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(54) **CABLE JACKET DESIGNS FOR HIGH DENSITY OPTICAL FIBER CABLES**

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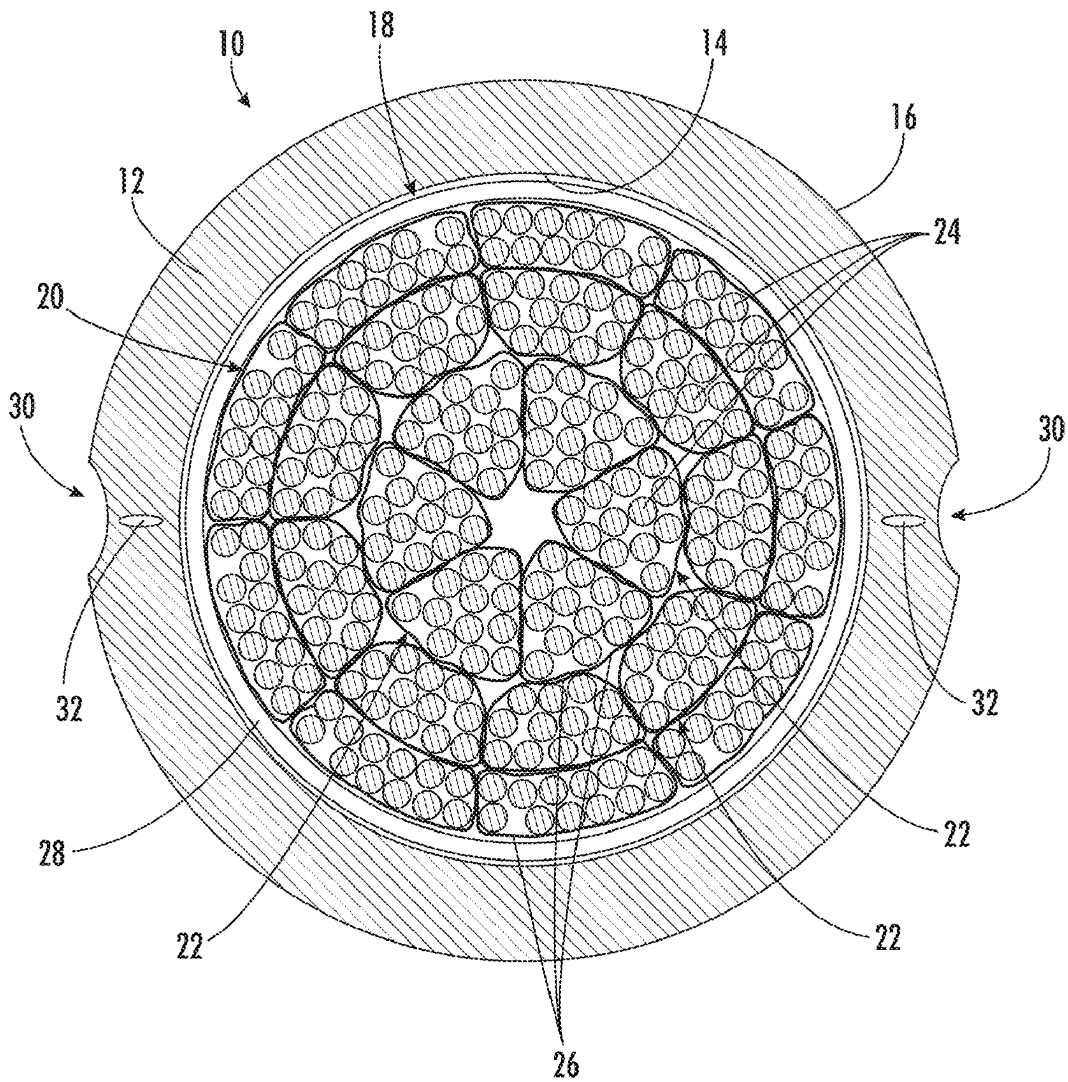
(57) **ABSTRACT**

Embodiments of the disclosure relate to an optical fiber cable. The optical fiber cable includes a cable jacket having an inner surface and an outer surface. The inner surface defines a central bore, and the outer surface defines an outermost surface of the optical fiber cable. The optical fiber cable also includes a cable core disposed in the central bore, and the cable core includes a plurality of optical fibers. The optical fiber cable has a cross-sectional area as defined by the outer surface of the cable jacket. The plurality of optical fibers divided by the cross-sectional area defines a fiber density of at least 7.5 fibers/mm^2. The cable jacket has a first layer, and the first layer is made of an engineering thermoplastic having an elastic modulus of at least 800 MPa.



