METHOD OF FORMING FILAMENTS


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ABSTRACT OF THE DISCLOSURE

A method of forming fine filaments, such as filaments of under approximately 15 microns, in long lengths wherein a plurality of sheathed elements are firstly constructed to form a reduced diameter billet by means of hot forming the bundled filaments. After the hot forming construction, the billet is then drawn to the final size wherein the filaments have the desired final small diameter. The material surrounding the filaments is then removed by suitable means leaving the filaments in the form of a tow.

This invention relates to the forming of fine filaments and in particular to the forming of such filaments having very long lengths.

In the manufacture of material, such as reinforcing fabrics, filtering media, etc., there has developed a need for high strength metallic filaments. More specifically, it has been found that, in such materials, metallic filaments having extremely small diameters, such as under 15 microns, may provide increased tensile strength. Further, such small diameter filaments when formed in suitable pads provide improved filtering action. The present invention is concerned with the forming of such metal filaments and comprehends an improved method of forming, providing extremely long lengths of such filaments having a diameter of under 15 microns.

Thus, a principal feature of the present invention is the provision of a new and improved method of forming filaments.

Another feature of the invention is the provision of such a method of forming fine filaments in extremely long lengths.

A further feature of the invention is the provision of such a method adapted to provide such filaments having a diameter of down to approximately 12 microns or less in lengths of over 50,000 feet.

Another feature of the invention is the provision of such a method utilizing metallic material surrounding the elements from which the filaments are formed with a high ratio of filament material to matrix material being employed.

Still another feature of the invention is the provision of such a method providing improved economy of manufacture.

A yet further feature of the invention is the provision of such a method including a step of high temperature reduction of the filament cross-section.

Another feature of the invention is the provision of such a method comprising the steps of sheathing each of a plurality of elongated elements from which the filaments are to be formed with a material having physical characteristics differing from those of the elements to permit separation of the sheathing material from the elements when desired, bundling the sheathed elements in substantially parallel relationship, hot forming the bundle to reduce the cross-section thereof, drawing the formed bundle to reduce the cross-section of the elements therein to a preselected filament cross-section, and removing the sheathing material.

Another feature of the invention is the provision of such a method wherein the hot forming step comprises selectively a hot extrusion step, a hot rolling step, or both.

A further feature of the invention is the provision of such a method wherein the drawing step comprises a cold drawing step.

Still another feature of the invention is the provision of such a method wherein the elements from which the filaments are formed are tubular with the resultant filaments comprising tubular filaments.

Yet another feature of the invention is the provision of such a method wherein a filler is inserted into the tubular elements prior to the forming step.

Another feature of the invention is the provision of a tow of metal filaments each having a maximum cross-section of approximately 12 microns and a length of greater than approximately 50,000 feet.

A further feature of the invention is the provision of a tubular filament having a maximum outside cross-section of approximately .015 inch.

Still another feature of the invention is the provision of a hexagonal tubular filament having a maximum outer cross-section of approximately .015 inch.

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

FIGURE 1 is a transverse cross-section of a metal wire from which a filament may be formed in following the method embodying the invention;

FIGURE 2 is a transverse cross-section of the wire disposed within a coaxial sheath as in a first step of the method;

FIGURE 3 is a perspective view of a plurality of sheathed wires disposed in a cylindrical housing in a subsequent step, the housing being broken away to illustrate the bottom portion thereof;

FIGURE 4 is a reduced vertical section of a compacting means illustrating a compaction of the assembly of sheathed wires in the cylindrical housing to define a compacted billet;

FIGURE 5 is a reduced vertical section of another form of compacting means illustrating another method of reducing the diameter of the assembly to define a compacted billet;

FIGURE 6 is a top plan view of a plurality of sheathed wires in a modified housing having a hexagonal internal cross-section as by the provision therein of sector shaped spacers;

FIGURE 7 is a top plan view of a modified arrangement of the sheathed elements in a cylindrical housing with spacers disposed between the sheathed elements to effectively minimize the voids therein;

