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Cable preparation and injection systems and methods

Abstract

A method for preparing an electrical cable may include coupling an injection barrel to an electrical cable that includes one or more conductors surrounded by a porous insulating material. The method may also include injecting epoxy resin into a chamber of the injection barrel, and the chamber may be fluidly coupled to an end face of the porous insulating material. Additionally, the method may include pressurizing the chamber such that the epoxy resin is forced to penetrate into the end face of the porous insulating material and removing the injection barrel to expose an epoxy-injected portion of the porous insulating material.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATION (1) This application is a non-provisional application claiming priority to and the benefit of U.S. Provisional Application No. 63/157,020, entitled "CABLE INJECTION PROCESS," filed Mar. 5, 2021, both of which are hereby incorporated by reference in their entirety for all purposes.

BACKGROUND

(1) The present disclosure generally relates to systems and methods for preparing a cable end for termination/connection via epoxy injection.

(2) This section is intended to introduce the reader to various aspects of art that may be related to various aspects of the present disclosure, which are described and/or claimed below. This discussion is believed to be helpful in providing the reader with background information to facilitate a better understanding of the various aspects of the present disclosure. Accordingly, it may be understood that these statements are to be read in this light, and not as admissions of prior art.

(3) Different industries such as oil and gas, aerospace, nuclear, automotive, and/or general infrastructure utilize electrical cables for a variety of reasons. For example, electrical cables may be used to transmit power, control signals, and/or data signals from one location to another and/or to generate heat (e.g., as resistive heaters). Furthermore, in some scenarios, such cables may need to withstand harsh operating conditions such as high or low ambient pressure, corrosive or debilitating environments, and/or extreme hot or cold temperatures. As such, insulation and environmental protection may be used to surround the conductor of the cable. However, providing terminating ends and/or connections for such cables may prove difficult while maintaining adequate protection and insulation.

SUMMARY

(4) A summary of certain embodiments disclosed herein is set forth below. It should be understood that these aspects are presented merely to provide the reader with a brief summary of these certain embodiments and that these aspects are not intended to limit the scope of this disclosure. Indeed, this disclosure may encompass a variety of aspects that may not be set forth below.

(5) In one embodiment, a method for preparing an electrical cable may include coupling an injection barrel to an electrical cable that includes one or more conductors surrounded by a porous insulating material. The method may also include injecting epoxy resin into a chamber of the injection barrel, and the chamber may be fluidly coupled to an end face of the porous insulating material. Additionally, the method may include pressurizing the chamber such that the epoxy resin is forced to penetrate into the end face of the porous insulating material, and removing the injection

barrel to expose an epoxy-injected portion of the porous insulating material.

(6) In another embodiment, an electrical cable preparation tool may include a cable clamp to be operatively coupled to an outer casing of an electrical cable that includes a conductor surrounded by a porous insulating material. The tool may also include an injection barrel, attachable to the cable clamp, which may include a chamber to be operatively exposed to an end face of the porous insulating material and one or more ports to operatively fill the chamber with an epoxy resin. Additionally, the tool may include a piston that may actuate into the chamber and operatively pressurize the chamber such that the epoxy resin is pressurized against the end face of the porous insulating material.

(7) In another embodiment, a method for connecting a prepared electrical cable may include inserting the prepared electrical cable into a cable connection that includes a first geometry. Moreover, the prepared electrical cable may include a shaped, epoxy-solidified portion of an insulating material that includes a second geometry complementary to the first geometry. Additionally, the prepared electrical cable may be prepared by coupling an injection barrel to an unprepared electrical cable that includes one or more conductors surrounded by the insulating material. Preparation may also include injecting epoxy resin into a chamber of the injection barrel that is fluidly coupled to an end face of the insulating material and pressurizing the chamber such that the epoxy resin is forced to penetrate into the end face of the insulating material. Preparation may further include removing the injection barrel to expose the epoxy-injected portion of the insulating material and shaping the epoxy-injected portion of the insulating material to generate the second geometry.

(8) In another embodiment, an electrical cable may include an outer casing, one or more conductors within the outer casing, and a porous insulating material disposed in an annulus between the outer casing and the one or more conductors. An end face of the porous insulating material may include an epoxy-solidified portion of the porous insulating material penetrating a distance into the porous insulating material in an axial direction from the end face of the porous insulating material.