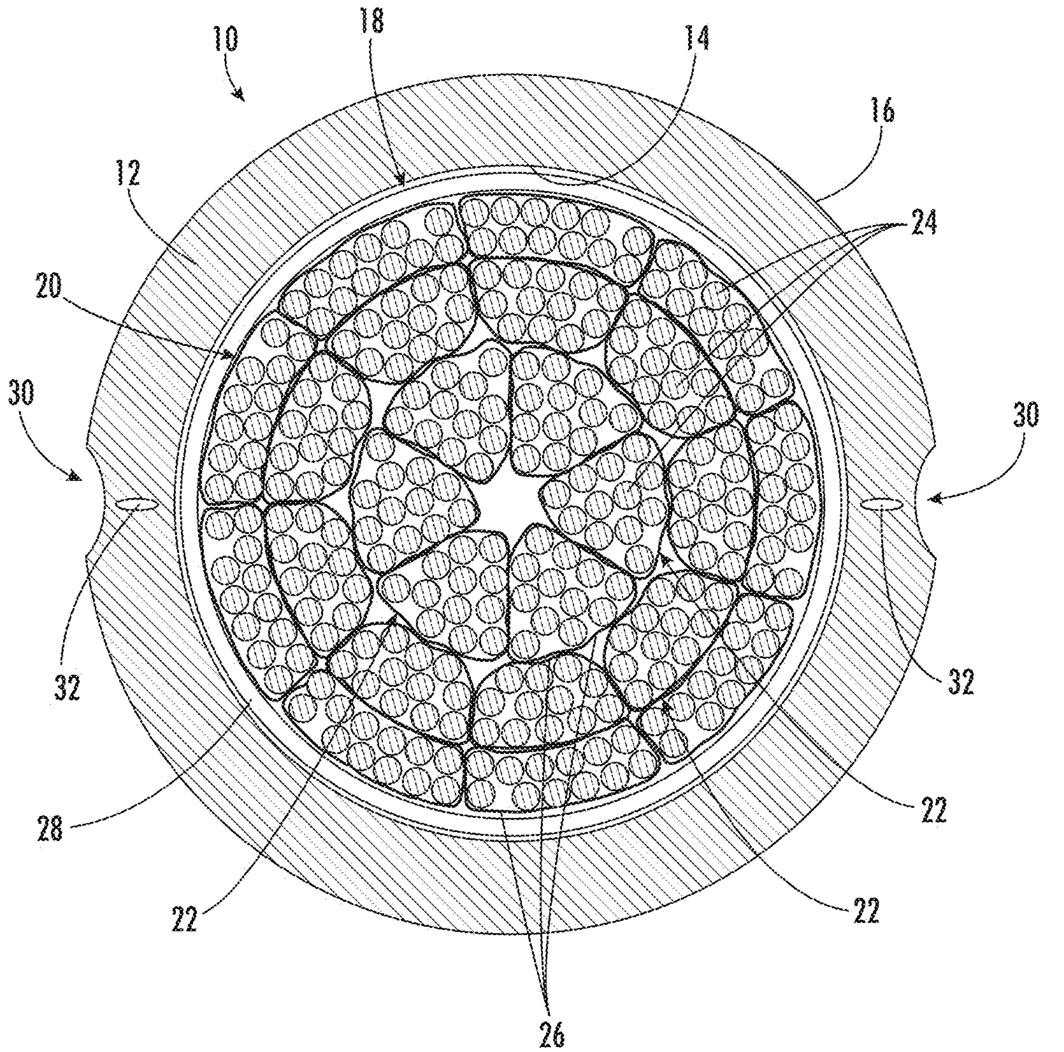


FIG. 1

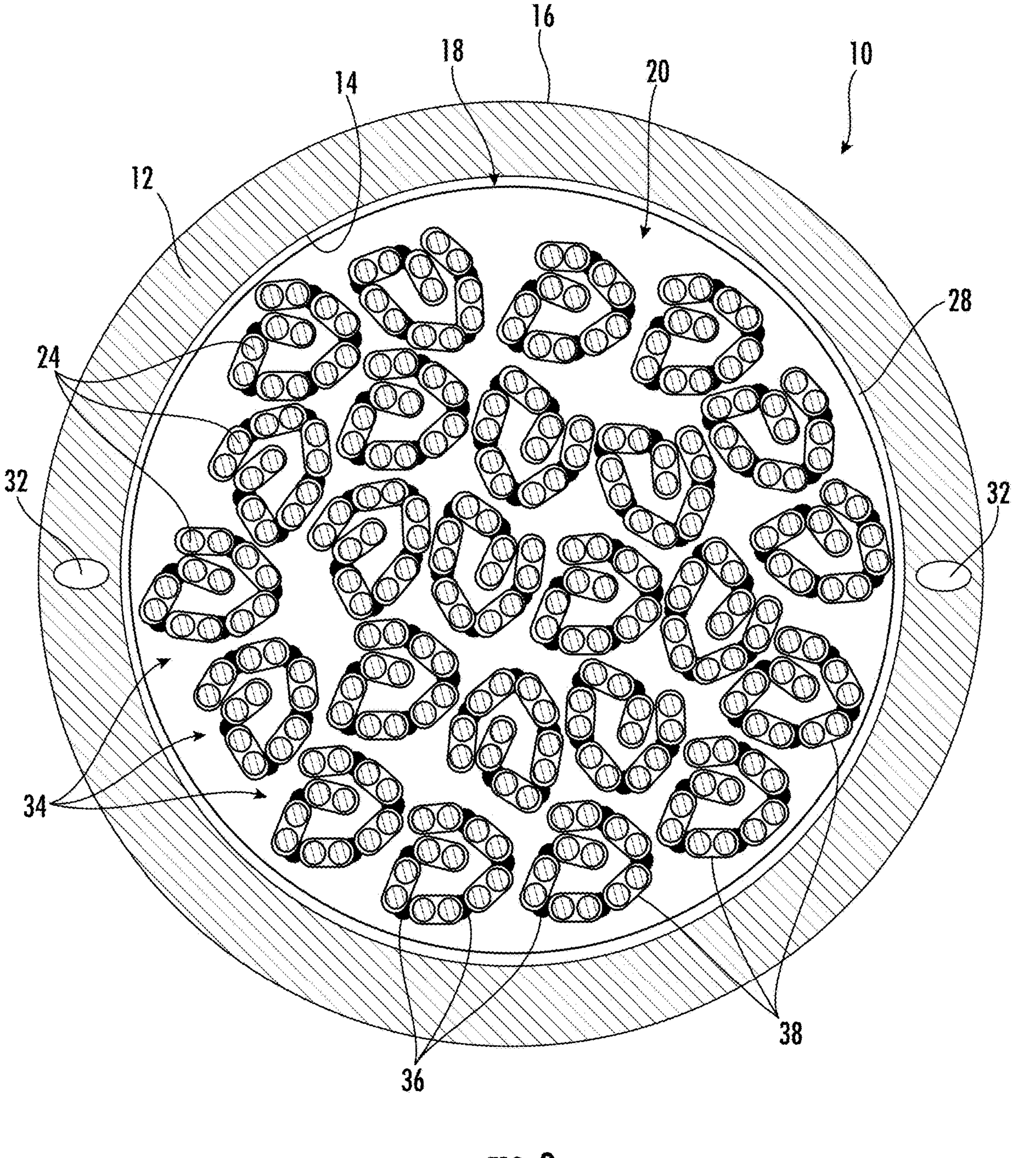


FIG. 2

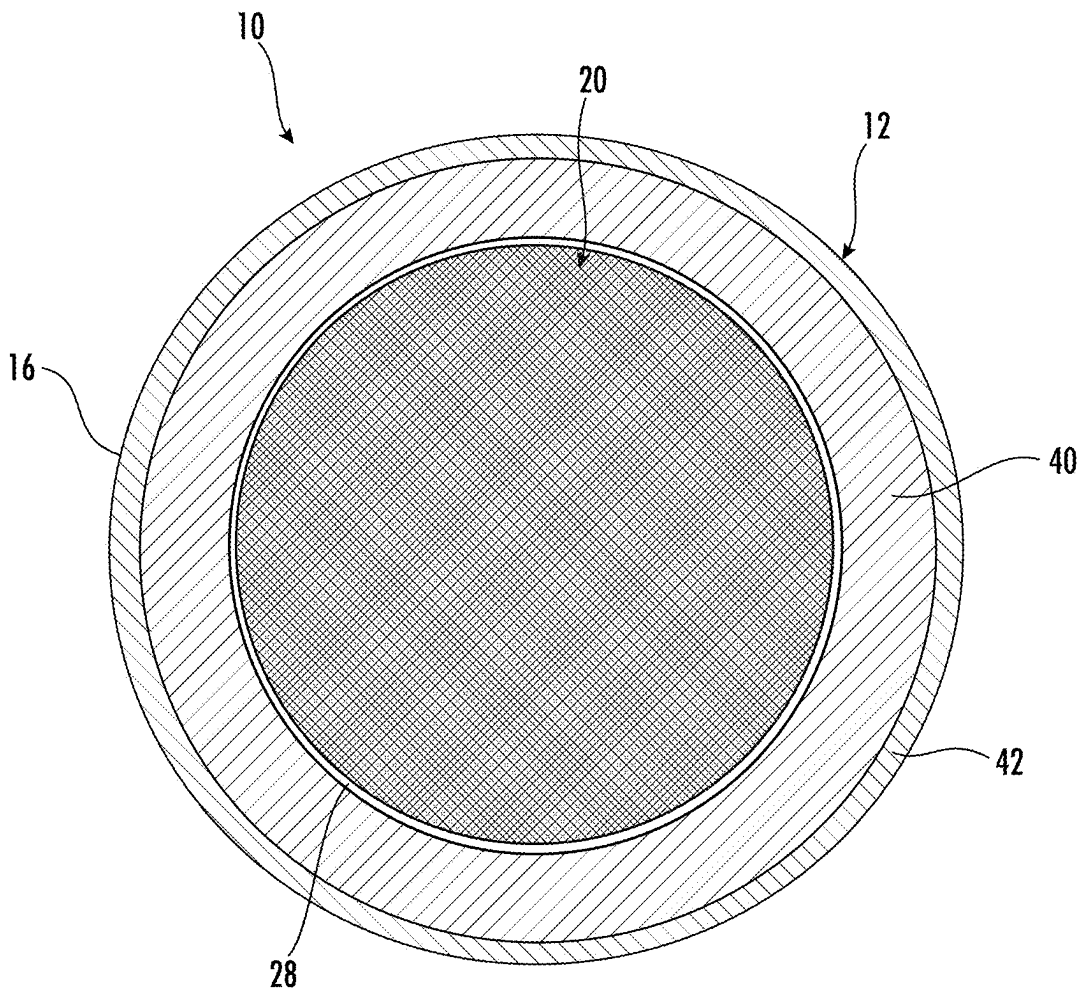


FIG. 3

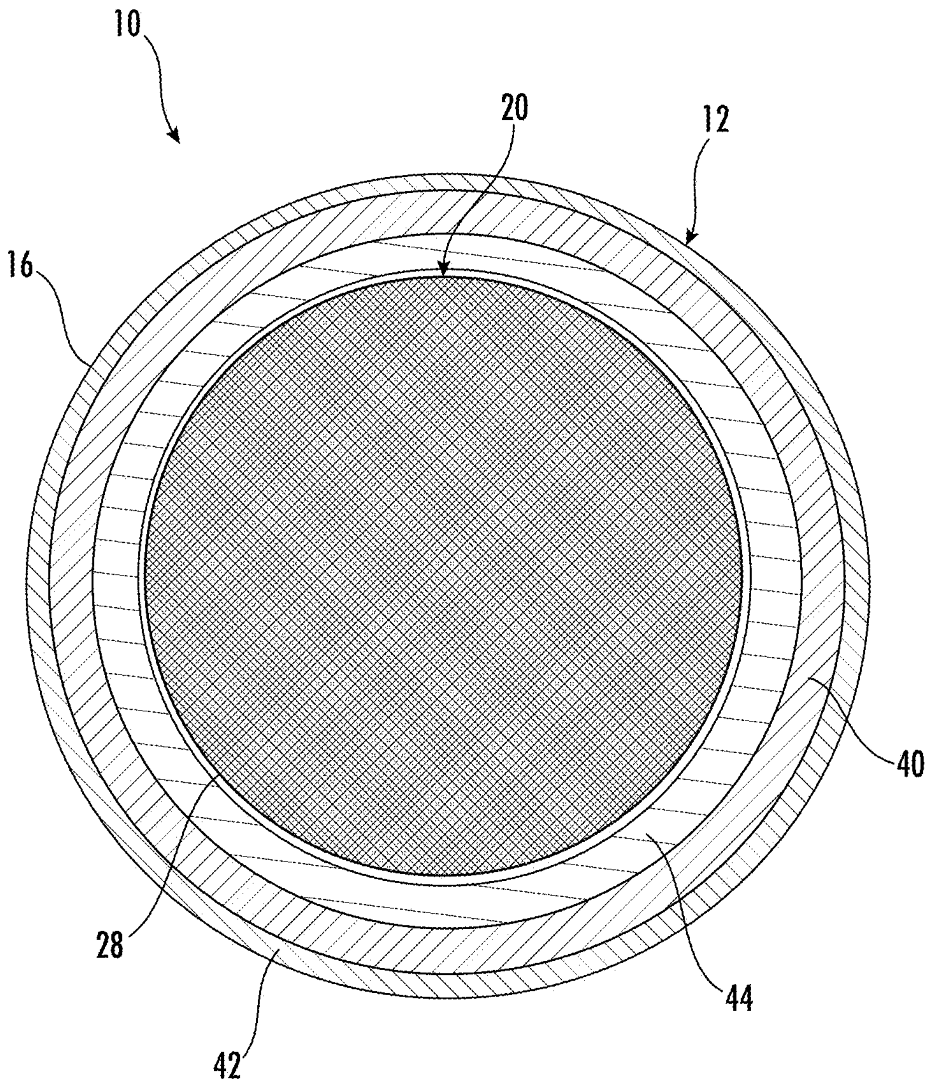


FIG. 4

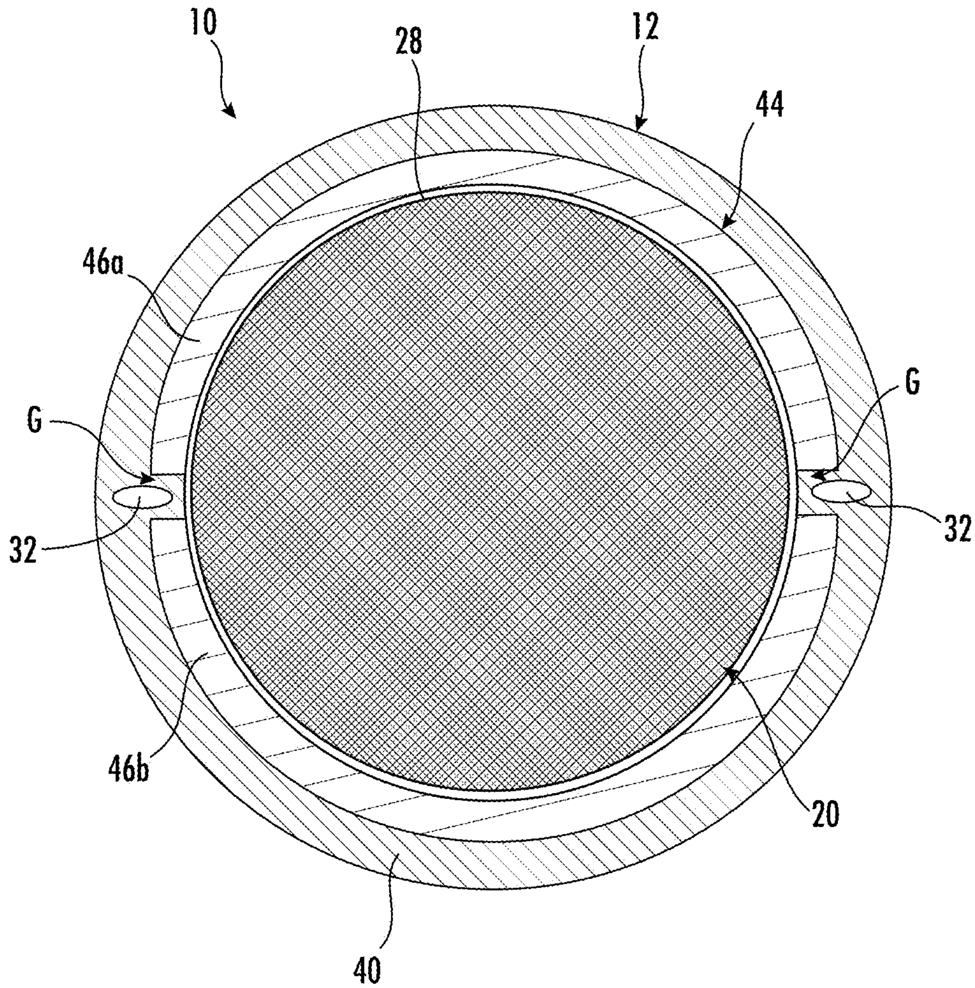


FIG. 5

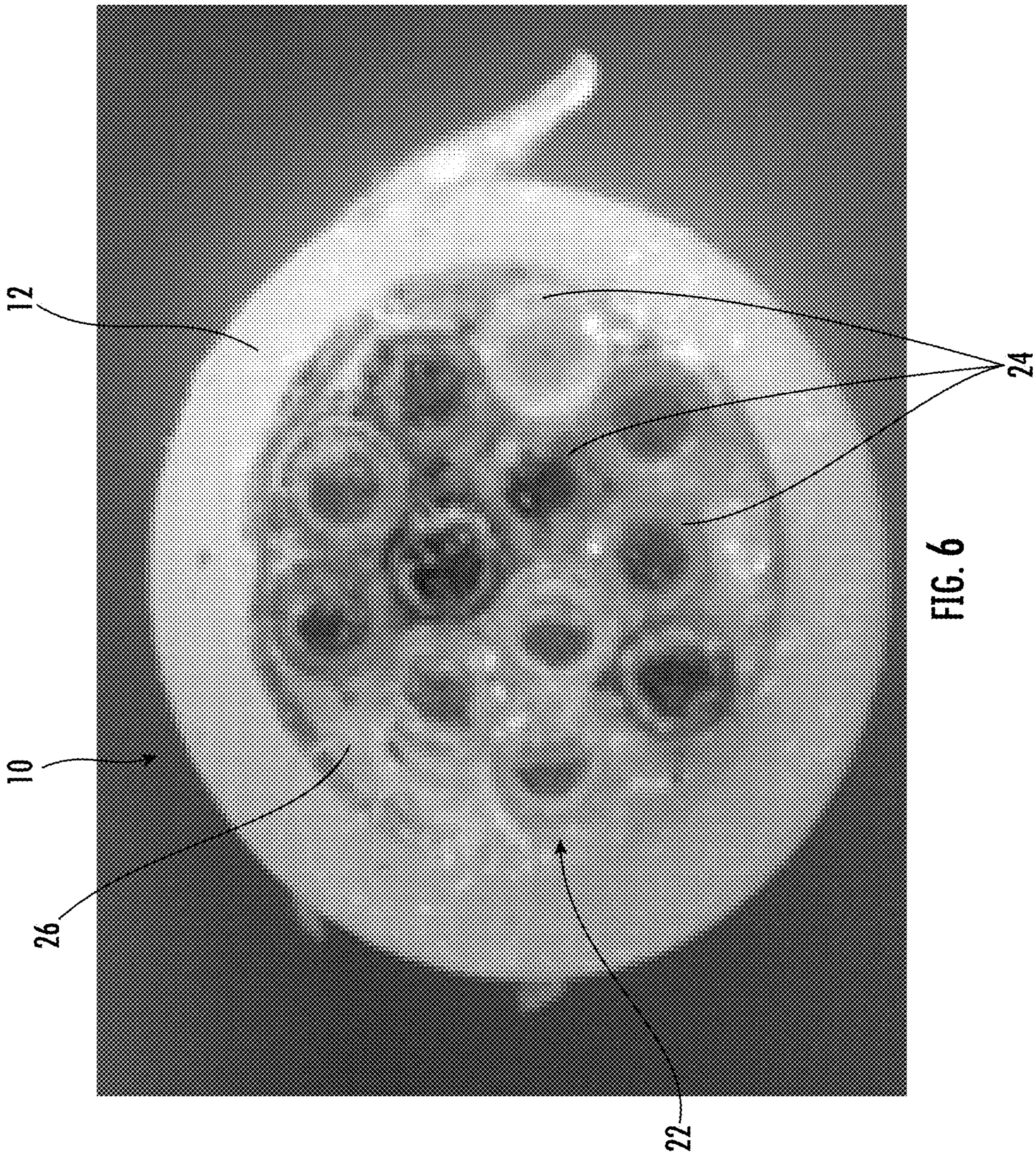


FIG. 6

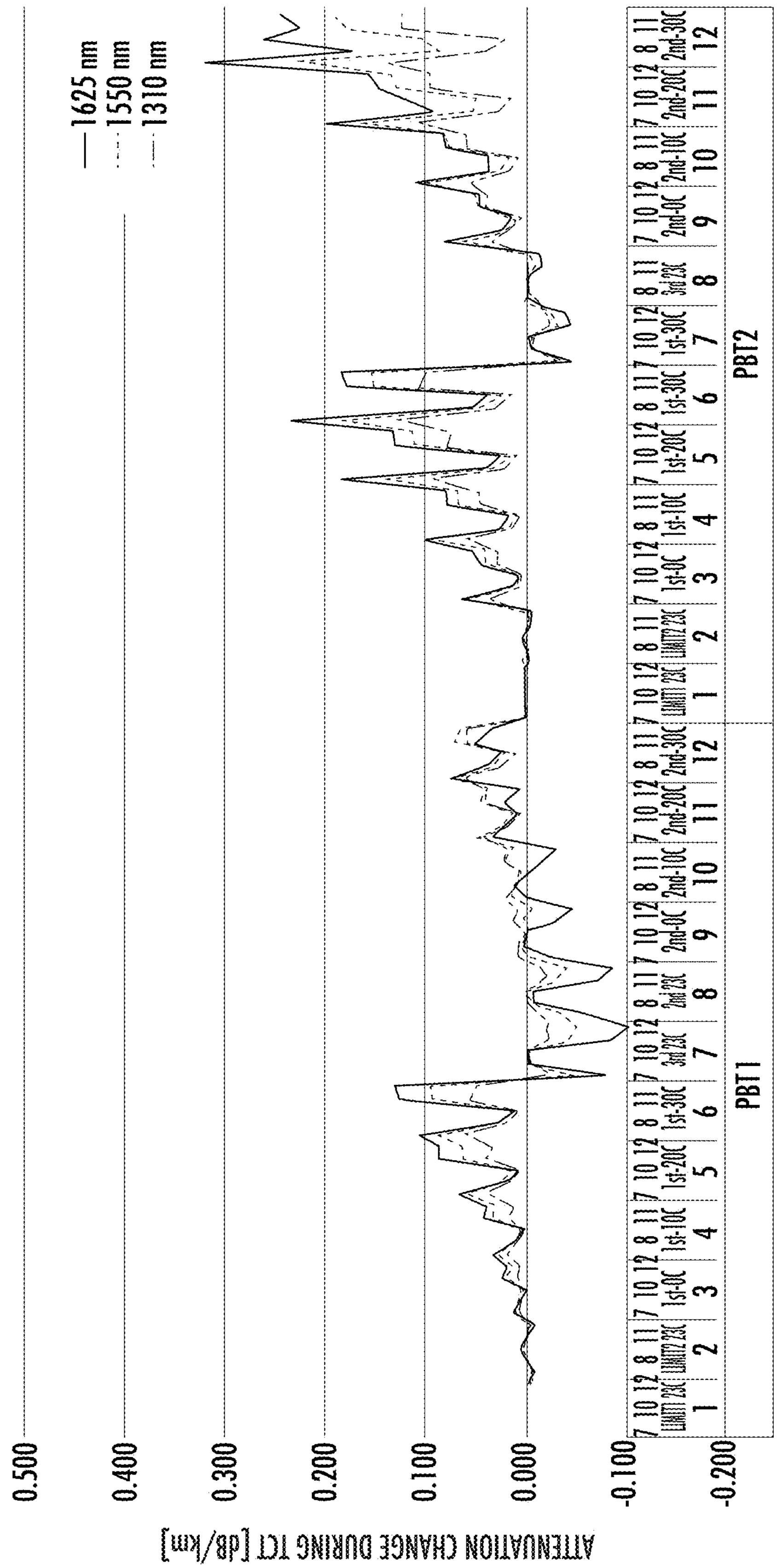

1625 nm
1550 nm
1310 nm
ATTENUATION CHANGE DURING TCT [dB/km]
0.500
0.400
0.300
0.200
0.100
0.000
-0.100
-0.200
PBT1
PBT2

FIG. 7

CABLE JACKET DESIGNS FOR HIGH DENSITY OPTICAL FIBER CABLES

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is a continuation of International Patent Application No. PCT/US2023/079750, filed Nov. 15, 2023, which claims the benefit of priority of U.S. Provisional Application No. 63/426,107 filed on Nov. 17, 2022, the content of which is relied upon and incorporated herein by reference in its entirety.

BACKGROUND

[0002] The disclosure relates generally to optical fiber cables and, in particular, to cable jacket designs for optical fiber cables having a high density of optical fibers.

[0003] In general, an optical fiber cable needs to carry more optical fibers in order to transmit more optical data, and in order to carry more optical fibers, the size of the optical fiber cable conventionally needed to be increased. The increased size is at least partially the result of free space considerations to avoid macro- and micro-bending attenuation losses. For existing installations, size limitations and duct congestion limit the size of optical fiber cables that can be used without the requirement for significant retrofitting. Thus, it may be desirable to provide optical fiber cables having a higher fiber density (i.e., more fibers per cross-sectional area of the cable) without increasing the cable diameter such that the high fiber density cables can be used in existing ducts.