FIGURE 8 is an exploded vertical section illustrating the arrangement of the housing subsequent to the installation of the sheathed wires therein and prior to the securing of the end plug across the open end thereof;

FIGURE 9 is a vertical section illustrating the arrangement of the sheathed wires in the housing with the end plug secured across the open end of the housing;

FIGURE 10 is a vertical section illustrating the step of evacuating and sealing of the housed sheathed wires to define the primary billet;

FIGURE 11 is a fragmentary diagrammatic elevation of the billet during a subsequent hot extrusion step;
FIGURE 12 is a diagrammatic elevation of the extruded billet with suitable cutting means acting to remove the opalescent ends of the extruded billet; FIGURE 13 is a diagrammatic elevation illustrating the cutting of the extruded billet into a plurality of shorter lengths; FIGURE 14 is an elevation of one of the short lengths being provided with a replacement plug at each of its opposite ends; FIGURE 15 is a fragmentary side elevation of a short length being further hot extruded to reduce the diameter thereof; FIGURE 16 is a side elevation of the original billet being reduced in diameter as by hot rolling means in lieu of or subsequent to the hot extrusion means of FIGURE 11; FIGURE 17 is a fragmentary diagrammatic vertical section illustrating the cold drawing of the hot formed billet in a subsequent step; FIGURE 18 is a vertical cross-section of a tank wherein the drawn billet of FIGURE 17 is disposed to be acted upon by a suitable fluid within the tank to remove the sheathing and housing material from the billet; FIGURE 19 is a resultant tow of filament embodying the invention; FIGURE 20 is a transverse cross-section of a metallic tubular element from which a tubular filament may be formed in accordance with the invention, a filler being disposed within the tubular element as in a first step of the method; FIGURE 21 is a transverse cross-section of the filled tubular element disposed within a tubular sheath as in a second step of the method; FIGURE 22 is a transverse cross-section thereof constructed to provide a tight assembly of the filler, tubular element, and sheath as in a third step of the method; FIGURE 23 is a perspective top view of the filled and sheathed tubular elements disposed within a cylindrical housing for subsequent sealing, hot forming, and drawing steps as illustrated in FIGURES 7 through 17; and FIGURE 24 is a fragmentary enlarged perspective view of a tubular filament formed by the method.

In the exemplary embodiment of the invention, a tow generally designated 10 of filaments 11, as shown in FIGURE 19, is formed by a process wherein a plurality of elongated elements, or wires, 12 are bundled in side-by-side relationship and, when so bundled, reduced in diameter by a transverse, or radial, constriction of the wires in the bundle to provide a resultant filament of extremely small diameter and great length. Alternatively, the invention comprehends the forming of the filament as a tubular filament 13, as shown in FIGURE 24, the original elongated element in this process comprising a tubular element 14, as shown in FIGURE 20. Broadly, the invention comprehends the constriction of the bundled wires, or tubular elements, by firstly forming the bundled wires or elements into a billet, and subjecting the billet successively to a hot forming constriction and a subsequent drawing constriction. The hot forming constriction may be alternatively by hot extrusion or hot rolling of the billet. The drawing operation may comprise a plurality of cold drawing steps with intermediate annealing steps.

Referring now to FIGURES 1 and 2, the wire 12 is firstly enclosed in a suitable sheath 15 formed of a material having physical characteristics differing from those of the wire 12 to permit separation of the sheath material from the resultant filaments when desired. As illustrated in FIGURE 2, the original internal diameter of the sheath may be slightly larger than the external diameter of the wire 12 to permit facilitated insertion of the wire into the sheath. The thusly, loosely sheathed wires may then be installed in a can, or housing, 16 having a bottom closure wall, or nose plug, 17, with the sheathed wires extending in parallel side-by-side upright relationship, as shown in FIGURE 3.

