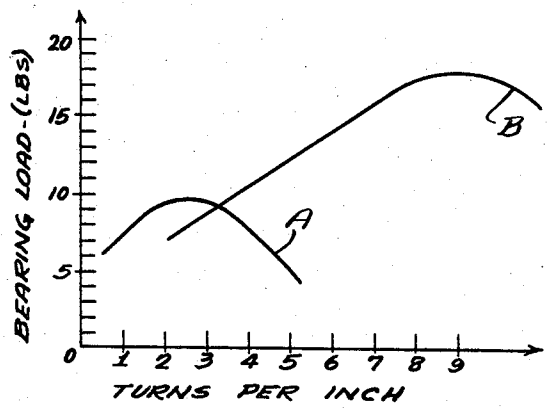
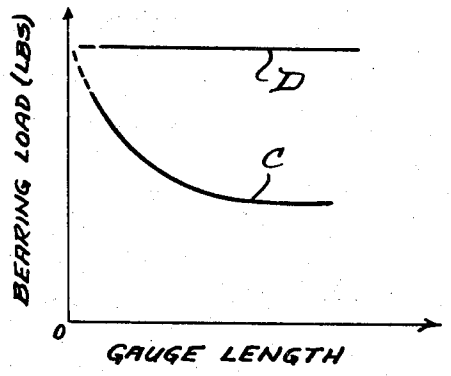


Fig. 16.



METALLIC YARN STRUCTURE

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Fig. 17.

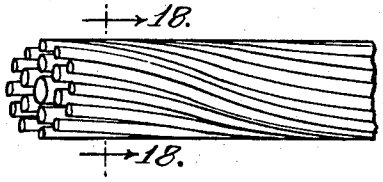


Fig. 18.

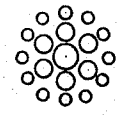


Fig. 19.

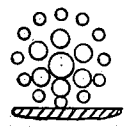


Fig. 20.

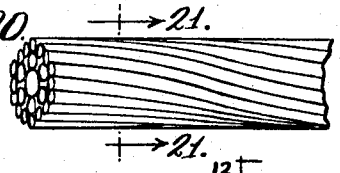


Fig. 21.



Fig. 22.

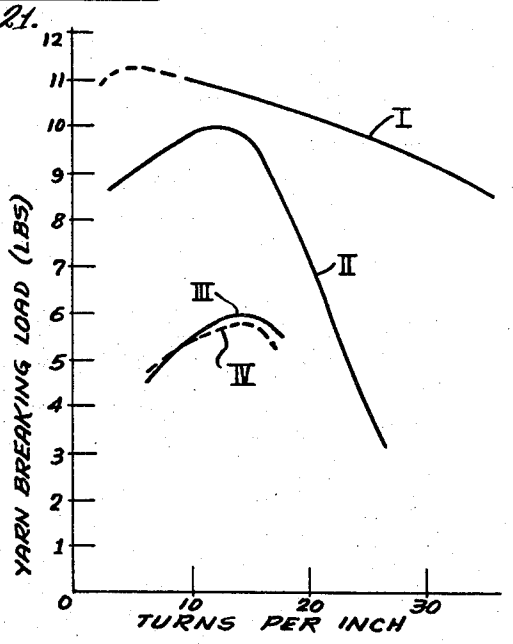


Fig. 23.

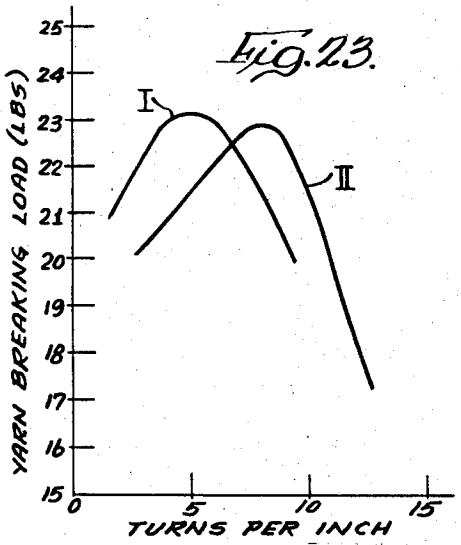
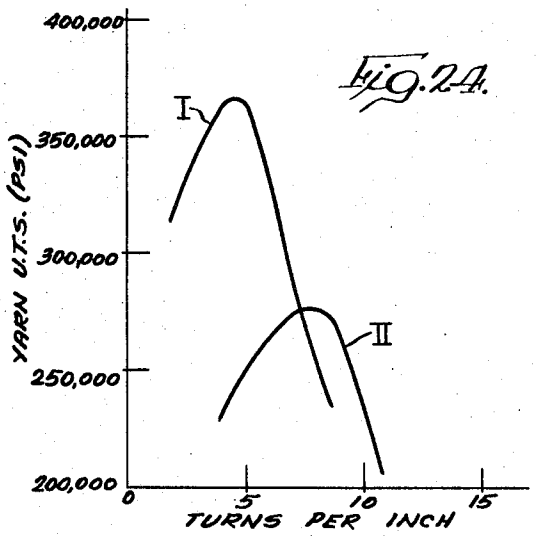


Fig. 24.