SUMMARY

[0004] According to an aspect, embodiments of the disclosure relate to an optical fiber cable. The optical fiber cable includes a cable jacket having an inner surface and an outer surface. The inner surface defines a central bore, and the outer surface defines an outermost surface of the optical fiber cable. The optical fiber cable also includes a cable core disposed in the central bore, and the cable core includes a plurality of optical fibers. The optical fiber cable has a cross-sectional area as defined by the outer surface of the cable jacket. The plurality of optical fibers divided by the cross-sectional area defines a fiber density of at least 7.5 fibers/mm^2. The cable jacket has a first layer, and the first layer is made of an engineering thermoplastic having an elastic modulus of at least 800 MPa.

[0005] According to another aspect, embodiments of the disclosure relate to a high fiber density optical fiber cable. The optical fiber cable includes a cable jacket having an inner surface and an outer surface. The inner surface defines a central bore, and the outer surface defines an outermost surface of the optical fiber cable. A cable core is disposed in the central bore, and the cable core includes a plurality of optical fibers. The optical fiber cable has a cumulative fiber filling coefficient of at least 50%. The cable jacket has at least two layers, and the at least two layers are selected from a group consisting of a skin layer, an engineering thermoplastic layer, and a thermoplastic elastomer layer.

[0006] Additional features and advantages will be set forth in the detailed description that follows, and, in part, will be readily apparent to those skilled in the art from the description or recognized by practicing the embodiments as described in the written description and claims hereof, as well as the appended drawings.

