

TERMINATION ARRANGEMENT FOR AN OVERHEAD ELECTRICAL CABLE INCLUDING A TENSILE STRAIN SHEATH

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the priority benefit of US Provisional Patent Application No. 62/704,516 by Webb et al. and filed on May 14, 2020, which is incorporated herein by reference in its entirety.

FIELD

[0002] This disclosure relates to the field of termination arrangements, including dead ends and splices, for use with overhead electrical cables having composite strength members.

SUMMARY

[0003] In one embodiment a termination arrangement is disclosed. The termination arrangement is configured for securing an overhead electrical cable comprising a strength member and an electrical conductor disposed around the strength member. The termination arrangement includes: a connector comprising a fastener disposed at a first end of the connector and a connector body extending from the fastener toward an end of the connector that lies opposite the fastener; a longitudinally-extending sheath having a central bore extending therethrough that is configured to receive a strength member within the central bore; and a conductive sleeve configured to be disposed over: (i) an end of the electrical cable, (ii) the sheath, and (iii) at least a portion of the connector body when the termination arrangement is operatively assembled.

[0004] In another embodiment, a termination arrangement that is secured to an overhead electrical cable comprising a strength member and an electrical conductor disposed around the strength member is disclosed. The termination arrangement includes: a connector comprising a fastener disposed at a first end of the connector and a connector body extending from the fastener toward an end of the connector that lies opposite the fastener; a longitudinally-extending sheath having a central bore extending therethrough that is operatively disposed over and compressed onto a portion of the

strength member to operatively grip the strength member; and a conductive sleeve that is disposed over (i) an end of the electrical cable, (ii) the sheath, and (iii) at least a portion of the connector body. The sheath is operatively attached to the connector body by one of (i) being disposed within a chamber in the connector body and having the connector body crimped onto the sheath, or (ii) being disposed within the conductive sleeve and having the conductive sleeve crimped onto the sheath.

[0005] In another embodiment, a method for the termination of an overhead electrical cable including a strength member and an electrical conductor disposed around the strength member is disclosed. The method includes the steps of comprising the steps of: removing the electrical conductor from a termination end of the electrical cable to expose an end portion of the strength member; placing the exposed end portion of the strength member through a central bore disposed within a longitudinally extending sheath; operatively attaching the sheath to a connector, the connector comprising a fastener disposed at a first end of the connector and a connector body extending from the fastener toward an end of the connector that lies opposite the fastener, the attaching comprising one of (i) disposing the sheath within a chamber in the connector body and crimping the connector body onto the steel sheath, or disposing the sheath within a conduit of a conductive sleeve and crimping the conductive sleeve onto the sheath.

DESCRIPTION OF THE DRAWINGS

[0006] **FIGS. 1A** and **1B** illustrate two examples of an overhead electrical cable having a composite strength member according to the prior art.

[0007] **FIG. 2** illustrates a partial cross-section of a termination arrangement for an overhead electrical cable having a composite strength member according to the prior art.

[0008] **FIG. 3** illustrates a perspective view of a termination arrangement for an overhead electrical cable having a composite strength member according to the prior art.

[0009] **FIGS. 4A** and **4B** illustrate a partial cross-section of a termination arrangement for an overhead electrical cable having a composite strength member according to the prior art.

[0010] **FIGS. 5A and 5B** illustrate an embodiment of a termination arrangement according to the present disclosure.

[0011] **FIGS. 6A and 6B** illustrate an embodiment of a termination arrangement according to the present disclosure.

[0012] **FIGS. 7A to 7E** illustrate an embodiment of a steel sheath according to the present disclosure.

[0013] **FIGS. 8A to 8D** illustrate an embodiment of a termination arrangement according to the present disclosure.

[0014] **FIGS. 9A to 9D** illustrate an embodiment of a termination arrangement according to the present disclosure.

[0015] **FIG. 10** schematically illustrates a method for measuring the strain placed on a composite strength member during crimping.

DESCRIPTION OF THE EMBODIMENTS

[0016] Overhead electrical transmission and distribution lines are constructed by elevating electrical cables (e.g., bare, non-insulated electrical cables) above the terrain using support towers (e.g., pylons). The transmission and distribution lines may span many miles, requiring extremely long lengths of electrical cable and many support towers. Some of the support towers are referred to as dead-end towers or anchor towers, and are placed at termination points, e.g., power substations or locations where the electrical line is routed underground. Dead-end towers may also be required where the electrical line changes direction (e.g., makes a turn), or at regular intervals in a long, straight line path. Another type of termination arrangement is a splice, which is used to make a mechanical and electrical connection between the ends of two adjacent electrical cables in an electrical line.