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3,378,999

METALLIC YARN STRUCTURE

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Filed June 17, 1965, Ser. No. 464,721
9 Claims. (Cl. 57—139)

ABSTRACT OF THE DISCLOSURE

A metal yarn structure wherein the filaments are set under pressure while in a substantially nonelastic state to be free of residual torsion while having a preselected helical twist. The setting of the filaments in the helical configuration is effected by twisting the filaments in a matrix while concurrently effecting constriction thereof to fluidize the filaments and permit the setting thereof upon release of the constriction forces in the torsion-free helical configuration.

Specification

This invention relates to twisted yarns, e.g. twisted bundles of filaments, and more particularly to yarns and methods of forming yarns of very small diameter filaments in twisted form.

There are many known or anticipated uses for high tensile strength, highly flexible yarns. Such yarns may be formed of synthetic plastic filaments or metal filaments adapted to be woven into suitable textile materials such as sheets or strips, or be embedded or otherwise disposed in other materials such as for reinforcement thereof, providing anti-static characteristics, etc.

In one known method of forming yarns of filaments, a plurality of filaments are disposed in parallel spaced relationship with matrix material extending between the respective filaments. The bundle of filaments is radially constricted such as by drawing of the bundle through a drawing die whereby the individual filaments are reduced in diameter. Alternately the bundle may be radially constricted by other constricting methods such as by hot or cold rolling. A plurality of constricting steps may be employed so as to reduce the filaments to an ultimate, extremely small diameter.

The final constricted bundle is then suitably treated to remove the matrix material from the small diameter filaments thereby providing a yarn comprised of a plurality of fine filaments. To provide desirable yarn characteristics it is common to provide in such yarns a twist of a number of turns per inch. One conventional method of applying such a twist to the filaments is to feed each of the filaments individually to a twisting apparatus which wraps the filaments about each other in a generally helical fashion. This method of providing a twist in the filaments of the yarns has the serious defect of leaving in the filaments a resultant torsion tending to untwist the filaments as a result of the natural resiliency of the filamentary material. Thus the resultant twisted yarn has a tendency to spring or curl to varying degrees depending on the amount of twisting and the specific materials of which the filaments are formed. One attempted solution to this problem has been to wrap a plurality of the twisted yarns in reverse direction so that the twist of one yarn offsets the twist of the next yarn thereby providing a thread wherein the curling tendencies of the respective yarn are counterbalanced. Such a solution however has not proven completely satisfactory as the residual torsion forces cannot be fully, accurately balanced.

The present invention comprehends an improved yarn structure and method of forming the same which eliminates the above discussed disadvantages of the known

twisted yarns in an extremely simple and novel manner. It is, therefore, a principal feature of the present invention to provide a new and improved yarn and method of forming the same.

Another feature of the invention is the provision of a yarn structure comprising: a plurality of filaments set free of residual torsion in substantially coaxial, spaced helical relationship and having engagement therebetween.

A further feature of the invention is the provision of such a yarn structure wherein the number of turns per inch of the helical filaments is preselected to provide a yarn strength substantially equal to the zero gauge length strength of said filaments.

Still another feature of the invention is the provision of such a yarn structure wherein the total area of the filaments transverse to the axis of the yarn being substantially constant along the axis.

A further feature of the invention is the provision of such a yarn structure wherein the filaments are disposed in radially spaced, generally cylindrical groups.

Yet another feature of the invention is the provision of such a yarn structure wherein the plurality of filaments includes axially, substantially rectilinear filament having a diameter larger than the helical filaments.

A yet further feature of the invention is the provision of such a yarn structure wherein the plurality of filaments includes filaments spaced at different distances radially of the axis of the set plurality, the diameter of the filaments being inversely related to the spacing thereof from the axis.

A further feature of the invention is the provision of such a yarn structure wherein the number of turns per inch of the filaments in the helical relationship is greater than 2.

Another feature of the invention is the provision of such a yarn structure wherein each of the filaments has an outer surface portion defining a diffusion zone.