[0007] It is to be understood that both the foregoing general description and the following detailed description are merely exemplary, and are intended to provide an overview or framework to understand the nature and character of the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] The accompanying drawings are included to provide a further understanding and are incorporated in and constitute a part of this specification. The drawings illustrate one or more embodiment(s), and together with the description serve to explain principles and the operation of the various embodiments. In the drawings:

[0009] FIG. **1** depicts a cross-sectional view of an optical fiber cable having optical fibers arranged in a plurality of lumens, according to an exemplary embodiment;

[0010] FIG. **2** depicts a cross-sectional view of an optical fiber cable having optical fibers arranged in a plurality of intermittently bonded ribbons, according to an exemplary embodiment;

[0011] FIG. **3** depicts a cross-sectional view of an optical fiber cable having a cable jacket made of an engineering thermoplastic, according to an exemplary embodiment;

[0012] FIG. **4** depicts a cross-sectional view of an optical fiber cable having a cable jacket with two layers, an engineering thermoplastic layer and a thermoplastic elastomer layer, according to an exemplary embodiment;

[0013] FIG. **5** depicts a cross-sectional view of an optical fiber cable having a cable jacket with a discontinuous inner layer, according to an exemplary embodiment;

[0014] FIG. **6** depicts a cross-sectional view of an optical fiber cable specimen prepared for thermal cycling testing, according to an exemplary embodiment; and

[0015] FIG. **7** depicts the results of the thermal cycling test, according to exemplary embodiments.