[0017] Overhead electrical cables have traditionally been constructed using an inner steel strength member surrounded by a plurality of conductive aluminum strands that are helically wrapped around the steel strength member, a configuration referred to as "aluminum conductor steel reinforced" (ACSR). Recently, overhead electrical cables

having a fiber-reinforced composite strength member have been manufactured and deployed in many electrical lines. As compared to steel, the fiber-reinforced composite materials used for the strength member have a lighter weight, lower thermal expansion and higher specific stiffness. However, fiber-reinforced materials do not reach a yield point where plastic deformation occurs when the materials are stressed.

[0018] Such fiber-reinforced composite strength members may include a single fiber-reinforced composite strength element (e.g., a single rod) as illustrated in **FIG. 1A**. An example of such a configuration is disclosed in U.S. Pat. No. 7,368,162 by Hiel et al., which is incorporated herein by reference in its entirety. Alternatively, the composite strength member may be comprised of a plurality of individual fiber-reinforced composite strength elements (e.g., individual rods) that are operatively combined (e.g., twisted or stranded together) to form the strength member, as is illustrated in **FIG. 1B**. Examples of such multi-element composite strength members include, but are not limited to: the multi-element aluminum matrix composite strength member illustrated in U.S. Patent No. 6,245,425 by McCullough et al.; the multi-element carbon fiber strength member illustrated in U.S. Patent No. 6,015,953 by Tosaka et al.; and the multi-element strength member illustrated in U.S. Patent No. 9,685,257 by Daniel et al. Each of these U.S. patents is incorporated herein by reference in its entirety. Other configurations for the fiber-reinforced composite strength member may be implemented as is known to those skilled in the art.

[0019] Referring to the overhead electrical cable illustrated in **FIG. 1A**, the cable **160A** includes an electrical conductor **162A** that includes a first conductive layer **164a** and a second conductive layer **164b**, each comprising a plurality of individual conductive strands that are helically wrapped around a fiber-reinforced composite strength member **166A**. It will be appreciated that such overhead electrical cables may include a single conductive layer, or more than two conductive layers, depending upon the desired use of the overhead electrical cable. The conductive strands may be fabricated from conductive metals such as copper or aluminum, and for use in bare overhead electrical cables are typically fabricated from aluminum, e.g., hardened aluminum, annealed aluminum, and/or aluminum alloys. As illustrated in **FIG. 1A**, the conductive strands have a substantially trapezoidal cross-section, although other configurations may be employed, such as

circular cross-sections. The use of polygonal cross-sections such as the trapezoidal cross-section advantageously increases the cross-sectional area of conductive metal for the same effective cable diameter, e.g., as compared to strands having a circular cross-section.

[0020] The conductive materials, e.g., aluminum, do not have sufficient mechanical properties (e.g., sufficient tensile strength) to be self-supporting when strung between support towers to form an overhead electrical line for transmission and/or distribution of electricity. Therefore, the overhead electrical cable **160A** includes the strength member **166A** to support the conductive layers **164a/164b** when the overhead electrical cable **160A** is strung between the support towers under high mechanical tension. In the embodiment illustrated in **FIG. 1A**, the strength member **166A** includes a single (e.g., only one) strength element **168A**. The strength element **168A** includes a core **170A** of high strength carbon reinforcing fibers in a binding matrix and a galvanic layer **172A**, e.g., comprised of glass fibers, to prevent contact between the carbon fibers and the first conductive layer **164A**, which may lead to corrosion of the aluminum.

[0021] **FIG. 1B** illustrates an embodiment of an overhead electrical cable **160B** that is similar to the electrical cable illustrated in **FIG. 1A**, wherein the strength member **166B** comprises a plurality of individual strength elements (e.g., strength element **168B**) that are stranded or twisted together to form the strength member **166B**. Although illustrated in **FIG. 1B** as including seven individual strength elements, it will be appreciated that a multi-element strength member may include any number of strength elements that is suitable for a particular application.