Another feature of the invention is the provision of such a yarn structure comprising a plurality of filaments disposed in generally coaxial, helical configurations wherein the helical configurations are permanently set in the filaments by delivering the filaments to a constricting means while in a bundled arrangement, the constricting means being suitably arranged to constrict the bundled arrangement sufficiently to cause a hydrostatic plasticizing of the filaments therein while the bundled filaments are concurrently twisted to cause the filaments to be repositioned within the constricting means in coaxial, spaced helical relationship with each other, and withdrawing the helically arranged filaments from the constricting means to release the hydrostatic pressure whereby the filaments set in the helical configuration free of residual torsion.

A further feature of the invention is the provision of a method of making a twisted yarn comprising the steps of providing a plurality of parallel, spaced filaments with matrix material therebetween, effecting a plasticizing of the filaments in the bundle, providing a twist in the plasticized filaments in the bundle, discontinuing the plasticizing of the filaments to cause the filaments to set in a substantially coaxial, spaced helical configuration free of residual torsion, and removing the matrix material.

Another feature of the invention is the provision of such a method wherein the plasticizing step comprises a step of radially constricting the bundle of filaments.

Yet another feature of the invention is the provision of such a yarn structure wherein the plasticizing step comprises a step of drawing the bundle through a drawing die.

A still further feature of the invention is the provision of a method of making a twisted yarn comprising the steps of providing a bundle of parallel, spaced filaments with matrix material therebetween, effecting a plasticizing

of the filaments in the bundle at a first limited portion of the length of the bundle, providing a twist in the plasticized filaments in the bundle by turning about its axis a second portion of the bundle, discontinuing the plasticizing of the filaments to cause the twisted filaments to set in a substantially coaxial, spaced helical configuration free of residual torsion, and removing the matrix material.

Another feature of the invention is the provision of such a method wherein the plasticizing step comprises a step of drawing of the bundle through a die, said first portion being disposed within the die and the second portion of the bundle being contiguous with the first portion.

A further feature of the invention is the provision of such a method wherein the bundle is cold worked over 90%.

Still another feature of the invention is the provision of such a method wherein the twist is provided in the bundle by application of twisting forces to the bundle portion entering the constricting means.

Yet another feature of the invention is the provision of such a method wherein the twist is provided in the bundle by application of twisting forces to the bundle portion leaving the constricting means.

A further feature of the invention is the provision of a method of making a twisted yarn comprising the steps of providing a bundle of parallel filaments, effecting a plasticizing of the filaments in the bundle, twisting the plasticized filaments in the bundle, discontinuing the plasticizing of the twisted filaments to cause the filaments to set in a helical configuration free of residual torsion, and removing the matrix material.

Other features and advantages of the invention will be apparent from the following description taken in connection with the accompanying drawings wherein:

FIGURE 1 is a schematic layout of an exemplary apparatus for carrying out the method of forming yarn embodying the invention;

FIGURE 2 is a perspective view of a rod from which a yarn embodying the invention may be formed;

FIGURE 2*a* is a cross sectional view of a rod enclosed in a sheath of matrix forming material;

FIGURE 3 is an enlarged diametric cross section of a die for use in the method of the invention;

FIGURE 4 is a transverse cross section of a bundle of the sheathed rods of FIG. 2*a*;

FIGURE 5 is a cross-section of the bundle of rods of FIG. 4 subsequent to a constriction thereof to form the rods therein into small diameter filaments;

FIGURE 6 is a transverse cross section of the bundle of FIG. 5 having a twist imparted to the filaments therein by the method of the invention;

FIGURE 7 is a diagrammatic view illustrating the method embodying the invention for providing the twisted bundle of FIG. 6;

FIGURE 8 is a diagrammatic view illustrating another method embodying the invention for providing the twisted bundles;

FIGURES 9–14 are diagrammatic views of additional different methods embodying the invention for providing the twisted bundles;

FIGURE 15 is a graph comparing the improved results of the invention with prior results;

FIGURE 16 is a graph comparing additional results of the invention with prior results;

FIGURE 17 is a fragmentary isometric view of a bundle of filaments without the matrix material;

FIGURE 18 is a transverse section taken substantially along the line **18—18** of FIGURE 17;

FIGURE 19 is a transverse section similar to that of FIGURE 18, but wherein the filaments assume a position somewhat different from that of FIGURE 18 but are still considered to be spaced;

FIGURE 20 is an elevational view of a short length of yarn twisted without a matrix material;

FIGURE 21 is a cross-sectional view of a bundle of filaments twisted in a die without matrix material;

FIGURE 22 is a chart illustrating the comparison between the mechanical properties of two bundles of yarn in a matrix subjected to a twist at different times in the processing of the yarn;

FIGURE 23 is a graph illustrating the comparison between the mechanical properties of two bundles of yarn in matrices subjected to different reductions in different dies; and

FIGURE 24 is a graph illustrating the comparison between mechanical properties of two bundles of yarn in matrices treated to a different degree of cold working.