DETAILED DESCRIPTION

[0016] Referring generally to the figures, various embodiments of cable jacket designs for a high fiber density optical fiber cable are provided. As will be discussed more fully below, embodiments of the cable jacket designs include at least one layer of an engineering thermoplastic configured to increase the bending stiffness of the optical fiber cable and improve the anti-buckling performance at low temperatures. In one or more embodiments discussed below, the cable jacket also includes a thermoplastic elastomer layer that can be foamed or unfoamed. The thermoplastic elastomer helps, in particular, with improving the anti-buckling performance of the optical fiber cable at low temperatures. In one or more embodiments discussed below, the cable jacket also includes a skin layer configured to provide environmental protection of the optical fiber cable or reduce friction for blowing or jetting operations. The exemplary embodiments of such cable jacket designs for a high fiber density optical fiber cable will be described in greater detail below and in relation to the figures provided herewith, and these exemplary embodiments are provided by way of illustration, and not by way of limitation.

[0017] FIG. **1** depicts an example embodiment of a high fiber density optical fiber cable **10**. The optical fiber cable **10** includes a cable jacket **12** having an inner surface **14** and an outer surface **16**. The inner surface **14** of the optical fiber cable **10** defines a central bore **18** that extends along a longitudinal axis of the optical fiber cable **10**. Disposed within the central bore **18** of the optical fiber cable **10** is high fiber density cable core **20**. In the embodiment shown in FIG. **1**, the high fiber density cable core **20** includes a plurality of subunits referred to herein as "lumens" **22**. The lumens **22** each include a plurality of optical fibers **24** surrounded by a membrane **26**. The membrane **26** is a thin and flexible sheath that allows for the lumen **22** to be reconfigured into a variety of different shapes. In this way, the lumens **22** can be densely packed within the cable core **20** by changing shape, e.g., flattening out, bunching up, or bending, as necessary to fill space within the cable core **20**.

[0018] In one or more embodiments, the interior surface of the membrane **26** defines an interior cross-sectional area of the lumen **22**. The portion of this interior cross-sectional area that is not occupied by the optical fibers **24** is referred to as "free space." In one or more embodiments, each lumen **22** comprises a free space of 50% or less, 40% or less, 30% or less, or 25% or less. In one or more embodiments, each lumen **22** comprises a free space of 20% or more. Not only does the low free space within the lumens **22** provide a high fiber density for the optical fiber cable **10**, but also, the low free space mechanically couples the optical fibers **24** together such that the optical fibers **24** may act as a composite strength element within the optical fiber cable **10**. In this way, and in accordance with aspects of the present disclosure, the cable core **20** may be configured to not include any additional strength elements, such as glass reinforced plastic rods, steel wires, or tensile strands (e.g., aramid or glass yarns).

[0019] In one or more embodiments, the thickness of the membrane **26** is 50 μm or less, 45 μm or less, 40 μm or less, 35 μm or less, 30 μm or less, 25 μm or less, 20 μm or less, 17 μm or less, or 15 μm or less. In one or more embodiments, the thickness of the membrane **26** is 5 μm or more, 6 μm or more, 7 μm or more, 8 μm or more, 9 μm or more, or 10 μm or more. In one or more embodiments, the thickness of the membrane **26** is from 5 μm to 50 μm, in particular from 7 μm to 30 μm, and most particularly from 10 μm to 20 μm.

[0020] In one or more embodiments, the membrane **26** groups from two to ninety-six in particular from eight to thirty-six, and particularly from twelve to twenty-four, optical fibers **24** into a lumen **22**. In one or more embodiments, the membrane **26** is formed from a polymer material, such as a polyethylene, a polypropylene, a polyester (e.g., polyethylene terephthalate or polybutylene terephthalate), a polystyrene, a polycarbonate, a polyamide, a polytetrafluoroethylene, or copolymers or blends thereof. In one or more embodiments, the membrane **26** includes a filler material dispersed in the polymer material to enhance the ability of the membrane **26** to be torn by an operator's fingers (i.e., without requiring any specialized tools) in a manner that does not damage the optical fibers **24** contained therein.

[0021] In one or more embodiments, the lumens **22** may be stranded (such as SZ-stranded) in the cable core **20**. The stranding provides the ability to bend the cable while minimizing tensile and contractive forces within any of the fibers. During cable bending, the optical fibers **24** must be able to shift position, moving longitudinally to relieve those forces so as not to cause attenuation or break the optical fibers **24**. Because the membranes **26** and cable core **20** do not provide free space for the optical fibers **24** to increase fiber density by design, the lumens **22** may be configured to move relative to each other in certain embodiments by using solid or gel lubricants, such as talc, or using water-absorbing powders.

[0022] In one or more embodiments, the high fiber density cable core **20** is surrounded by a binder **28**. In one or more embodiments, the binder **28** is a thin film jacket having a thickness between 40 microns and 150 microns. In such embodiments, the binder **28** having a thickness in this thickness range reduces the thermal load of the binder **28** on the lumens **22** during extrusion. That is, a thick binder could hold enough heat after extrusion to degrade the thin membranes **26** of the lumens **22**. In one or more embodiments, the binder **28** is made from, e.g., linear low-density polyethylene (LLDPE). In one or more other embodiments, the binder **28** is a wrap or tape that is wound around the cable core **20**.

[0023] In one or more embodiments, the cable jacket **12** has a thickness of between 0.5 mm and 2 mm. In particular embodiments, the cable jacket **12** has a thickness that is from 8% to 10% of the outer diameter of the optical fiber cable **10**.

[0024] In one or more embodiments, the cable jacket **12** includes tactile locator features **30**. In the embodiment depicted, the tactile locator features **30** comprise diametrically arranged depressions defined by the outer surface **16** of the cable jacket **12**. However, in one or more other embodiments, the tactile locator features **30** comprise diametrically arranged bumps defined by the outer surface **16** of the cable jacket **12**. The tactile locator features **30** assist a user in opening the cable **10** by guiding the user to the location of access features **32**. In the embodiment of the optical fiber cable **10**, the access features **32** are strips of dissimilar polymer embedded in the polymer of the cable jacket **12**. For example, the cable jacket **12** may substantially comprise polyethylene, and the dissimilar polymer of the access feature **32** may be polypropylene. The immiscibility of polyethylene in the cable jacket **12** and the polypropylene of the access features **32** prevents a strong bond from forming between the cable jacket **12** and the access features **32**, allowing for a user to tear through the cable jacket **12** in the region of the access features **32**. Further, once opened at the access features **32**, the cable jacket **12** can be split along its length along the access features **32**.

[0025] In one or more embodiments, the optical fiber cable **10** may consist essentially of the cable jacket **12** surrounding a plurality of lumens **22**. Other components that do not affect the basic and novel characteristics of the optical fiber cable **10** that may be included are, for example, a binder **28** provided between the plurality of lumens **22** and the cable jacket **12**, water blocking material (e.g., tapes and powders), lubricants, friction-enhancing materials, and access features **32** (e.g., ripcords or preferential tear features, such as a strip of dissimilar polymer in the cable jacket **12**). In one or more embodiments, armor layers and strength elements are excluded from the construction of the optical fiber cable **10**.

[0026] FIG. **2** depicts another example embodiment of a high-density optical fiber cable **10**. The optical fiber cable **10** includes a cable jacket **12** having an inner surface **14** and an outer surface **16**. The inner surface **14** of the optical fiber cable **10** defines a central bore **18** that extends along a longitudinal axis of the optical fiber cable **10**. Disposed within the central bore **18** of the optical fiber cable **10** is high fiber density cable core **20**. In one or more embodiments, including the embodiment depicted in FIG. **2**, the high fiber density cable core **20** includes a plurality of intermittently bonded optical fiber ribbons **34**. In one or more embodiments, each optical fiber ribbon **34** includes from four to thirty-six optical fibers **24**, in particular eight to twenty-four optical fibers **24**, and particularly about twelve optical fibers **24**.