(9) Various refinements of the features noted above may exist in relation to various aspects of the present disclosure. Further features may also be incorporated in these various aspects as well. These refinements and additional features may exist individually or in any combination. For instance, various features discussed below in relation to one or more of the illustrated embodiments may be incorporated into any of the above-described aspects of the present disclosure alone or in any combination. The brief summary presented above is intended only to familiarize the reader with certain aspects and contexts of embodiments of the present disclosure without limitation to the claimed subject matter.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) These and other features, aspects, and advantages of the present disclosure will become better understood when the following detailed description is read with reference to the accompanying drawings in which like characters represent like parts throughout the drawings, wherein:

(2) FIG. 1 a schematic view of a subsea production system having electrical cables used for transmitting information and power and/or for heating of equipment and/or pipes, according to an embodiment of the present disclosure;

(3) FIG. 2 is a perspective view of an electrical cable having a conductor, an insulating material, and an outer casing, according to an embodiment of the present disclosure;

(4) FIG. 3 is a perspective view of the electrical cable of FIG. 2 with a length of the outer casing and insulating material removed, according to an embodiment of the present disclosure;

(5) FIG. 4 is a perspective view of an example cable clamp disposed on the electrical cable of FIG.

3, according to an embodiment of the present disclosure;

(6) FIG. 5 is a schematic cross-sectional view of the example cable clamp secured onto the outer casing of the electrical cable, according to an embodiment of the present disclosure;

(7) FIG. 6 is a schematic cross-sectional view of an example injection barrel coupled to the cable clamp and electrical cable of FIG. 5, according to an embodiment of the present disclosure;

(8) FIG. 7 is a perspective view of the electrical cable of FIG. 2 after having an epoxy-solidified portion of the insulating material, according to an embodiment of the present disclosure;

(9) FIG. 8 is a perspective view of an example cutting tool for shaping the epoxy-solidified portion of the insulating material of FIG. 7, according to an embodiment of the present disclosure;

(10) FIG. 9 is a schematic cross-sectional view of an example cable connection utilizing an electrical cable prepared with an epoxy-solidified portion of the insulating material, according to an embodiment of the present disclosure; and

(11) FIG. 10 is a flowchart of an example process for preparing an electrical cable for termination/connection via epoxy resin injection, according to an embodiment of the present disclosure.

DETAILED DESCRIPTION

(12) Certain embodiments commensurate in scope with the present disclosure are summarized below. These embodiments are not intended to limit the scope of the disclosure, but rather these embodiments are intended only to provide a brief summary of certain disclosed embodiments. Indeed, the present disclosure may encompass a variety of forms that may be similar to or different from the embodiments set forth below.

(13) As used herein, the term “coupled” or “coupled to” may indicate establishing either a direct or indirect connection (e.g., where the connection may not include or include intermediate or intervening components between those coupled), and is not limited to either unless expressly referenced as such. The term “set” may refer to one or more items. Wherever possible, like or identical reference numerals are used in the figures to identify common or the same elements. The figures are not necessarily to scale and certain features and certain views of the figures may be shown exaggerated in scale for purposes of clarification.

(14) Furthermore, when introducing elements of various embodiments of the present disclosure, the articles “a,” “an,” and “the” are intended to mean that there are one or more of the elements. The terms “comprising,” “including,” and “having” are intended to be inclusive and mean that there may be additional elements other than the listed elements. Additionally, it should be understood that references to “one embodiment,” “an embodiment,” or “some embodiments” of the present disclosure are not intended to be interpreted as excluding the existence of additional embodiments that also incorporate the recited features. Furthermore, the phrase A “based on” B is intended to mean that A is at least partially based on B. Moreover, unless expressly stated otherwise, the term “or” is intended to be inclusive (e.g., logical OR) and not exclusive (e.g., logical XOR). In other words, the phrase A “or” B is intended to mean A, B, or both A and B.