In the exemplary embodiments of the invention as shown and described in the drawing, similar reference numerals refer to similar parts throughout the several views, an elongated element or filament **20** is provided with a sheath or coating of a matrix **22** of a material different from the material of the elongated element or filament **20**. The elongated element or filament **20** is of a material capable of becoming somewhat fluid or plasticized under pressure such as the pressure created in a constricting die.

The matrix material **22** can be initially bonded to the rod or filament **20** in many ways such as by passing the composite through a constricting die **24** or by applying the matrix onto the rod **20** in a fluid state whereby the sheath will become bonded to the filament or rod **20** upon the solidification of the matrix material **22** around the rod **20**. Sometimes the sheathed rod or filament **20** is passed through a few successively smaller dies to initially reduce the diameter of the rod or filament **20**.

A plurality of like sheathed rods or filaments **20** are assembled together in a bundle of filaments **26** which bundle is then sheathed or embedded in a matrix **28** preferably of the same matrix material and the matrix bound bundle **26** of filaments **20** is fed consecutively through successively smaller constricting dies **24** to reduce the diameter of the bundle **26** and likewise to reduce the diameter of the individual filaments **20** in the bundle. In some cases, just before the last draw of the bundle **26** of filaments **20** through the last constricting die **24**, the bundle **26** of filaments **20** is wound onto a roll **30**. The roll **30** is positioned on a spindle **32** carried by the frame **34** of the drawing machine **36** as shown in FIGURE 1. A payout device **38** is shown as having an arm **40** pivoted at **42** on the same axis as the drum or roll **30** and includes an eyelet **44** through which the bundle **26** of filaments **20** is fed. The arm **40** is driven about the pivot axis in any will known manner so as to provide a twist to the bundle **26** and to guide the unwinding of the bundle **26** off the roll **30**. The bundle **26** of filaments **20** is then passed through the constricting or forming die **24**, passed around a capstan **46**, or other tensioning device and onto the rewinding roll **48**.

As the capstan or tensioning device **46** pulls the bundle **26** of filaments **20** through the die **24**, the twist imparted to the filaments in the bundle **26** is set into the bundle. That is, as the bundle **26** of filaments **20** and matrix **22** is drawn through the die **24** the die working or constriction on each progressive or successive increment of the bundle causes the material of the filaments **20** to become plasticized as the particular increment is compressed under the relatively high hydrostatic pressures of the die **24**. In some cases the matrix material will also become fluid or plasticized. With the increment of the bundle of filaments in a plastic state, the twist imparted to the filaments by the payout device **38** will be formed in the individual filaments **20** such that almost instantaneously after the increment or segment of the bundle leaves the die, the bundle of filaments takes a permanent set with the twist set therein. The filaments will be set free of residual torsion in substantially coaxial spaced helical relationship. No further heat treatment is required on the bundle; however, subsequently processing can be per-

formed on the bundle if the ultimate use to be made of the bundle **26** of filaments so demands. The twist can be added to the bundle of filaments in successive steps a few twists at a time. Each time the constricting die reduces the diameter of the bundle, produces instantaneous plasticity and sets the twist imparted thereto by the twisting device.

The twisted bundle of filaments with the matrix material therein is next subjected to either chemicals, heat or the like to remove the matrix material to produce the bundle of twisted filaments or yarn ready for use. A bundle of twisted filaments of the type just described is sometimes called a yarn or a hollow yarn. With the matrix material removed from the bundle of filaments there will be an open space between each filament and its adjacent filaments. FIGURES 17 and 18 illustrate the appearance and form of a bundle of filaments without the matrix material. The filaments are referred to as being spaced from their adjoining filaments. The term spaced is intended to include the condition when the filaments in a bundle assume a position somewhat similar to the showing of FIGURE 19. That is, the filaments without matrix could not just suspend themselves as shown in FIGURE 18 and will assume a position at rest wherein the filaments of each ring of filaments will settle or sag onto the inside of the immediately contiguous outside ring of filaments. Certain filaments will touch certain other filaments at points along the length of the yarn, but essentially the filaments will be spaced apart. Therefore, when the filaments are referred to as being spaced apart, it is intended that the incidental touching between filaments at spaced points throughout the circumference, diameter and length of the yarn is to be included within the scope of the term.