[0027] The optical fiber ribbons **34** include optical fibers **24** that are joined by intermittent bonds **36**. In one or more embodiments, the individual optical fibers **24** are intermittently bonded together. In one or more other embodiments, including the embodiment shown in FIG. **2**, the optical fibers **24** are arranged in subunits **38** of two or more optical fibers **24** that are joined by intermittent bonds **36**. The intermittent bonding between the optical fibers **24** or the subunits **38** of optical fibers **24** allows the optical fiber ribbon **34** to roll, fold, collapse, or otherwise transition from a planar configuration to a non-planar configuration. Advantageously, the non-planar configuration of the optical fiber ribbon **34** permits the optical fiber ribbons **34** to be more densely packed into the cable core **20**. In contrast, conventional optical fiber ribbons that are held rigidly in the planar configuration require a greater amount of free space within the cable core to accommodate the ribbon stack without creating stress on the edge fibers.

[0028] In one or more embodiments, the high fiber density cable core **20** is surrounded by a binder **28** as described above.

[0029] In one or more embodiments, the optical fiber cable **10** includes a cable jacket **12** having one or more tactile locator features **30** (not shown in FIG. **2**) as described above. Additionally, in one or more embodiments, the cable jacket **12** may include one or more access features **32**, such as strips of dissimilar polymer embedded in the polymer of the cable jacket **12**.

[0030] In one or more embodiments, the optical fiber cable **10** may consist essentially of the cable jacket **12** surrounding a plurality of intermittently bonded optical fiber ribbons **34**. Other components that do not affect the basic and novel characteristics of the optical fiber cable **10** that may be included are, for example, a binder **28** provided between the plurality of optical fiber ribbons **34** and the cable jacket **12**, water blocking material (e.g., tapes and powders), lubricants, friction-enhancing materials, and access features **32** (e.g., ripcords or preferential tear features, such as a strip of dissimilar polymer in the cable jacket **12**). In one or more embodiments, armor layers and strength elements are excluded from the construction of the optical fiber cable **10**.

[0031] In one or more embodiments, the optical fiber cable **10** includes from 12 to 3456 optical fibers **24**, more particularly from 48 to 864 optical fibers **24**, or still more particularly from 96 to 576 optical fibers **24**. In one or more embodiments, the optical fiber cable **10** has a fiber density of at least 7.5 fibers/mm^2. The fiber density is measured based on the number of optical fibers **24** per cross-sectional area of the optical fiber cable **10** as measured from the outer surface **16**. In one or more embodiments, the fiber density is at least 8 fibers/mm^2, at least 8.5 fibers/mm^2, at least 9 fibers/mm^2, at least 9.5 fibers/mm^2, at least 10 fibers/mm^2, at least 10.5 fibers/mm^2, at least 11 fibers/mm^2, at least 11.5 fibers/mm^2, or at least 12 fibers/mm^2. In one or more embodiments, the fiber density may be up to 17 fibers/mm^2.

[0032] In one or more embodiments, the outer diameter of the optical fiber cable **10** as measured at the outer surface **16** is 9 mm or less, 8.5 mm or less, 8 mm or less, 7.5 mm or less, 7 mm or less, 6.75 mm or less, 6.5 mm or less, 6.25 mm or less, 6 mm or less, 5.75 mm or less, 5.5 mm or less, 5.25 mm or less, or 5 mm or less. Further, in one or more embodiments, the outer diameter of the optical fiber cable **10** as measured from the outer surface **16** is at least 2 mm.

[0033] In one or more embodiments, the optical fiber cable **10** has a cumulative fiber filling coefficient of at least 50%, at least 60%, at least 65%, or at least 70%. In one or more embodiments, the optical fiber cable **10** has a cumulative fiber filling coefficient of up to 85%. As used herein, the term "cumulative fiber filling coefficient" of an optical-fiber cable **10** refers to the ratio of (1) the sum of the cross-sectional areas of all of the optical fibers **24** within the optical-fiber cable **10** to (2) the inner cross-sectional area of the optical-fiber cable **10** (i.e., defined by the inner surface **14** of the cable jacket **12** or inner surface of binder **28**, if included). The cross-sectional area of each optical fiber **24** is determined based on an outer surface of the optical fiber **24**.

[0034] In one or more embodiments, the optical fiber cable **10** comprises a free space of at most 50%, at most 42.5%, at most 30%, or at most 25%. In one or more embodiments, the free space of the optical fiber cable **10** is at least 15%. As used herein, the free space is the inverse of cumulative fiber filling coefficient (i.e., 100%-cumulative fiber filling coefficient).

[0035] The high fiber density optical fiber cables **10** as described herein are beneficial for reducing cable diameter and duct size or for increasing fiber count within an existing duct. While the optical fibers may provide sufficient tensile strength for the optical fiber cable **10**, allowing for the avoidance of dedicated strength elements, the optical fiber cables **10** may not have sufficient stiffness for blowing applications and anti-buckling performance at low temperatures. In order to address these challenges, embodiments of the present disclosure relate to cable jacket designs configured to enhance the cable stiffness and improve the anti-buckling performance at low temperatures. In one or more embodiments, the bending stiffness of the cable is at least 0.1 $N \cdot m^2$, in particular up to 0.15 $N \cdot m^2$ or even 0.2 $N \cdot m^2$. As will be discussed more fully below, the goal of improving cable bending stiffness typically is counter to the goal of improving anti-buckling performance at low temperatures, and the inventors surprisingly and unexpectedly were able to capture improvements to both aspects through the disclosed cable jacket designs.

[0036] As mentioned above, cable blowing or jetting performance is largely based on cable bending stiffness, and the bending stiffness is proportional to the elastic modulus of the optical fiber cable. Conventionally, the elastic modulus of the cable is increased by incorporating strength elements, such as fiber-reinforced plastic rods. Absent incorporating such elements to enhance the fiber density of the cable, the primary mechanism of increasing the elastic modulus of the optical fiber cable is to increase the elastic modulus of the cable jacket.

[0037] At low temperatures, the cable jacket contracts (or buckles), creating contraction stress on the optical fibers in the optical fiber cable. The contraction stress is related to the elastic modulus and to the coefficient of thermal expansion (CTE). Thus, to reduce contraction stress, it is typically desirable to use a low modulus and low CTE material for the cable jacket. However, using a lower modulus material runs counter to the goal of increasing cable stiffness.

[0038] Nevertheless, the inventors identified particular materials and cable designs that provide not only high modulus by also low contraction stress at low temperatures. FIG. **3** depicts a first concept for a cable jacket **12**. In FIG. **3**, the cable jacket **12** surrounds a high density cable core **20**, such as a lumen **22** cable core **20** as shown in FIG. **1** or intermittently bonded optical fiber ribbons **34** as shown in FIG. **2**. In one or more embodiments, the cable jacket **12** includes a first layer **40** comprising an engineering thermoplastic. In one or more embodiments, the engineering thermoplastic has an elastic modulus of at least 800 MPa, in particular at least 1000 MPa, still more particularly 1200 MPa, and yet more particularly 1500 MPa. In one or more embodiments, the engineering thermoplastic has an averaged CTE (measured from −40° C. to 25° C.) of at most 150 ppm/° C., in particular at most 100 ppm/° C. . . . In one or more embodiments, the engineering thermoplastic has a strain at break of at least 100% at 23° C., in particular at least 200% at 23° C.

[0039] In one or more non-limiting embodiments, the engineering thermoplastic is selected from polyester (e.g., polybutylene terephthalate (PBT), polyethylene terephthalate (PET), dimethyl terephthalate (DMT)), polyamide, polycarbonate, acrylonitrile butadiene styrene (ABS), copolymers thereof, or blends thereof. In one or more preferred embodiments, the engineering thermoplastic is PBT, and specific examples of suitable PBT include Ultradur® B 6550 LN, Ultradur® B 6551 LNI (available from BASF SE, Ludwigshafen, Germany), CELANEX® 2001 (available from Celanese Corporation, Irving, TX), DURANEX® 201 HR (available from Polyplastics Co., Ltd., Tokyo, Japan), POCAN® B1205XHR (available from LANXESS Deutschland GmbH, Cologne, Germany), among others.