For improved uniformity of the wires in the subsequent constriciting steps, it is desirable to closely pack the sheathed wires within the housing 16 as by suitably compacting the assembly. Referring to FIGURE 4, one method of effecting the desired compaction is by placing the assembly in a press generally designed 18 having a liner 19a defining a cylindrical cavity closely fitting the cylindrical housing 16. The lower end of the cavity is closed by a blind die 19b and the liner 18a and blind die 19b are supported on a suitable anvil 18c. A ram 19d is provided to apply pressure on the top of the assembly whereby the assembly is axially shortened and thereby laterally or radially compacted. Such compacting apparatus are well known in the art and need no further description herein.

Turning now to FIGURE 5, an alternate method of effecting the desired compaction of the assembly is shown to comprise the compaction of the assembly by means of an extrusion apparatus generally designated 118. In apparatus 118 an extrusion die 118a is provided through which the assembly is longitudinally forced by means of a suitable pressure applied element 118b. Only a small amount of constriction of the assembly is effected by die 118a so that only an elimination of the voids in the assembly is effected in this step.

Referring now to FIGURE 6, a method of facilitating the compaction of the assembly is illustrated. More specifically, the internal configuration of the housing 16 is made to be hexagonal in transverse cross section by means of a plurality of spacers 19 comprising chordal sector pieces.

FIGURE 7 illustrates a further method of facilitating the compaction of the assembly. More specifically, in FIGURE 7 the sheathed wires 12 are shown installed within the housing 16 with a plurality of spacers, or suitably particulate materials such as metal powder, 21 disposed between the wires. Thus, with the arrangements illustrated in FIGURES 6 and 7, less compaction of the assembly by the steps illustrated in FIGURES 4 and 5 is required to provide the desired compacted billet.

Prior to the compaction steps discussed above, the sheathed wires 12 are sealingly enclosed within the housing 16 by means of an end plug 23 installed across the open end 24 of the housing 16. As illustrated in FIGURE 8, the end plug 23 is constructed in a generally cylindrical disk having a notched portion 23a adapted to engage the upper end of the housing in the housing closing arrangement. The end plug 23 is further provided with an evacuation pipe 26 which opens through a central hole 23b in the end plug 23. The evacuation pipe 26 is required to the end plug by suitable means such as weld 26a.

With the sheathed wires 12 installed in the housing 16, as shown in FIGURE 10, the end plug 23 is secured across the open upper end 24 of the housing by suitable means such as weld 23c. The evacuation pipe 26 is utilized during the welding of the end plug 23 to the housing end 24 to flush the interior of the housing during the welding of the plug. Upon completion of the installation of the end plug on the housing, a vacuum is applied to the pipe 26 by suitable means (not shown) to withdraw substantially all gas from the interior of the housing.

As shown in FIGURE 10, when the desired vacuum condition is obtained within the housing 16 the pipe 26 is pinch and welded closed as at 26b to complete the sealing of the wires 12 within the housing 16. To provide an improved vacuum within the housing, the housing may be disposed within a suitable conventional heater 27.

The resultant housed bundle comprises a billet 31 which is next subjected to a hot forming process to reduce the diameter thereof in one or more passes. As illustrated in FIGURE 11, the billet 31 may be reduced in diameter by a hot extrusion step wherein the billet is forced through heated extrusion dies 32 by a suit
able pressure device 33. It is desirable that the billet 31 be preheated to a preselected suitable temperature and suitably lubricated for facilitated extrusion in this step. The extrusion materials of the billet are selected to provide optimum diametric reduction of the billet in conformity with the nature of the materials involved. In the event that a second extrusion step is employed, the opposite ends 34 of the reduced diameter billet 35 are trimmed (see FIGURE 12) as by suitable cutters 36. Any nonuniform extruded end portion of the billet determined by observation thereof may be included in the ends 34 so cut from the billet. The trimmed billet 35 is then divided into a plurality of short lengths 37, as shown in FIGURE 13, by suitable means such as cutting wheels 38. Each of the short length billets 37 is then provided with a nose plug 39 and a tail plug 40 as by welding as illustrated in FIGURE 14. The short length billet 37 is then reheated and passed through heated extrusion dies 41 (see FIGURE 15) for further diametric construction thereof to a final formed billet 42.