There are certain parameters that influence the ultimate properties of the bundle or yarn **26** which has been twisted while it is passing through a constricting device, such as a die **24**. Specifically, the die contour is important and in particular the percent or reduction of area of the bundle to be effected in the die, the die angle, the length of the die bearing surface and the relief angle of the die. The effect of the percent reduction of area of the bundle due to the die will be discussed hereinafter with reference to FIGURE 21. If the die angle is too steep the bundle will have a tendency to wedge or block up at the die opening which can cause rupturing of the bundle. If the die angle is too shallow, the buildup of pressure will be over too great a distance and the proper degree of plasticity for inducing the correct permanently set twist into the bundle or yarn **26** will not be reached. The relief radius of the die should be standard as established in the trade. The die lubrication, the area of reduction of the cross section of the die and the surface characteristics of the die and wire should be carefully controlled to produce the desired characteristics in the resulting yarn. A controlled back pull on the bundle of filaments entering the die effects better results in the yarn produced by the draw.

One embodiment of our invention known as Example I used a constricting device, in this case a die having a polished tungsten carbide surface. The contour of the die included a die angle *a* of 12° (twelve degrees), a bearing surface *b* of 4.4 mils which is 35% of the diameter of the bundle being drawn, and a standard relief radius *c*. The die was lubricated with Apex 201 sulphated or chlorinated wire drawing oil. The die was designed to reduce the area of the bundle 20% during the twisting.

A bundle of 271 filaments of 0.5 mil diameter No. 304 stainless steel cold drawn wire was embedded in a matrix of Monel 400 material. The back pull on the bundle of filaments entering the die was approximately plus or minus 8 ounces. Applying seven (7) turns per inch to the bundle, as the bundle was advanced into the die, each advancing increment of the bundle of filaments and matrix was heated due to the die working to above the elastic limit of the material of the filaments whereupon each increment of the bundle of filaments became somewhat plastic such that the twist applied to the bundle permanently realigned the individual filaments **20** in a new angular orientation with respect to the axis of the bundle. As each increment or discrete segment of the bundle **26** emerged from the die **24**, it immediately reset itself to the solid state whereupon the bundle of filaments had a twist permanently set in the filaments of the bundle. The bundle was then soaked in a chemical bath or heated to a preselected level to remove the Monel metal matrix, whereupon a hollow bundle of filaments having a tensile strength of 295,000 pounds per square inch resulted. The resulting bundle of filaments or yarn is suitable for a wide variety of uses requiring either strength or flexibility or combinations of both. The optimum twist for the bundle of Example I was 9 turns per inch which produced a yarn having a breaking strength of 18.1 pounds.

FIGURE 7 is a diagrammatic or schematic showing of the same process as is illustrated in FIGURE 1, that is, in FIGURE 1 a twist is added to the bundle of filaments as the bundle is unwound from the roll **30**. The twist of FIGURE 1 is illustrated in FIGURE 7 by a circular arrow **27** indicating a twist in a clockwise direction to the bundle **26** as it is fed to the die or constricting device **24**.

FIGURE 8 shows a modified form of the invention wherein the takeup roll **50** and its mount **52** are rotated in a clockwise direction about the axis **54** of the mount **52**. In this way the twist is induced into the bundle of filaments as each increment or discrete segment of the bundle is in the plastic state in the die or constricting device **24**. The twist is set in the bundle of filaments immediately upon releasing the hydrostatic pressure on the increment of the bundle as each increment of the bundle emerges from the die. As the bundle is continuously advanced and the twist is continuously applied, a bundle of filaments will be produced with a continuous spiral or helix permanently set therein.

FIGURE 9 shows a modified form of the invention wherein the feed-in roll **56** and takeup roll **58** are used only to unwind and wind the bundle thereon respectively. A loop **60** is formed in the bundle on the downstream or exit side of the die **24**. The loop **60** is then turned about the axis of the bundle as shown by the arrow **62**. The number of turns of the loop **60** about the axis of the bundle will determine the number of twists induced in the bundle of filaments which is being drawn through the die **24**. The twists or turns will be set in the bundle in the constricting die as set out in detail above.

FIGURE 10 is similar to FIGURE 9 except that the loop **64** is on the entrance or upstream side of the die **24**. There are times when the nature of the material making up the filaments **20** requires that the twist be added to the bundle as the bundle enters the die instead of as the bundle leaves the die. The process is flexible enough to provide for both. Different and improved results are obtained with different filament materials depending upon whether the twist is applied during or after the bundle enters the die as will become apparent hereinafter.