(15) Hydrocarbon fluids, such as oil and natural gas, may be obtained from subterranean or subsea geologic formations, often referred to as reservoirs, by drilling one or more wells that penetrate the hydrocarbon-bearing geologic formation. In subsea applications, various types of infrastructure may be positioned underwater and/or along a sea floor to aid in retrieving the hydrocarbon fluids. In both land-based and subsea applications, electrical cables may be used to carry power, data signals, and/or control signals and/or for the heating of equipment and pipes. Such electrical cables may transmit high voltages and/or currents. Additionally, in some scenarios, the cables may encounter extreme operating conditions such as low temperatures (e.g., less than 20 degrees, less than zero degrees, or less than -20 degrees Celsius), high temperatures (e.g., above 40 degrees, above 70 degrees, above 100 degrees, or above 130 degrees Celsius), temperature variations between low and high temperatures within a short time frame (e.g., seconds, minutes, or hours), and/or corrosive environments such as downhole or subsea. As such, one or more electrical

conductors within a cable may be surrounded by one or more layers of an electrically insulating material and/or one or more layers of additional protective materials. These layers of materials may function as an insulating barrier (e.g., electrical and/or thermal insulating barrier), a chemical barrier (e.g., corrosion resistant barrier, oxidation resistant barrier, etc.), a mechanical barrier (e.g., impact resistant barrier), or a combination thereof, between the conductor(s) and the surrounding environment.

(16) In some embodiments, the cable may include one or more electrical conductors surrounded by a porous insulating material. The insulating material may include a loose or tightly packed fill of insulating elements, such as insulating fibers, powder, or other discrete particles distributed about the electrical conductors. The insulating material may include one or more of polymers, ceramics, porcelains, glass, fabrics, or any combination thereof. For example, a mineral insulator such as an inorganic powder (e.g., magnesium oxide (MGO) or other ceramic) may be used to fill an annulus between the conductor(s) and an outer casing to form the cable. Such insulated cables may be suitable for high heat (e.g., greater than or up to 200 degrees, greater than or up to 400 degrees, greater than or up to 600 degrees Celsius, etc.) environments, which may be advantageous for heating (e.g., pipeline heating). In the case of multiple conductors, the individual conductors may or may not include individual shielding or other insulation between the conductors.

(17) In some scenarios, the porous and/or powdered insulating material may be hygroscopic (i.e., tending to absorb moisture). Additionally, it is noted that powdered insulating materials may be structurally unstable and have a tendency to crumble or otherwise lose their form when handled. Furthermore, if allowed to absorb moisture, the electrical (e.g., insulating) properties of the porous and/or powdered insulating material may be altered and/or degraded, reducing the effectiveness, efficiency, and/or efficacy of the cable. As such, when preparing ends of the cable for termination/connection it may be desired to effectively seal the porous and/or powdered insulating material such that moisture does not permeate through the cable from the exposed end during and/or after a connection is formed.

(18) In some scenarios, oil may be utilized as a moisture barrier for the porous and/or powdered insulating material. However, being a fluid, oil may still allow some moisture to gain access to the porous and/or powdered insulating material, as well as form air bubbles, and has little structural integrity. Alternatively, in some embodiments, the insulating annulus of porous and/or powdered insulating material may be injected with a solidifying material (e.g., adhesives, sealants, encapsulating materials, etc.), such that the solidifying material can be injected in one state (e.g., liquid, gel, etc.) into the insulating material and subsequently harden into another state (e.g., solid) that generates a solid end portion of the cable. The solidifying material may include one or more epoxy resins, polymers (e.g., thermosetting polymers), polyester, vinyl, polyimides, polyurethane, nylon, or any combination thereof. However, the following discussion may refer to an epoxy material as an example of a solidifying material to penetrate an end of a cable. For example, the solidifying material may include a dielectric epoxy resin to seal the end face of the insulating annulus. Additionally, the epoxy-solidified insulating material may provide structural integrity at the end face of insulating annulus, which may assist in forming a stable physical connection for the cable. For example, the end face of the insulating annulus may be shaped using a cutting tool for proper fitment of a cable connection, which may provide improved (e.g., increased) tracking resistance at the connection.