[0022] As noted above, the fiber-reinforced composite material from which the strength elements are constructed may include reinforcing fibers that are operatively disposed in a binding matrix. The reinforcing fibers may be substantially continuous reinforcing fibers that extend along the length of the fiber-reinforced composite, and/or may be short reinforcing fibers (e.g., fiber whiskers or chopped fibers) that are dispersed through the binding matrix. The reinforcing fibers may be selected from a wide range of materials including, but not limited to, carbon, glass, boron, metal oxides, metal carbides, high-strength polymers such as aramid fibers or fluoropolymer fibers, basalt fibers and

the like. Carbon fibers are particularly advantageous in many applications due to their very high tensile strength, and/or due to their relatively low coefficient of thermal expansion (CTE).

[0023] The binding matrix may include, for example, a plastic (e.g., polymer) such as a thermoplastic polymer or a thermoset polymer. For example, the binding matrix may include a thermoplastic polymer, including semi-crystalline thermoplastics. Specific examples of useful thermoplastics include, but are not limited to, polyether ether ketone (PEEK), polypropylene (PP), polyphenylene sulfide (PPS), polyetherimide (PEI), liquid crystal polymer (LCP), polyoxymethylene (POM, or acetal), polyamide (PA, or nylon), polyethylene (PE), fluoropolymers and thermoplastic polyesters.

[0024] The binding matrix may also include a thermosetting polymer. Examples of useful thermosetting polymers include, but are not limited to, benzoxazine, thermosetting polyimides (PI), polyether amide resin (PEAR), phenolic resins, epoxy-based vinyl ester resins, polycyanate resins and cyanate ester resins. In one exemplary embodiment, a vinyl ester resin is used in the binding matrix. Another embodiment includes the use of an epoxy resin, such as an epoxy resin that is a reaction product of epichlorohydrin and bisphenol A, bisphenol A diglycidyl ether (DGEBA). Curing agents (e.g., hardeners) for epoxy resins may be selected according to the desired properties of the fiber-reinforced composite strength member and the processing method. For example, curing agents may be selected from aliphatic polyamines, polyamides and modified versions of these compounds. Anhydrides and isocyanates may also be used as curing agents. Other examples of polymeric materials useful for a binding matrix may include addition cured phenolic resins, e.g., bismaleimides (BMI), polyetheramides, various anhydrides, or imides.

[0025] The binding matrix may also be a metallic matrix, such as an aluminum matrix. One example of an aluminum matrix fiber-reinforced composite is illustrated in U.S. Patent No. 6,245,425 by McCullough et al., noted above.

[0026] One configuration of a composite strength member for an overhead electrical cable that is particularly advantageous is the ACCC® composite configuration that is available from CTC Global Corporation of Irvine, CA and is illustrated in U.S. Pat. No.

7,368,162 by Hiel et al., noted above. In the commercial embodiment of the ACCC® electrical cable, the strength member is a single element strength member of substantially circular cross-section that includes an inner core of substantially continuous reinforcing carbon fibers disposed in a polymer matrix. The core of carbon fibers is surrounded by a robust insulating layer of glass fibers that are also disposed in a polymer matrix and insulate the carbon fibers from the surrounding conductive aluminum strands. See **FIG. 1A**. The glass fibers also have a higher compressive strain capability than the carbon fibers and provide bendability so that the strength member and the electrical cable can be wrapped upon a spool for storage and transportation.

[0027] During installation of the electrical line, the overhead electrical cable must be terminated and secured to the dead-end tower under high tension. Overhead electrical cables utilizing a steel or other ductile metal strength members can be attached to a termination arrangement by crimping the components surrounding the strength member using high compressive forces since the underlying strength member is ductile and will not fracture under the compressive stresses. Fiber-reinforced composite strength members, having a lower ductility and elongation to break than steel, are susceptible to being fractured under high compressive forces, and termination arrangements for such strength members are typically designed to reduce the compressive force on the strength member. **FIGS. 2 to 4** illustrate two different termination arrangements that are particularly useful for overhead electrical cables having a fiber-reinforced composite strength member. **FIG. 2** illustrates a cross-section of a termination arrangement (e.g., a dead-end) for use with a bare overhead electrical cable, i.e., to terminate an electrical cable while maintaining the cable under high tension. The termination arrangement **200** illustrated in **FIG. 2** is similar to that illustrated and described in PCT Publication No. WO 2005/041358 by Bryant and in U.S. Patent No. 8,022,301 by Bryant et al., each of which is incorporated herein by reference in its entirety.