FIGURE 11 shows a modified version of the invention wherein two dies or constricting devices **24**, **25** are spaced apart a short distance with a loop **64** in the bundle or composite therebetween. As the loop **64** is rotated about the axis of the bundle as the bundle is pulled through the successive dies, the twist will be added progressively to the bundle, each die receiving and permitting permanently induced twist to the bundle as it passes therethrough.

FIGURES 12, 13 and 14 show another set of modifications for inducing twist into a bundle of filaments. In FIGURE 12 a partial loop **66** is created in the bundle by training the bundle over or through a shaped path. As the bundle is pulled through the die and around the shaped path forming the loop **66** the loop **66** is rotated about the

axis of the bundle to add a twist to the bundle as it is pulled through the die **24**.

FIGURE 13 is similar to FIGURE 10 and shows a method of twisting the bundle by using the partial loop **66** in place of the complete loop **64** as the bundle is fed into the die. FIGURE 14 is similar to FIGURE 11 wherein a partial loop **66** is used between successive constricting dies **24**, **25** for inducing twist into the bundle.

It has been found that although when an increment or discrete segment of the bundle of filaments is worked as it passes through the constricting die without twisting, the diameters of each filament in any cross section taken across the width of the bundle will be substantially the same. That is, in each size reduction of the whole bundle a proportionate size reduction will take place in each and every filament such that the diameter of the center filament will be substantially the same as the diameter of a filament in the outermost circle of filaments in the bundle.

However, when a bundle such as shown in FIGURE 4 is twisted as it passes continuously through the die **24**, the cross section shown in FIGURE 5 results, that is, the diameter of the filament at the center will be reduced a smaller amount as compared to the reduction in the diameter of the filament in the outer ring of filaments. There will be a proportional gradation in the diameters extending from the largest at the center of the bundle and gradually reducing in diameter outward from the center until at the outermost ring of filaments the smallest diameter of filaments will result. The degree or ratio of reduction will be greater the greater the number of turns or twists per inch is put into the bundle. It has been found that the addition of twists to the bundle will elongate the outermost filaments and reduce in diameter the outermost filaments the most and will provide just enough elongation that there will not be any lengthwise creep between concentric layers of filaments. For example, a one foot long straight bundle of filaments will be some amount longer than one foot after the bundle is passed through the die with the twisting added, but the over-all axial length of the bundle will be the same even though the outermost filaments will now be actually considerably longer due to the helix or spiral than the length of the centermost filament. The twist can be added a few degreese or a few turns per inch at a time by successive passes through constricting dies, each pass adding additional twist to the bundle.

The average area or sums of the cross section of all filaments is identical no matter whether the bundle is passed through the die straight or by adding a twist to the bundle as it passes through the die. This is true even though with a straight bundle all of the filaments will have substantially identical cross sections resulting from the straight pass while with a twisted bundle the center filaments will be larger in cross section and the filaments will gradually decrease in diameter outward from the center. The radial distribution of cross section obtained in the twisting process will produce a bundle of filaments or yarn having improved flex properties compared with a twisted bundle or yarn with no radial distribution of area of cross section. Adding the twist while the bundle is in a state of plasticity in the die inherently produces a bundle of filaments of extreme uniformity of twist and extreme uniformity of weight per unit of length.

When tensile strength is an important factor, it has been found that a much higher tensile strength can be obtained from a bundle of filaments twisted in a matrix in a constricting device than can be obtained from the same bundle of filaments twisted after the matrix has been removed and without a constricting device. In particular, the tensile strength of the bundle twisted in the matrix is increased as the number of turns per inch is increased until a maximum or optimum tensile strength is obtained at a particular number of turns per inch. This, of course, varies with the types and diameters of the materials of the filaments.

FIGURE 15 illustrates in graphic form a set of comparison values for the material used in our Example I above, namely a 304 stainless filament. The horizontal calibration of the chart is in turns per inch and the vertical calibration is the yarn breaking load in pounds. The curve labeled A is the yarn twisted without a matrix and without a constricting die. It can be observed that the maximum or optimum values are reached at 2.5 turns per inch and 9.75 pounds breaking load. Curve B is based on Example I above and is the same yarn as curve A embedded in a matrix of Monel 400 material and twisted in a constricting die. The matrix is removed after the twist is set in the bundle. A maximum breaking strength or load of 18.1 pounds was obtained at an optimum of 9 turns or twists per inch. The values shown on the chart of FIGURE 15 clearly indicate the improved breaking strength that can be produced by providing the twist to the bundle just prior to or as the bundle is being worked in the constricting die together with the improved results based on the number of turns per inch in the bundle as compared to the prior system of twisting the bundle of filaments without a constricting die.