(19) In some embodiments, to prepare the electrical cable for termination/connection via epoxy resin injection, a length of the outer casing and insulating material may be removed leaving a portion of the conductor exposed. A cable clamp may be fitted around the outer casing near the open end face of the outer casing to allow an injection barrel to be attached to the electrical cable via the cable clamp. The injection barrel may include one or more ports for filling a chamber of the injection barrel with epoxy and evacuating air from the chamber. In some embodiments, the injection barrel may form a seal with the cable clamp, and a piston, coupled to the injection barrel,

may be actuated to pressurize the epoxy within the chamber, forcing the epoxy to permeate into the insulating material. After the epoxy has been injected, the injection barrel and cable clamp may be removed before curing, after curing, or at an intermediate stage of curing. After curing, the insulating material may then have an epoxy-solidified portion that penetrates a distance into the end face of the cable. Moreover, the epoxy-solidified portion of the insulating material may then be shaped as desired for termination/connection.

(20) With the foregoing in mind, FIG. 1 is a schematic view of a subsea production system **10** with electrical cables **12** used for transmitting information and power and/or heating of equipment and/or pipes, according to an embodiment of the present disclosure. Additionally, the subsea production system may include a subsea tree **14** coupled to a wellhead **16** to form a subsea station **18** that extracts formation fluid, such as oil and/or natural gas, from the sea floor **20** through the well **22**. In some embodiments, the subsea production system **10** may include multiple subsea stations **18** that extract formation fluid from respective wells **22**. After passing through the subsea tree **14**, the formation fluid flows through jumper cables **24** to a pipeline manifold **26**. The pipeline manifold **26** may connect to one or more flowlines **28** to enable the formation fluid to flow from the wells **22** to a surface platform **30**. In some embodiments, the surface platform **30** may include a floating production, storage, and offloading unit (FPSO) or a shore-based facility. In addition to flowlines **28** that carry the formation fluid away from the wells **22**, the subsea production system **10** may include lines or conduits **32** that supply fluids, as well as carry control and data lines to the subsea equipment. These conduits **32** connect to a distribution module **34**, which in turn couples to the subsea stations **18** via supply lines **36**. In some scenarios, the platform **30** may be located a significant distance (e.g., greater than 100 m, greater than 1 km, greater than 10 km, or greater than 60 km) away from the wells **22**. As fluids (e.g., reservoir fluids) flow between the wells **22** and the platform **30** the fluids may cool, potentially slowing flow (e.g., due to increased viscosity) and/or allowing wax and/or hydrates to form. To prevent such undesired effects, heating elements, such as insulated cables (e.g., electrical cables **12**), may be used to heat the flowlines **28**.

(21) As should be appreciated, each of the jumper cables **24**, flowlines **28**, conduits **32**, supply lines **36**, and/or other equipment may include electrical cables **12** for heating (e.g., resistive heating) and/or for transmitting power/electrical signals. Moreover, as should be appreciated, such electrical cables **12** may also be used on the surface (e.g., above water) above ground or buried for land-based operations. For example, electrical cables **12** may be used in regions of cold temperatures to heat pipes and/or equipment to facilitate the flow of oil or other fluids through the pipes/equipment and/or to prevent freezing. Furthermore, although discussed herein as relating to oil and gas technologies, as should be appreciated, aspects of the present disclosure may be applicable to electrical cables **12** used in many different fields such as aerospace, nuclear, automotive, and/or civil infrastructure.

(22) FIG. 2 is a perspective view of an electrical cable **12** disposed along an axial axis **40**, according to an embodiment of the present disclosure. The electrical cable **12** includes one or more conductors **42**, an outer casing **44**, and an insulating material **46** forming an annulus therebetween. The conductor **42** may be any suitable conductive material such as copper, nickel, aluminum, gold, silver, etc. or any suitable conductive alloy (e.g., nickel-iron alloy, steel, etc.). Additionally, the outer casing **44** may include any suitable rigid housing such as steel, iron, copper, etc. or flexible housing such as a polymer. In some embodiments, the electrical cable **12** may be a mineral insulated cable having a porous and/or powdered insulating material **46** such as MGO or other mineral or ceramic. As should be appreciated, while MGO is discussed herein as a suitable insulating material **46**, other insulating materials that are porous enough to allow for injection of a solidifying material (e.g., epoxy) may also be utilized. For example, the insulating material **46** may include one or more of polymers, ceramics, porcelains, glass, fabrics, or any combination, wherein the insulating material **46** may be porous or distributed as a plurality of insulating elements (e.g., powder, fibers, particles, etc.).