[0028] Broadly characterized, the termination arrangement **200** illustrated in **FIG. 2** includes a gripping element **210** that is secured to a connector **220**, which anchors the termination arrangement **200** to a dead-end structure (e.g., to a tower), not illustrated, e.g., with a fastener **226** (e.g., an eyebolt). At the end of the termination arrangement **200**, opposite the fastener **226**, the termination arrangement **200** is operatively connected

to a bare overhead electrical cable **260** that includes an electrical conductor **262** (e.g., comprising conductive strands) that surrounds and is supported by a strength member **266**, e.g., a fiber-reinforced composite strength member.

[0029] The gripping element **210** tightly grips the strength member **266** to secure the overhead electrical cable **260** to the termination arrangement **200**. As illustrated in **FIG. 2**, the gripping element **210** includes a compression-type fitting, specifically a collet **212** having a lumen **216** (e.g., a bore) that surrounds and grips onto the strength member **266**. The collet **212** is disposed in a collet housing **214**, and as the electrical cable **260** is tensioned (e.g., is pulled onto support towers), friction develops between the strength member **266** and the collet **212** as the collet **212** is pulled further into the collet housing **214**. The conical (outer) shape of the collet **212** and the mating inner funnel shape of the collet housing **214** increase the compression on the strength member **266**, ensuring that the strength member **264** does not slip out of the collet **212** and therefore that the overhead electrical cable **260** is secured to the termination arrangement **200**.

[0030] As illustrated in **FIG. 2**, a conductive outer sleeve **240** is disposed over the gripping element **210** that includes a conductive body **244** to facilitate electrical conduction between the electrical conductor **262** and a jumper plate **246**. An inner sleeve **248** (e.g., a conductive inner sleeve) may be placed between the conductor **262** and the conductive body **244** to facilitate the electrical connection between the conductor **262** and the conductive body **244**. The inner sleeve **248** and the conductive body **244** may be fabricated from aluminum, for example. The jumper plate **246** is attached (e.g., welded) to the conductive body **244** and is configured to attach to a connection plate **276** to facilitate electrical conduction between the electrical conductor **262** and another conductor, e.g., another electrical cable (not illustrated) that is in electrical communication with the connector plate **276**.

[0031] The connector **220** includes a fastener **226** and gripping element mating threads **228** disposed at a gripping element end of the connector **220**, with a connector body **222** disposed between the fastener **226** and the gripping element mating threads **228**. The gripping element mating threads **228** are configured to operatively mate with connector mating threads **218** on the collet housing **214** to facilitate movement of the

connector **220** toward the collet **212** when the threads **218** and **228** are engaged and the connector **220** is rotated relative to the collet housing **214**, pushing the collet **212** into the collet housing **214**. This strengthens the grip of the collet **212** onto the strength member **266**, securing the overhead electrical cable **260** to the termination arrangement **200**. The fastener **226** is configured to be attached to a dead-end structure, e.g., to a dead-end tower, to secure the termination arrangement **200** and the electrical cable **260**, to the dead-end structure.

[0032] After assembly of the termination arrangement, the outer sleeve may then be crimped (e.g., compressed, swaged) onto portions of the underlying structure to prevent movement of the outer sleeve and/or to enhance the connection between the conductive body and the electrical conductor. **FIG. 3** illustrates a perspective view of a termination arrangement similar to that shown in **FIG. 2** that has been crimped onto an overhead electrical cable. The termination arrangement **300** includes a connector having a fastener **326** that extends outwardly from a proximal end of an outer sleeve **340**. A jumper plate **346** is integrally formed with the conductive body **342** for electrical connection to a connection plate (e.g., see **FIG. 2**). As illustrated in **FIG. 3**, the outer sleeve **340** is crimped over (e.g., onto) two regions of the underlying structure, namely crimped sleeve region **340b** and crimped sleeve region **340a**. Crimped sleeve region **340b** is generally situated over the connector body (e.g., see **222** in **FIG. 2**), and the crimped sleeve region **340a** is generally situated over a portion of the overhead electrical cable **360**, e.g., to enhance the electrical connection to the electrical cable. The compressive forces placed onto the outer sleeve **340** during the crimping operation are transferred to the underlying components, i.e., to the connector body under the crimped region **340b** and to the overhead electrical cable **360** under the crimped region **340a**.