As indicated briefly above, the hot forming of the billet 31 may be effected by hot rolling the billet in lieu of the extrusion thereof. Thus, as shown in FIGURE 16, the billet 31 may be suitably heated and passed between suitable rolls 43. The hot forming by the extrusion step illustrated in FIGURE 11 and subsequent hot forming effected by hot rolling as desired. The rolls 43 are preferably arranged to produce a hot forming construction of the billet wherein the elements therein are maintained in a substantially circular cross-sectional configuration.

Subsequent to the hot forming steps discussed above, as shown in FIGURE 17, the resultant final formed billet 42 is drawn through a suitable conventional drawing die 44 by a subsequent conventional drawing device 45. The billet may be successively drawn down to smaller and smaller diameters by means of successively smaller dies 44 to produce the final desired small diameter filaments. Annealing may be effected between the successive drawing steps in conformity with the requirements of the metal of which the filaments are formed. The cold drawing of the billet may be conducted suitably to develop texture in the filaments and to work-harden the filaments for providing improved mechanical properties thereof.

Where the hot rolling steps are employed, the final cold drawing of the billet may be conducted with, such as where the physical characteristics provided by the cold drawing are not required. Thus, the hot rolling steps may be continued with successively smaller rolls 43 providing the desired ultimate constrictive deforming of the billet whereby the billet may be cold drawn to the desired diameter of approximately 12 microns or less.

The filaments are released from the final constricted billet 46 by suitable means such as selective chemical attack of the sheathing 15 and can 16. Thus, as shown in FIGURE 18, the final billet 46 may be disposed within a tank 47 holding a suitable acid 48 to dissolve the sheathing and can material. Obviously, other methods of removal of the can and sheathing material may be employed; illustratively, the sheathing and can material may be removed by electrolysis, dissolution, selective oxidation, mechanical removal, etc. In the final tow 10 of filaments 11, as illustrated in FIGURE 19, the filaments have an extremely small diameter, for example, down to approximately .0005 inch or 12 microns or less. Where the filaments are formed by utilizing the hot extrusion process, the tow filaments may have a length of up to 50,000 feet or more, and where the tow filaments are formed by the hot rolling process, the length may be up to 500,000 feet or more.

More specifically, the wire 12 of which the filament is made may comprise a metal wire formed of a suitable material, one example being stainless steel. The sheathing may comprise copper or monel metal. Alternatively, the sheathing may comprise an oxide coating deposit on the wire 12. One example of material of which can 16 may be formed is mild steel. Thus, in the final step, the mild steel can and the copper, or monel, sheathing material may be removed from the stainless steel filaments by use of a nitric acid fluid 48.

One example of the formation of stainless steel filaments comprehended by the invention is as follows. The wires 12 may comprise 304 stainless steel wires .250 inch in diameter and 18 inches long. The sheath 15 may comprise a Monel 400 tube having a .293 inch outside diameter, a .253 inch inside diameter, and a length of 18 inches. The can 16 may be formed of mild steel having a 5.95 inch outside diameter, a 5.25 inch inside diameter, and an overall length of 22 inches. The nose plug 23 may comprise a 45 degree angle plug. Two hundred sixty-eight (268) of the sheathed wires may be placed in the can 16, and the can evacuated to less than .1 torr of mercury at 800°F. and sealed off. The billet may then be heat treated at 1800°F. for six hours in a graphite container. The extrusion dies 32 may be preheated to 900°F. and have an internal diameter of 2.925 inches, whereby an extrusion ratio of 4.3× can be achieved. The billet 31 may be suitably lubricated, and the ram 33 operated at a speed of approximately 500 inches per minute under a pressure 1540 tons upset, 1200 tons running.