(23) To facilitate preparation for injection and a subsequent connection, a length **48** of the insulating material **46** and outer casing **44**, measured from the end face **50** of the insulating material **46**, may be removed, as shown in FIG. 3. For example, an orbital cut may be made around the circumference of the outer casing **44** and/or one or more longitudinal cuts may be performed down the length **48** of the outer casing **44** that is to be removed. In the case of a powdered insulating material **46**, the exposed portion of the conductor **42** may be cleaned of excess insulating material **46**. As should be appreciated, while discussed herein as exposing a portion of the conductor **42** by cutting back the insulating material **46** and outer casing **44**, different shapes and types of terminations/connections may leave the end face **50** of the insulating material **46** flush with or at different angles relative to the conductor **42** during the injection process.

(24) To facilitate injecting an epoxy or other setting resin/fluid into the insulating material **46**, a cable clamp **60** may be coupled around the outer casing **44**, as shown in FIG. 4. The cable clamp **60** may form a stable basis from which to force the epoxy into the annulus, between the outer casing **44** and the conductor **42**, occupied by the insulating material **46**. In some embodiments, the cable clamp **60** may utilize a compression fitting to be secured to the electrical cable **12**. For example, the cable clamp **60** may include a clamp body **62** (e.g., annular clamp body), a clamp collet **64** (e.g., annular clamp collet), and a clamp collar **66** (e.g., annular clamp collar). The clamp collet **64** may be compressed by the clamp collar **66** as the clamp body **62** and the clamp collar **66** are secured (e.g., bolted) together such that, as a whole, the cable clamp **60** is secured around the outer casing **44** of the electric cable **12**. In some embodiments, the clamp body **62** or other portion of the cable clamp **60** may be near and/or flush with the end face **50** of the insulating material **46** to facilitate directing the epoxy into the annulus. As should be appreciated, although described herein as a compression fitting, the cable clamp **60** may use any other suitable securements to couple to the electrical cable **12** such as threads along the outer casing **44** and/or a compression fitting, or threads, on a portion of the conductor **42**.

(25) FIG. 5 is a schematic cross-sectional view of the cable clamp **60** coupled to the outer casing **44** of the electrical cable **12**, according to an embodiment of the present disclosure. As one or more fasteners **68** (e.g., bolts, screws, nuts, etc.) are secured between the clamp collar **66** and the clamp body **62**, an axial force is applied by the clamp collar **66** to compress the clamp collet **64** and fix the clamp body **62** to the outer casing **44** of the electrical cable **12**. The clamp collet **64** may include a tapered annular interface **70** (e.g., conical interface) to operatively contact a complementary tapered annular interface **72** of the clamp collar **66** such that the axial force may be translated to a radial force. For example, as the axial force is applied by the fasteners **68** to compress the clamp collar **66** onto the clamp collet **64**, the tapered annular interface **70** of the clamp collet **64** is compressed radially, generating a radial inward force from the clamp collet **64** onto the electrical cable **12**, securing the cable clamp **60** to the outer casing **44**. In some embodiments, the clamp body **62** may include one or more body seals **74** (e.g., gaskets, O-rings, bellow seals, etc.) such that epoxy leakage along the exterior of the outer casing **44** (e.g., between the outer casing **44** and the cable clamp **60**) is minimized or eliminated.

(26) The cable clamp **60** may allow for an injection barrel **80** (e.g., annular barrel) to be secured to the electrical cable **12**, as shown in FIG. 6. For example, the clamp body **62** may include threads **82** or other securement to couple the injection barrel **80** to the cable clamp **60**. Additionally, in some embodiments, the cable clamp **60** (e.g., the clamp body **62**) and/or the injection barrel **80** may include one or more barrel seals **84** (e.g., gaskets, O-rings, bellow seals, etc.) to minimize or eliminate epoxy leakage between the injection barrel **80** and the cable clamp **60**. The injection barrel **80** may include one or more ports **86** (e.g., port **86A** and/or port **86B**, cumulatively **86**) for filling a chamber **88** within the injection barrel **80** with epoxy resin and/or for evacuating air from the chamber **88**. For example, one port **86A** may be used to fill the chamber **88** with epoxy while air is allowed to escape, naturally or via suction (e.g., using a vacuum), through the other port **86B**. The chamber **88** may be open to the exposed end face **50** of the insulating material **46** such that