At the optimum twist in a bundle, which will be different for different sizes and numbers of filaments, the tensile strength of the bundle will be almost equal to 100% of the individual or single filament strength. This is contrary to the usual results obtained when a bundle of filaments is reduced in diameter as by passing through a constricting die. Normally there is a decrease in the tensile strength greater than the proportionate decrease in the diameters of each filament. Using our invention it has been found that at the optimum twist condition for a particular bundle of filaments the tensile strength of the bundle will be close to the full tensile strength of the combined individual filament strengths.

When there is a dependence of the individual filament strength on the gauge length, the tensile strength of the bundle or yarn at optimum twist corresponds to the zero gauge length tensile strength of the individual filaments. In FIGURE 16 a comparison is made between single filament data, as shown by curve C, and a bundle or yarn data, as shown by curve D, at optimum twist condition. The vertical scale is the breaking load in pounds while the horizontal scale is gauge length. It is to be observed that as the gauge length of curve C increases, the breaking load falls off rather sharply. In the case of a bundle or yarn at optimum twist the breaking load remains constant for any reasonable increases in the gauge length.

With the bundle of yarn capable of producing maximum tensile strengths and nearly 100% translation of individual filament strengths, both at optimum twist per unit of length, a superior bundle of filaments or yarn results which is tougher and stronger and still has improved flex properties. It is contemplated within the scope of the invention that a twisted filament yarn may be formed by passing a bundle of filaments without matrix material therebetween through the constricting device while twist is added to the bundle. The resultant yarn has a permanently set twist free of torsion as in the above described embodiments but has the filaments set in engagement with each other. FIGURES 20 and 21 show a side and cross sectional view of a bundle of filaments with the twist set therein during the pass of the bundle through the die. The bundle does not contain any matrix material and has the filaments set free of torsion by the pass through the die as the twist is applied.

FIGURE 22 illustrates graphically the different results obtained in yarns that have been twisted in two different ways and either annealed or not annealed. In the first case, using the teaching of FIGURES 1 and 7, the twist was applied to the bundle as the bundle entered the die and is shown in FIGURE 22 as curve III. Curve I is the bundle the same as FIGURES 1 and 7 only the bundle was annealed prior to twisting as it passed into the die. In the second case, using the teaching of FIGURE 8,

the twist was applied downstream of the die or at the die exit as the bundle passed through the die and is shown in FIGURE 22 as the curve IV. Curve II is a bundle the same as FIGURE 8 only the bundle was annealed prior to passing through the die and with the twist applied at the exit or downstream of the die. FIGURE 22 results from the following Example II:

Mechanical properties of heavily cold worked yarn twisted in a reduction die

Material	304 stainless steel Monel 400-matrix.
Filament diameter	0.593 mil.
No. of filaments	301.
Reduction in die	20%.
$\sigma/\bar{X}$ UTS	Coefficient of variation of UTS values of yarn (ultimate tensile strength).

Standard lubrication and twist conditons

COMPOSITE OR BUNDLE TWISTED (NOT ANNEALED)

Twist and Percent Cold Work	Entering the Die (III)		Leaving the Die (IV)	
	Breaking Load	$\sigma/\bar{X}$ UTS, Percent	Breaking Load	$\sigma/\bar{X}$ UTS, percent
15 turns per inch [1] (95.1% cold worked)	5.98	9.7	5.80	6.4
9 turns per inch (97% cold worked)	5.03	3.2	5.11	3.6
7 turns per inch (97.5% cold worked)	4.79	5.6	4.82	5.8

COMPOSITE OR BUNDLE TWISTED—ANNEALED

Twist	Entering the Die (II)	Leaving the Die (I)
	Breaking Load	Breaking Load
5 turns/inch	9.1	[1] 11.25
12 turns/inch	[1] 10	10.9
25 turns/inch	3.8	9.95

[1] Optimum.

From these values and from the chart FIGURE 22, it can be seen that for this type of material and matrix the addition of the twist to the composite or bundle from the downstream side of the die or on the exit end of the die produces varied results. Without annealing the addition of the twist to the bundle as it enters the die produces better results than adding the twist on the exit side of the die. However, when the bundle is annealed before twisting in the die, the results are phenomenally better no matter whether the twist is added on the entrance or on the exit end of the die. The annealed bundle when twisted from the exit end of the die produces the strongest torsion free yarn as is shown by curve I in FIGURE 22. The bundle that was annealed and twisted as it entered the die produced very strong yarns also as shown by curve II in FIGURE 22.

Example III illustrates the effect of the magnitude of reduction of the area of the bundle in the twisting die on the optimum turns per inch and breaking load of the bundle. FIGURE 23 illustrates the graphic results of twisting several bundles of filaments having the following characteristics:

Material	304 stainless steel.
Matrix	400 Monel metal.
Total cold work	93.8%.
No. of filaments	271.
Filament diameter	0.593 mil.