[0040] In one or more embodiments, the first layer **40** comprises the engineering thermoplastic as well one or more additives. In one or more embodiments, the additives include antioxidants, slip agents, melt strength enhancers, and hydrolysis stabilizers. Further, the additive may be a pigment or colorant, such as carbon black, which may be provided to absorb ultraviolet light for outdoor applications.

[0041] In one or more embodiments, the cable jacket **12** having the first layer **40** of engineering thermoplastic provides a cable stiffness of at least 0.1 N·m^2. Table 1, below, provides a comparison of materials used for a conventional cable jacket (HDPE) and a cable jacket **12** according to the present disclosure. Of the properties provided in Table 1, contraction stress was measured using dynamic mechanical analysis (DMA) from room temperature down to −40° C., determining the stress required to hold the sample against contraction. The elastic modulus is the modulus of the material for the cable jacket. The cable bending stiffness was calculated from the product of the sum of the elastic moduli of the components in the cable and the bending moment of the cable.

TABLE 1

Properties of Cable Jacket Material and Cable Made Therefrom

Material	Contraction Stress (MPa)	Elastic Modulus (MPa)	Cable Bending Stiffness (N · m^2)
HDPE[1]	9.13	800	0.05
Copolyester[2]	5.36	1600	0.10
Polyamide 12[3]	7.06	1800	0.11
PBT1[4]	13.57	2300	0.14

[1]DGDA-6321 BK (The Dow Chemical Company, Midland, MI)
[2]Tritan ® TX-3001 (Eastman Chemical Company, Longview, TX)
[3]GRILAMID ® L 20 G POLYAMID 12 (EMS-GRIVORY, Switzerland)
[4]Ultradur ® B 6550 LN (BASF SE, Ludwigshafen, Germany)

[0042] As can be seen from Table 1, the conventional HDPE jacket material does not provide sufficient bending stiffness for cable blowing or jetting applications. Further, the elastic modulus is only about 800 MPa, and the contraction stress is over 9 MPa. The engineering plastics of copolyester, polyamide 12 have elastic moduli at least twice as high as HDPE, but the contraction stress is lower for each, in particular half as much as HDPE for the copolyester.

[0043] In one or more embodiments, the cable jacket **12** further includes a skin layer **42**. The engineering plastics used in the first layer **40** have enhanced mechanical properties, but these polymers may also be susceptible to environmental degradation or may not possess certain other desired properties for the outer surface **16** of the optical fiber cable **10**. In such embodiments, the first layer **40** may be surrounded with a skin layer **42**. For example, the skin layer **42** may provide UV, chemical, and/or hydrolysis protection and may reduce friction at the outer surface **16**, which can enhance blowing or jetting performance. In one or more embodiments, the skin layer **42** has a thickness of five micrometers to a few hundreds of micrometers (e.g., 5 μm to 500 μm). In one or more embodiments, the skin layer **42** comprises high density polyethylene (HDPE) or medium density polyethylene (MDPE).

[0044] In embodiments in which a skin layer **42** is included, the first layer **40** of engineering plastic may optionally include a compatibilizer to improve bonding between the first layer **40** and the skin layer **42**. For example, for a skin layer **42** of HDPE or MDPE, a first layer **40** of PBT may include such compatibilizers as reactive ethylene, butyl acrylate, and glycidyl methacrylate terpolymer (e.g., Lotader® AX series, available from Arkema Functional Polyolefins, Colombes Cedex, France) or maleic anhydride (MAH) containing compositions.

[0045] FIG. **4** depicts another concept for a cable jacket design that improves bending stiffness and enhances anti-buckling performance at low temperatures. In one or more embodiments, including the embodiment shown in FIG. **4**, the cable jacket **12** includes a first layer **40** of engineering plastics around a second layer **44** of a thermoplastic elastomer. In this way, a softer inner layer is surrounded by a harder outer layer. In this way, the cable jacket **12** has a high modulus component to enhance bending stiffness and a low modulus component to address buckling and contraction stress at low temperature.

[0046] In one or more embodiments, the thermoplastic elastomer of the second layer **44** has an elastic modulus of at most 10 MPa. In one or more embodiments, the thermoplastic elastomer of the second layer **44** has an elastic modulus of at least 5 MPa. In one or more embodiments, the thermoplastic elastomer has a strain at break of at least 200%

at 23° C., in particular at least 400% at 23° C. In one or more embodiments, the thermoplastic elastomer has a glass transition temperature of less than −30° C., in particular less than −40° C.

[0047] In one or more embodiments, the thermoplastic elastomer is selected from olefin block copolymers (e.g., Infuse® available from The Dow Chemical Company, Midland, MI), olefin random copolymers (e.g., Engage® available from The Dow Chemical Company, Midland, MI), ethylene-propylene rubber (EPR), ethylene-propylene-diene rubber (EPRM), ethylene-octene (EO), ethylene-hexene (EH), ethylene-butene (EB), ethylene-vinyl acetate (EVA), polyester elastomer (e.g., Hytrel available from Celanese Corporation, Irving, TX), polyamide elastomer, thermoplastic polyurethane, styrene-ethylene-butadiene-styrene (SEBS), and combinations thereof.

[0048] In one or more embodiments, the ratio of thickness of the second layer **44** to the first layer **42** is at most 1:1, and preferably at most 0.5:1.

[0049] Table 3 provides material properties and cable performance properties for a cable jacket having a conventional HDPE jacket, for a jacket with a single layer of engineering plastic as shown in FIG. **3**, and for a dual layer jacket as shown in FIG. **4**. The contraction stress was measured using DMA as described above. The elastic modulus pertains to a particular material of the cable jacket **12** (first layer **40** or second layer **44**), and the bending stiffness relates to the cable jacket design (single layer or dual layer).

TABLE 2

Properties of Cable Jacket Layer and Cable Made Therefrom

Material	Contraction Stress (MPa)	Elastic Modulus (MPa)	Cable Bending Stiffness ($N \cdot m^2$)
HDPE[1]	9.13	800	0.05
OBC1[2]	0.425	1.2	—
OBC2[3]	0.066	1.3	0.12[4]
Polyamide 12[5]	7.06	1800	0.11
PBT1[6]	13.57	2300	0.14

[1]DGDA-6321 BK
[2]Infuse 9100 TPE (The Dow Chemical Company, Midland, MI)
[3]Infuse 9077 TPE (The Dow Chemical Company, Midland, MI)
[4]bending stiffness calculated based on 0.2 μm thick second layer 44 with first layer 42 of PBT (Ultradur ® B 6550 LN)
[5]GRILAMID ® L 20 G POLYAMID 12 (EMS-GRIVORY, Switzerland)
[6]Utradur ® B 6550 (BASF SE, Ludwigshafen, Germany)

[0050] As can be seen from Table 2, the OBC2 thermoplastic elastomer had an extremely low contraction stress compared to the conventional HDPE and to the engineering thermoplastics. Further, when the thermoplastic elastomer second layer **44** is incorporated into the structure of a cable jacket **12** with the first layer **42**, the bending stiffness of the cable is maintained well above an HDPE cable jacket and also above the desired level of 0.1 $N \cdot m^2$ for blowing and jetting applications.

[0051] As with the previous embodiment, the dual layer cable jacket **12** can also include a skin layer **12** as described above. In one or more such embodiments, the first layer **40** of the engineering thermoplastic may be provided with a compatibilizer as described above.

[0052] According to another concept based on the dual layer cable jacket **12**, the second layer **44** of thermoplastic elastomer is foamed. In one or more embodiments, the second layer **44** is foamed via physical foaming or via chemical foaming during an extrusion process. Advantageously, foaming the second layer provides additional cushion to the cable core **20**. In particular, the foamed second layer **44** provides additional space to deflect excessive loads during bending, twisting, coiling, and crushing of the cable core **20**.

[0053] In one or more embodiments, the second layer **44** can be foamed to provide a 10% to 60% density reduction (i.e., the foamed material has a density that is 40% to 90% of the density of the unfoamed material). In one or more embodiments, the foamed second layer **44** has a closed cell morphology, which provides water blocking around the cable core **20**. In one or more embodiments, the foamed second layer **44** has voids with an average void size of 20 μm to 100 μm, in particular 20 μm to 50 μm.

[0054] As with the previous concepts, the dual layer jacket **12** with a foamed second layer **44** may also include a skin layer **42**.