The extrusion 35 may be water quenched immediately after extrusion, and cut into 10 inch lengths. A new 45 degree angle nose plug and a .5 inch end plug may be welded to the opposite ends of the short length billet 37 for a second extrusion operation. The extrusion die may be preheated to 900°F., and have an internal diameter of .625 inch providing an extrusion ratio of 22.8× in area. The billet 37 may be preheated at a temperature of 1800°F. for three hours in a graphite container. The rolling speed may be 145 inches per minute at a pressure 590 tons upset, 560 tons running. The extruded billets 42 may be water quenched immediately after this second extrusion.

The billet 42 may then be cold drawn in four passes to a total reduction of approximately 60%, each pass providing a reduction of approximately 20% of the cross-sectional area. Between the 60% reductions the drawn billet may be annealed at a temperature of approximately 1700°F. for two seconds per .001 inch of wire diameter. The final diameter may be approximately 0.015 inch producing filaments approximately 0.0007 inch in diameter.

The can 16 and sheath 15 material may be removed by means of nitric acid in tank 47.

The resultant filaments formed as above have an average ultimate tensile strength, cold worked, of approximately 250,000 p.s.i. with an average elongation, cold worked, of approximately 2.1%. The filaments have an average ultimate tensile strength annealed of approximately 109,000 p.s.i. with the average elongation annealed being approximately 11%.

Another example of the forming of fine filaments by the present invention comprises the following. The wires 12 may comprise 304 stainless steel wires .080 inch in diameter and 18 inches long and the sheath 15 may comprise a Monel 400 tube having a .097 inch outside diameter, a .085 inch inside diameter, and a length of 20 feet. The can 16 may be formed of mild steel having a 1.970 inch outside diameter, a 1.740 inch inside diameter, and an overall length of 6 inches. The nose plug 23 may comprise a 45 degree angle plug. Lengths of the stainless steel wire may be sheathed with the Monel tube and drawing through a .091 inch diameter die to facilitate mating. After straightening the sheathed wire may be cut into 3 inch lengths for packing in the can. Two hundred forty-two (242) of the sheathed wires may be placed in the can 16, and the can evacuated to less than .1 torr of mercury at 800°F. and sealed off. The billet may then be heat treated at 1800°F. for two hours in a graphite container. The extrusion dies 32 may be preheated to 900°F. and
have an internal diameter of .500 inch, whereby an extrusion ratio of 16X in area is obtained. The billet 31 may be suitably lubricated, and the ram 33 operated at a speed of approximately 65 inches per minute under a pressure of 272 tons upset, 260 tons running.

The extruded billet 31 may then be cold drawn in successive passes to a final diameter of .008 inch. Between steps of 60% reduction in area the drawn billet may be annealed at a temperature of approximately 1700° F. for two seconds per .001 inch of wire diameter.

The can 16 and sheath 15 material may be removed by means of nitric acid in tank 47. The final diameter of the filaments 11 as formed above is approximately .00034 inch.

As indicated briefly above, the present invention comprehends the forming of tubular filaments by the process described above for forming fine solid wire filaments. As illustrated in FIGURES 20 through 24, in forming tubular filaments, the starting elongated element comprises the metal tube 14 which may be firstly filled with a solid wire 49 and then enclosed in a suitable sheath 50. Each of the wire 49 and the sheath 50 are formed of a material having physical characteristics differing from those of the tubes 14 to permit separation of the wire 49 and sheath 50 material when desired. Illustratively, the tube 14 may be formed of 304 stainless steel, the wire 49 may be formed of copper, and the sheath 50 may be formed of Monel 400 metal. As shown in FIGURE 22, the tube, wire and sheath assembly may be firstly drawn to contract the tube onto the wire 49 and the sheath onto the tube 14 in intimate contact. Illustratively, the resultant composite 51 may have an outside diameter of .100 inch with the tube having an outside diameter of .085 inch, and the wire having an outside diameter of .045 inch.

The composites 51 may be cut to three inch lengths, and sixty-one such lengths may be retained in a mild steel can 52 having an outside diameter of 1.063 inches and an inside diameter of .920 inch, whereby the extrusion ratio may be approximately 16X in area. The billet temperature may be 1800° F. and the extrusion pressures may be 70 tons upset and 65 tons running.