Curve I is the result of values received from bundles twisted in a die producing 36% reduction in the area of the bundle as the bundle passed through the die. Curve II is the result of values received from bundles twisted in a die producing 20% reduction in the area of the bundle as the bundle passed through the die. It will be noted that the total breaking load in both cases reaches about the same maximum of about 23 pounds. The difference is in the fact that the bundles receiving the greater percent reduction in area during the twisting reached the optimum breaking load with 5 turns per inch where the bundles receiving the lesser reduction in area produced their maximum breaking load at 8 turns per inch.

Example IV illustrates the effect of yarn diameter on twisting characteristics together with the effect of filament diameters on the ultimate tensile strength. FIGURE 24 illustrates the results of twisting several bundles of filaments having the following characteristics:

Material	304 stainless steel.
Matrix	400 Monel metal.
Reduction in die	20%.
No. of filaments	301.

Curve I is the result of applying the twist to filaments having a diameter of 1.005 mil, while curve II is the result of applying the twist to filaments having a diameter of 0.580 mil. It will be noted that an optimum ultimate tensile strength of 365,000 pounds per square inch was reached at around 4.5 turns per inch using the 1.005 mil filament (curve I) while the optimum ultimate tensile strength of 276,000 pounds per square inch was reached at about 8 turns per inch using the 0.580 mil filament (curve II).

The twisted torsion free bundle or yarn may have many unique geometrical configurations which will impart particularly desirable properties to the yarn for specific applications. With the matrix material removed, a twisted bundle of filaments or yarn has the individual filaments in a torsion free, uniaxial helical configuration such that the bundle or yarn will have the property of high elongation. That is, as the yarn is pulled lengthwise the outer filaments will close in on the inner filaments permitting the yarn to appear to stretch lengthwise which is desirable for certain applications for which the yarn can be used.

The twisted yarn can have the individual filaments with high surface roughness or wherein the surface chemical composition can be different as a result of interdiffusion of the matrix with the filament material during the repeated plasticized states caused by the successive passes through the constricting die. The surface condition, i.e., roughness or modified chemical composition, together with the twist to the filaments, can radically influence the transference or equalization of stress on the filaments of the bundle and thus produce the high translation of single filament to yarn strength.

Using the teaching of this invention, it is possible to induce the torsion free twist into the material of the filaments in a heavily cold worked condition. No external heat need be added to the die area to either create the plastic state of the material of the filaments or to stress relieve the twisted bundles after the twist has been induced therein in the die.

The method of producing the hydrostatic pressure on the filament or bundle of filaments is by means of a constricting device. The constricting device referred to hereinbefore is generally a constricting die. However, there are other mechanical constricting devices which can be used such as roller dies and rolls which can be used on materials in either a hot or cold condition. It is also possible to use a high pressure fluid to maintain die pressure sufficiently high to create a state of plasticity under the hydrostatic pressure sufficient to induce and set a torsion free twist in a bundle of filaments to produce a torsion free yarn of desirable characteristics not heretofore contemplated.

While we have shown and described certain embodiments of our invention, it is to be understood that it is capable of many modifications. Changes, therefore, in the construction and arrangement may be made without departing from the spirit and scope of the invention as defined in the appended claims.

We claim:

1. A yarn structure comprising a plurality of cold worked, unannealed metallic filaments twisted while under pressure in a substantially nonelastic state and set free of residual torsion in substantially coaxial, spaced helical relationship and movably associated to have engagement therebetween.

2. The yarn structure of claim 1 wherein said metallic filaments are formed of stainless steel.

3. The yarn structure of claim 1 wherein the number of turns per inch of the helical filaments is preselected to provide a yarn strength substantially equal to the zero gauge length strength of said filaments.

4. The yarn structure of claim 1 wherein the total area of said filaments transverse to the axis of the yarn is substantially constant along said axis.

5. The yarn structure of claim 1 wherein said filaments are disposed in radially spaced, generally cylindrical groups.

6. The yarn structure of claim 1 wherein said plurality of filaments further includes an axial, substantially rectilinear filament having a diameter larger than the helical filaments.

7. The yarn structure of claim 1 wherein said plurality of filaments includes filaments spaced at different distances radially of the axis of the set plurality, the diameter of said filaments being inversely related to the spacing thereof from said axis.

8. The yarn structure of claim 1 wherein the number of turns per inch of the filaments in said helical relationship is greater than two.

9. The yarn structure of claim 1 wherein each of said filaments has an outer surface portion defining a diffusion zone.

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