[0033] The foregoing termination arrangement utilizes a smooth surfaced collet **214** to grip onto the composite strength over a sufficient length such that points of high stress are generally avoided and the composite strength member is unlikely to fracture under the collet.

[0034] **FIGS. 4A** and **4B** illustrate an alternative prior art termination arrangement **400** for use with composite strength members. For the sake of clarity, **FIGS. 4A** and **4B**

illustrate the relevant components of the termination arrangement, omitting the outer sleeve, jumper plate, etc. illustrated in **FIGS. 2** and **3**. Rather than using a tapered collet to grip the strength member, the termination arrangement illustrated in **FIGS. 4A** and **4B** is secured to the strength member by radial compression (e.g., crimping, swaging) of the connector body onto the strength member using a crimping tool, e.g., using a hydraulic press. The arrangement **400** includes a steel connector **420** having a connector body **422** and a fastener **426** (e.g., an eyebolt). An inner sleeve **432** of aluminum, which is softer than the surrounding steel connector body **422**, is placed between the composite strength member **466** and the connector body **422**. The crimping operation typically includes sequentially crimping the connector body with a crimping tool beginning at the proximal end, i.e., near the fastener **426**, and working toward the distal end. The crimping tool may apply up to about 100 tons of compressive force to the connector body **422** to secure the connector body to the strength member **466**. The inner aluminum sleeve **432** is intended to redistribute a portion of this radial crimping force so that the force on the strength member **466** is reduced.

[0035] When the connector body **422** is crimped onto the underlying inner aluminum sleeve **432** and strength member **466** as illustrated in **FIG. 4B**, the sleeve **432** and body **422** elongate due to the crimping force, e.g., from initial length l_1 (**FIG. 4A**) to an expanded length l_2 (**FIG. 4B**). When this elongation occurs, the aluminum sleeve **432** is expected to slide over the strength member **466** as the sleeve **432** elongates, imparting little to no elongation strain onto the strength member. For example, crimping the connector body **422** may elongate the aluminum sleeve **432** by up to about 5%, substantially higher than the strain to failure limit of the underlying composite strength member **466**, which is typically less than 2%. However, it has been found that the aluminum sleeve **432** may “pull” the underlying strength member **466**, e.g., due to frictional forces, such that the strength member **466** elongates with the sleeve **432**, which subjects the strength member to a high elongation (e.g., tensile) strain. If the elongation strain is too high, the strength member **466** may fracture (e.g., fracture **466f**) due to the lower elongation properties of the composite strength member **466**.

[0036] It is an objective to provide a termination arrangement that reduces the amount of elongation strain on the strength member caused by the crimping of the surrounding

components. In the embodiments of this disclosure, the elongation strain on the strength member is reduced or substantially eliminated by placing a high tensile modulus sheath, e.g., a hard steel sheath, over the strength member. The steel sheath is then compressed onto the strength member by crimping a connector body and/or crimping a conductive sleeve onto the steel sheath. The properties of the sheath, e.g., the material from which the sheath is fabricated and/or the wall thickness of the sheath, protects the strength member from being subjected to tensile strains that may damage the strength member, and the sheath may be referred to as a tensile strain sheath. Although generally described herein as a steel sheath, the tensile strain sheath may be fabricated from other high tensile modulus materials, e.g., materials having a higher tensile modulus than aluminum. In addition to steel (e.g., hardened steel), the sheath may also be fabricated from materials such as high tensile modulus composites, e.g., carbon fiber, boron fiber or ceramic fiber in a matrix such as a thermosetting polymer matrix, a thermoplastic polymer matrix, or a metal matrix. In one characterization, the tensile strain sheath is fabricated from a material having a tensile modulus of at least about 125 GPa, such as at least about 150 GPa, or even at least about 175 GPa.

[0037] **FIGS. 5A and 5B** illustrate one embodiment of a termination arrangement according to the present disclosure. The termination arrangement **500** is configured for securing an overhead electrical cable that includes a strength member and an electrical conductor (e.g., conductive strands) disposed around the strength member. Broadly characterized, the termination arrangement includes a sheath (e.g., a steel sheath) that operatively surrounds the strength member of the overhead electrical cable to reduce elongation strain on the strength member.