[0055] FIG. **5** depicts another concept for the cable jacket design that increases the bending stiffness and improves anti-buckling performance at low temperatures. As shown in FIG. **5**, the cable jacket **12** includes a first layer **40** that is an outer layer of the cable jacket **12** and a second layer **44** that is an inner layer of the cable jacket **12**. The second layer **44** is divided into a first section **46*a*** and a second section **46*b***. Each end of the first section **46*a*** is separated from a respective end of the second section **46*b*** by a gap G. As can be seen, the material of the first layer **40** fills the gaps G between the first section **46*a*** and the second section **46*b*** of the second layer **44**. Thus, the second layer **44** may be described as forming a discontinuous layer around the cable core **20**. In one or more embodiments, including the embodiment shown in FIG. **5**, an access feature **32** can also be provided in each gap G between the first section **46*a*** and the second section **46*b***. In one or more embodiments, the combined span of the gaps G is 25% or less, 15% or less, or 10% or less of the circumference of the second layer **44**.

[0056] In one or more embodiments, the second layer **44** comprises an engineering thermoplastic as opposed to the other dual layer jackets where the inner second layer **44** comprises a foamed or unfoamed a thermoplastic elastomer. In one or more embodiments, the outer first layer **40** comprises a polyethylene (e.g., HDPE or MDPE). In one or more embodiments, the first and second sections **46*a***, **46*b*** of the second layer **44** make up at least 50% of the cross-sectional area of the cable jacket **12**. In this way, the first layer **40** acts similarly to the skin layer **42** of the previously described embodiments.

[0057] In one or more embodiments, the second layer **44** comprises a halogen-free engineering thermoplastic with a flame retardant additive. In one or more embodiments, the first layer **40** comprises a flame retardant polymer, such as a low smoke, zero halogen flame retardant composition.

[0058] In order to determine the low temperature performance of the optical fiber cable as described in the foregoing embodiments, a sample optical fiber cable was prepared as shown in FIG. **6**. The sample optical fiber cable **10** included a single lumen **22** having twelve optical fibers **24** disposed within a membrane **26**. A cable jacket **12** was extruded around the single lumen **22**. Two cable jackets **12** having two different PBT types were extruded around the lumen **22**, and the optical fiber cable **10** samples were subjected to thermal cycling testing (TCT).

[0059] FIG. 7 depicts the results of the TCT. As can be seen in FIG. 7, TCT involves subjecting the optical fiber cable 10 to a decrease in temperature starting from room temperature to −30° C., and then the temperature is raised to 70° C. Thereafter, the temperature is decreased to room temperature again and decreased to −30° C. a second time. As can be seen, the optical fiber cable 10 experienced a change in attenuation of less than 0.15 dB/km throughout the thermal cycling at a wavelength of 1310 nm. For the higher wavelengths of 1550 nm and 1625 nm, the change in attenuation substantially remained below 0.3 dB/km.

[0060] Unless otherwise expressly stated, it is in no way intended that any method set forth herein be construed as requiring that its steps be performed in a specific order. Accordingly, where a method claim does not actually recite an order to be followed by its steps or it is not otherwise specifically stated in the claims or descriptions that the steps are to be limited to a specific order, it is in no way intended that any particular order be inferred. In addition, as used herein, the article "a" is intended to include one or more than one component or element, and is not intended to be construed as meaning only one.

[0061] It will be apparent to those skilled in the art that various modifications and variations can be made without departing from the spirit or scope of the disclosed embodiments. Since modifications, combinations, sub-combinations and variations of the disclosed embodiments incorporating the spirit and substance of the embodiments may occur to persons skilled in the art, the disclosed embodiments should be construed to include everything within the scope of the appended claims and their equivalents.

What is claimed is:

1. An optical fiber cable, comprising:

a cable jacket comprising an inner surface and an outer surface, the inner surface defining a central bore and the outer surface defining an outermost surface of the optical fiber cable; and

a cable core disposed in the central bore, the cable core comprising a plurality of optical fibers;

wherein the optical fiber cable comprises a cross-sectional area as defined by the outer surface of the cable jacket;

wherein the plurality of optical fibers divided by the cross-sectional area defines a fiber density of at least 7.5 fibers/mm^2; and

wherein the cable jacket comprises a first layer, the first layer comprising an engineering thermoplastic having an elastic modulus of at least 800 MPa.

2. The optical fiber cable of claim 1, wherein the engineering thermoplastic is selected from a group consisting of polyester, polyamide, polycarbonate, acrylonitrile butadiene styrene (ABS), copolymers thereof, or blends thereof.

3. The optical fiber cable of claim 1, wherein the engineering thermoplastic further comprises an averaged coefficient of thermal expansion as measured between −40° C. and 25° C. of at most 150 ppm/° C.

4. The optical fiber cable of claim 1, wherein the optical fiber cable comprises a bending stiffness of at least 0.1 N·m^2.

5. The optical fiber cable of claim 1, wherein the cable jacket further comprises a skin layer having a thickness in a range from 5 μm to 500 μm disposed around the first layer, the skin layer defining the outer surface of the cable jacket.

6. The optical fiber cable of claim 5, wherein the first layer further comprises a compatibilizer configured to enhance bonding between the engineering thermoplastic of the first layer and the skin layer.

7. The optical fiber cable of claim 1, wherein the cable jacket further comprises a second layer, the second layer comprising a thermoplastic elastomer and the second layer defining the inner surface of the cable jacket, and wherein the first layer surrounds the second layer.

8. The optical fiber cable of claim 7, wherein the thermoplastic elastomer is selected from a group consisting of olefin block copolymers, olefin random copolymers, ethylene-propylene rubber (EPR), ethylene-propylene-diene rubber (EPRM), ethylene-octene (EO), ethylene-hexene (EH), ethylene-butene (EB), ethylene-vinyl acetate (EVA), polyester elastomer, polyamide elastomer, thermoplastic polyurethane, styrene-ethylene-butadiene-styrene (SEBS), and combinations thereof.

9. The optical fiber cable of claim 7, wherein the first layer comprises a first thickness and the second layer comprises a second thickness and wherein a ratio of the second thickness to the first thickness is 1:1 or less.

10. The optical fiber cable of claim 7, the thermoplastic elastomer of the second layer is a foamed thermoplastic elastomer having a foam density that is 40% to 90% of a density of the thermoplastic elastomer.

11. The optical fiber cable of claim 10, wherein the foamed thermoplastic elastomer has a closed cell morphology and the foamed thermoplastic elastomer comprising voids having an average void size of 20 μm to 100 μm.

12. The optical fiber cable of claim 7, wherein the cable jacket further comprises a skin layer having a thickness in a range from 5 μm to 500 μm disposed around the first layer, the skin layer defining the outer surface of the cable jacket.

13. The optical fiber cable of claim 1, wherein the first layer is discontinuous and comprises a first section and a second section, the first section being separated from the second section by a gap, and wherein the cable jacket comprises a second layer that surrounds the first layer and fills the gap between the first section and the second section.

14. The optical fiber cable of claim 13, wherein the engineering thermoplastic of the first layer is halogen-free and wherein a flame retardant additive is dispersed in the engineering thermoplastic.

15. The optical fiber cable of claim 13, wherein the second layer comprises a low smoke, zero halogen polymer composition.

16. The optical fiber cable of claim 1, wherein the plurality of optical fibers of the cable core are arranged into a plurality of lumens, each lumen of the plurality of lumens comprising at least two optical fibers surrounded by a membrane.

17. The optical fiber cable of claim 1, wherein the plurality of optical fibers of the cable core are arranged into a plurality of intermittently bonded ribbons.

18. An optical fiber cable, comprising:

a cable jacket comprising an inner surface and an outer surface, the inner surface defining a central bore and the outer surface defining an outermost surface of the optical fiber cable; and

a cable core disposed in the central bore, the cable core comprising a plurality of optical fibers;

wherein the optical fiber cable has a cumulative fiber filling coefficient of at least 50%; and wherein the cable jacket comprises at least two layers, the at least two layers being selected from a group consisting of a skin layer, an engineering thermoplastic layer, and a thermoplastic elastomer layer.

19. The optical fiber cable of claim **18**, wherein the cable jacket comprises the skin layer and the engineering thermoplastic layer, the skin layer surrounding the engineering thermoplastic layer and the skin layer defining the outer surface of the cable jacket.

20. The optical fiber cable of claim **19**, wherein the cable jacket further comprises the thermoplastic elastomer layer, the thermoplastic elastomer layer defining the inner surface of the cable jacket.

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