The resultant tubular filaments 13 may then be released after cutting the composite drawn billet into suitable lengths in the manner illustrated in FIGURE 18. The resultant tubular filaments 13 are uniform in cross-sectional dimension within 5% standard deviation from the mean and have an average transverse dimension (i.e., between vertices) of .015 inch.

Thus, the present invention comprehends an improved method of forming both solid and tubular filaments permitting facilitated and economical manufacture, while yet the filaments produced thereby have uniform cross-section and extremely long lengths.

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. The method of forming a plurality of filaments, comprising the steps of:
   providing in a housing a bundle of substantially parallel sheathed elongated drawable elements from which the filaments are to be formed, the housing and sheath material differing from that of the elements to permit separation of the sheath material from the elements when desired; evacuating said housing;
   hot forming the evacuated, housed bundle as by hot rolling or hot extruding the bundle to reduce the cross-section thereof;
   cold drawing the formed bundle to further reduce the cross-section of the elements therein to a preselected filament cross-section; and
   removing the housing and sheathing material.

2. The method of claim 1 wherein said elements are formed of metal.

3. The method of claim 1 wherein said elements are formed of stainless steel.

4. The method of claim 1 wherein said sheathing material is preselected to have flow characteristics suitable for the volume ratio of said element material to said sheathing material to produce a continuous filament.

5. The method of claim 1 including the step of placing spacers between the sheathed elements in the bundle to substantially fill the spaces therebetween.

6. The method of claim 1 wherein said housing includes means defining a polygonal internal cross-section therein.

7. The method of claim 1 wherein said housing includes means defining a hexagonal internal cross-section therein.

8. The method of claim 1 including the step of causing the bundle to be hot during the evacuating step.

9. The method of claim 1 including the step of constricting the bundle to define a tight packed bundle prior to the hot forming thereof.

10. The method of claim 1 including the steps of transversely dividing the hot formed bundle to define a plurality of billets and hot forming said billets and said cold drawing step comprises drawing of said hot formed billets.

11. The method of claim 1 wherein said elongated elements comprise tubular elements, and including the step of inserting an axial filler into each said element prior to the hot forming thereof, the filler material differing from that of the elements to permit separation of the fillers from the elements when desired, and said removing step including the removing of said filler material.

12. The method of claim 1 wherein the cross section of said filaments is less than .0005 inch.

13. The method of claim 1 wherein the length of said filaments is at least approximately 50,000 feet.

14. The method of claim 1 wherein said filaments have a hexagonal cross-section, the maximum cross-sectional dimension thereof being no greater than approximately .015 inch.

15. The method of claim 1 wherein said hot forming comprises hot rolling.

16. The method of claim 1 wherein the method of claim 11 is followed by sheathing the elements with monel.

17. The method of claim 1 wherein said elements are formed of stainless steel and said sheathing is formed of Monel metal.

18. The method of claim 1 wherein said housing is formed of mild steel.

19. The method of claim 1 wherein the sheathing material is monel.

20. The method of forming a plurality of filaments, comprising the steps of:
   providing a bundle of substantially parallel sheathed elongated drawable elements from which the filaments are to be formed, the sheath material differing from that of the elements to permit separation of the sheath material from the elements when desired; hot forming the bundle as by hot rolling or hot extruding the bundle to reduce the cross-section thereof;
   cold drawing the formed bundle to further reduce the cross-section of the elements therein to a preselected filament cross-section; and
   removing the sheathing material.

21. The method of forming a plurality of filaments, comprising the steps of:
   providing in a housing a bundle of substantially parallel sheathed elongated drawable elements from which the filaments are to be formed, the housing and sheath material differing from that of the elements to
permit separation of the housing and sheath material from the elements when desired; hot forming the bundle as by hot rolling or hot extruding the bundle to reduce the cross-section thereof; cold drawing the formed bundle to further reduce the cross-section of the elements therein to a preselected filament cross-section; and removing the housing and sheathing material.