[0038] Referring to **FIGS. 5A and 5B**, the termination arrangement **500** includes a connector **520** having a connector body **522** and a fastener **526**. The connector body **522** defines an internal cylindrical chamber **524** for receiving the strength member **566** therein. A steel sheath **510**, optionally having one or more slits **514**, is placed over the strength member **566** so that the sheath **510** is disposed between the strength member **566** and the connector body **522**. In the embodiment illustrated in **FIGS. 5A and 5B**, an inner sleeve **532**, e.g., an aluminum sleeve that is softer than the connector body **522** and the sheath **510**, is placed between the steel sheath **510** and the connector body **522**.

[0039] **FIG. 5A** illustrates the termination arrangement **500** in an uncrimped state, e.g., before the connector body **522** is crimped onto the underlying aluminum inner sleeve **532**, steel sheath **510** having one or more slits **514**, and strength member **566**. Before crimping, the connector body has an initial length l_3 . **FIG. 5B** illustrates the termination arrangement **500** after crimping the connector body **522** onto the underlying components. The crimping process involves using a crimping tool to compress a portion of the connector body **522**, working from the distal end of the connector body **522**, i.e., adjacent to the fastener **526**, toward the opposite end until the connector body **522** is crimped along its length overlying the sleeve **532** and sheath **510**, e.g., as illustrated in **FIG. 5B**. As with the embodiment shown in **FIG. 4B** above, the connector body elongates due to the crimping strain to an expanded length l_4 , as does the aluminum sleeve **532**. However, the underlying steel sheath **510** substantially resists elongation and therefore limits the elongation of the strength member **566**, e.g., to a point substantially below that required to fracture the strength member **566**. In one characterization, the steel sheath **510** is formed from a steel that is harder than the steel used to form the connector body **522**. In this configuration, the harder steel sheath will be less likely to elongate during the crimping procedure. In another characterization, additional resistance to elongation can be achieved by increasing the cross-sectional area, e.g., the wall thickness, of the steel sheath.

[0040] **FIGS. 6A** and **6B** illustrate another configuration of a termination arrangement **600** according to the present disclosure. The termination arrangement includes a connector **620** having a connector body **622** and a fastener **626**. The connector body **622** defines a cylindrical space **624** for receiving the strength member **666** therein. A steel sheath **610** having one or more slits **614** is placed over the strength member **666** so that it is disposed between the strength member **666** and the connector body **622**.

[0041] **FIG. 6A** illustrates the termination arrangement **600** in an uncrimped state, e.g., before the connector body **622** is crimped onto the underlying steel sheath **610** and strength member **666**. Before crimping, the connector body has an initial length l_5 . **FIG. 6B** illustrates the termination arrangement **600** after crimping the connector body **622** onto the underlying components as is described above. The connector body **622** elongates due to the crimping strain to an expanded length l_6 . However, the underlying

steel sheath **610** does not elongate to a substantial degree and therefore does not cause the strength member **666** to elongate to a point that would fracture the strength member **666**. The embodiment illustrated in **FIGS. 6A** and **6B** show that an inner aluminum sleeve (e.g., sleeve **532** in **FIG. 5A**) is not necessary to adequately protect the strength member **666** from the crimping forces and from elongation forces.

[0042] Referring to **FIGS. 7A** to **7E**, one embodiment of a steel sheath **710** is illustrated, e.g., a sheath that may be utilized in the termination arrangements illustrated in **FIGS. 5** and **6**. The sheath **710** has an outer diameter (d_o) and a length (l_7) and includes a bore **712** having an inner diameter (d_i). The inner diameter of the bore **712** is configured (e.g., shaped and sized) to enable a strength member to be inserted into the bore **712**, e.g., to be inserted into the bore **712** through a first end **716a** of the sheath and out a second end **716b** of the sheath. The inner diameter should be sufficiently large to enable the strength member to be inserted through the bore **712** (e.g., with only moderate friction against the sidewall of the bore). However, the diameter of the bore **712** should not be so great that the strength member is able to move axially within the bore when the one or more slits are approaching contact, e.g., are closing. In one characterization, bore **712** has a diameter of at least about 2.5 mm. In another characterization, the bore has a diameter of not greater than about 15 mm.

[0043] The outer diameter d_o of the sheath **710** should be sufficiently large that the sheath may be fit within the cylindrical space defined by the connector body without a significant gap between the sheath and the inner wall of the connector body (**FIG. 6A**), or within the aluminum sleeve (**FIG. 5A**). In one characterization, the outer diameter d_o is at least about 5 mm. In another characterization, the outer diameter d_o is not greater than about 46 mm.

[0044] The length l_7 of the sheath **710** should be long enough to ensure that a sufficient length of the strength member is disposed within the sheath to form a sufficient grip on the strength member after crimping without having points of high stress concentration. For example, the sheath **710** may have a length l_7 of at least about 100 mm. Typically, the length l_7 will not exceed about 300 mm. In another characterization, the sheath **710** has an outer diameter d_o and a length l_7 , and the length is at least 10 times greater than

the outer diameter, such as at least about 15 times greater than the outer diameter, such as at least about 20 times greater than the outer diameter. In a further characterization, the length is not greater than about 50 times the outer diameter, such as not greater than about 40 times the outer diameter. However, smaller diameter strength members, e.g., having a diameter of about 3 mm or less, may benefit from the use of a sheath **710** having a length that is near or slightly more than 50 times the outer diameter.

[0045] The sheath **710** also has a wall thickness, e.g., the difference between the outer diameter d_o and the inner diameter d_i of the sheath. The wall thickness of the sheath **710** should be sufficient to limit axial tension forces. In one characterization, the wall thickness of the sheath **710** is at least about 3 mm. In another characterization, the wall thickness of the sheath is not greater than about 20 mm. As is noted above, increasing the wall thickness of the sheath may increase the resistance to elongation.

[0046] As illustrated in **FIGS. 7A to 7E**, the sheath **710** includes two longitudinally extending slits (e.g., slit **714a**) that are disposed through a first end **716a** of the sheath and extend toward a second end **716b** of the sheath, e.g., without extending through the second end **716b**. These two slits are disposed on opposite sides of the sheath **710**, e.g., at a radial angle of about 180°. The sheath **710** also includes two slits (e.g., slit **714b**) that are disposed through the second end **716b** and extend toward the first end **716a** of the sheath, e.g., without extending through the first end **716a**. These longitudinally extending slits advantageously enable the sheath **710** to accommodate variations in the strength member diameter, and to enable the sheath **710** to resist axial tension forces while providing minimal restriction to closure of the sheath onto the strength member when crimped. Although illustrated as including four longitudinally extending slits, the sheath may include a single slit, two slits, three slits or more. The interior surface of the sheath **710** (e.g., the surface of the bore **712**) may be smooth or may have surface features to enhance the grip of the sheath **710** onto the strength member. For example, the interior surface may have grit applied to the surface or may be machined to provide surface texture, e.g., small ridges on the surface. Further, although not illustrated, the sheath may be slightly tapered from one end to the other, e.g., where the outer diameter of the sheath changes along the length of the sheath.

[0047] FIGS. 8A and 8B illustrate a schematic cross-sectional view of a termination arrangement 800 according to the present disclosure before placement and crimping of an outer sleeve 840. FIGS. 8C and 8D illustrate a schematic cross-sectional view of the termination arrangement 800 after placement of the outer sleeve 840 (FIG. 8C) and crimping of the outer sleeve 840 (FIG. 8D). The termination arrangement 800 includes a longitudinally-extending steel sheath 810 having a central sheath bore extending therethrough, e.g., from one end of the sheath 816a through the opposite end 816b of the sheath. In this manner, an end portion of the strength member 864 is disposed within the sheath 810.

[0048] A connector 820 (e.g., a steel connector) includes a fastener 826 disposed at a first end of the connector 820 and a connector body 822 that extends from the fastener 826 toward a second end of the connector 820. The second end of the connector includes an axial bore 824 that is configured (e.g., sized and shaped) to receive an end of the strength member 864. Thus, as illustrated in FIG. 8A, the electrical cable 860 is stripped of a portion of the electrical conductor 862 to expose the underlying strength member 864. The exposed strength member is then inserted into the sheath 810, which is placed within the axial bore 824 of the connector 820. As illustrated in FIG. 8B, a portion 828 of the connector body 822, e.g., the portion including the axial bore 824, is crimped (e.g., compressed, swaged) onto the sheath 810, which compresses onto the strength member 864 to secure the connector 820 to the strength member 864.

[0049] As illustrated in FIG. 8C, the outer sleeve 840 can then be placed over the termination arrangement 800 illustrated in FIG. 8B. Once the outer sleeve 840 is in place over the termination arrangement 800, the sleeve 840 may be crimped onto the sub-assembly and the electrical cable 860 as shown in FIG. 8D. The outer sleeve 840 is crimped at two locations, namely a first portion 840a over the electrical cable and a second portion 840b over the connector body 822.

[0050] As noted above, the overhead electrical cable 860 may be configured for the transmission and/or distribution of electricity when placed on support towers (e.g., pylons). In one arrangement, the conductor 862 comprises one or more layers of aluminum strands wrapped (e.g., helically wrapped) around the strength member 864. In

another arrangement, the strength member **864** includes longitudinally-extending reinforcing fibers (e.g., high strength carbon fibers) in a binding matrix (e.g., in an epoxy resin or thermoplastic matrix).

[0051] **FIGS. 9A to 9D** illustrate an alternative embodiment of a termination arrangement according to the present disclosure. Specifically, **FIGS. 9A** and **9B** illustrate a perspective view and a cross-sectional view respectively of the termination arrangement **900** before crimping, and **FIGS. 9C** and **9D** illustrate a cross-sectional view and a perspective view respectively of the termination arrangement **900** after crimping. The termination arrangement **900** includes a longitudinally-extending steel sheath **910** having a central sheath bore **912** extending therethrough, e.g., from one end **916a** (e.g., a distal end) of the sheath through the opposite end **916b** (e.g., a proximal end) of the sheath and at least one or more slits. In this manner, a portion **964b** of the strength member **964** is disposed within the sheath **910**.

[0052] A connector **920** (e.g., a steel connector) includes a fastener **926** disposed at a first end of the connector **920** and a connector body **922** that extends from the fastener **926** toward a second end of the connector **920**. The second end of the connector includes a notch **924** that is configured to receive an end of the strength member **964**. A conductive outer sleeve **940** is disposed over the sheath **910**, e.g., in a position where the outer sleeve **940** can be crimped onto the sheath **910**, e.g., to compress the sheath **910** onto the strength member **964**. As illustrated in **FIGS. 9C** and **9D**, the outer sleeve **940** is crimped along substantially its entire length (e.g., at least about 80% or 90% of its length), such that the outer sleeve **940** is crimped onto the connector body **922** and is crimped onto a portion of the overhead electrical cable **960** in addition to being crimped onto the sheath **910**.

EXAMPLE

[0053] To assess the effectiveness of the termination arrangement according to the present disclosure, two overhead electrical cables including fiber-reinforced composite strength members having a diameter of 7.11 mm are tested during compression swaging (e.g., crimping) of dead-end termination assemblies onto the strength members. One of the termination arrangements is according to the prior art (e.g., as illustrated in **FIGS. 4A**

- **4B**), and a second termination arrangement includes a steel sheath (e.g., as illustrated in **FIGS. 6A – 6B**).

[0054] To measure the strain on the strength member during the crimping process, a single optical fiber is placed along the outer surface of each of the two strength members. As illustrated in **FIG. 10**, the optical fiber includes six Fiber Bragg Gratings (FBG), each about 7 mm in length and evenly spaced about 18 mm apart, resulting in a center to center spacing of about 25 mm. The eyebolt of a dead-end is compression swaged (crimped) onto the composite strength members including the FBGs following the same procedure and using the same equipment that is used in a field attachment.

[0055] The strain measured by the FBG's is monitored continuously during the crimping procedure. The numbering sequence of the FBG's was such that FBG #6, which is closest to the eyebolt, is the first to experience crimping forces followed by FBG #5 down to FBG #1. The typical pattern is that FBG #6 does not experience significant levels of axial strain with the subsequent FBG's building up higher levels of axial strain. Modeling of the arrangements indicates that as the radial compaction occurs a substantial amount of plastic deformation also occurs. If this axial deformation is not relieved by slippage of the crimping metal over the composite strength member, the strains may be large enough to exceed the 1.9% maximum elongation of the composite strength member.

[0056] The foregoing testing and analysis finds that a termination arrangement including a steel sheath according to the present disclosure reduces axial strain considerably while allowing full radial compression for gripping of the composite strength member. Specifically, the peak strain in the standard assembly according to the prior art reaches 1.2% in FBG #5, whereas the peak strain in the composite strength member protected by the steel sheath is reduced to 0.52%, with this peak strain also occurring in FBG #5.

[0057] While various embodiments of a termination arrangement and method for terminating an overhead electrical cable have been described in detail, it is apparent that modifications and adaptations of those embodiments will occur to those skilled in the art.

However, it is to be expressly understood that such modifications and adaptations are within the spirit and scope of the present disclosure.