pressurization of epoxy in the chamber **88** forces the epoxy into the insulating material **46**. In some embodiments, the injection barrel **80** may include a removable endcap **90** and one or more cap seals **92** (e.g., gaskets, O-rings, bellow seals, etc.) disposed on the endcap **90** or the injection barrel **80**. The endcap **90** may be removed to facilitate access to the chamber **88** (e.g., for a pre-filling of the chamber **88** with epoxy, cleaning of the chamber **88**, etc.).

(27) In some embodiments, the epoxy resin is a dielectric epoxy, such as to maintain the insulating electrical properties of the insulating material **46**. Furthermore, in some embodiments, the epoxy resin may be of relatively low viscosity (e.g., less than 200 mPaS, less than 300 mPaS, less than 400 mPaS, etc.) such that the epoxy may be pressurized and permeated into the insulating material. As should be appreciated, any suitable epoxy, single or multi-part (e.g., two-part epoxy), having a viscosity low enough to permeate the insulating material **46** may be used.

(28) In some embodiments, the chamber **88** (e.g., annular chamber) may be pressurized via the inflow of pressurized epoxy through a port **86**. Additionally or alternatively, the port(s) **86** may be sealed (e.g., via one or more plugs (not shown)) and a piston **94** (e.g., annular piston) may be actuated (e.g., hydraulically actuated, electronically actuated, or actuated by hand) to pressurize the chamber **88**. The piston **94** may be linearly actuated by an axial force or rotationally actuated (e.g., using a jackscrew) to move into the chamber **88**, decreasing the volume within the chamber **88** and, thus, increasing the pressure within the chamber **88**. For example, the piston **94** may include a threaded portion operatively screwed into the injection barrel **80** (e.g., through endcap **90**) to a given torque to pressurize the epoxy in the chamber **88** to a particular pressure. For example, the piston **94** may be torqued to provide a pressure of 1000-3000 psi, 2000-4000 psi, 3000-5000 psi, 4000-6000 psi, or greater than or equal to 5000 psi. As should be appreciated, the applied pressure to facilitate permeation of the epoxy into the insulating material **46** may vary based on implementation (e.g., viscosity of the epoxy, porosity of the insulating material **46**, etc.). In some embodiments, the pressure within the chamber **88** may be maintained at a desired level constantly or periodically to continue forcing the epoxy into the insulating material **46** until the epoxy has reached a handling time, reached a desired depth of penetration, or fully cured. For example, the piston **94** may be actuated every few minutes (e.g., every 1 minute, every 2 minutes, every 5 minutes, every 10 minutes, etc.) to maintain pressure within the chamber **88** as the epoxy permeates into the insulating material **46**. Pressure may be maintained until the epoxy has reached a desired depth into the insulating material **46**, until an intermediate setting (i.e., prior to full curing) of the epoxy, or until full curing of the epoxy. However, as should be appreciated, waiting until full curing of the epoxy may lead to difficulty removing the injection barrel **80**, cable clamp **60**, and/or excess epoxy from the electrical cable **12**. The epoxy may penetrate the insulating material **46** by any suitable amount, and may depend on the insulating material **46** and the viscosity of the epoxy. For example, a relatively low viscosity epoxy may penetrate the insulating material **46** at least 2 mm, at least 5 mm, at least 20 mm, between 5 mm and 15 mm, between 15 mm and 25 mm, between 25 mm and 35 mm, or greater than 35 mm. In certain embodiments, the epoxy may penetrate the insulating material **46** to an axial depth of at least 10, 20, 30, 40, 50, 60, 70, 80, 90, or 100 percent of a diameter of the electrical cable **12**. Additionally, as should be appreciated, the pressure utilized within the chamber **88** may be based on implementation (e.g., type and/or density of insulating material **46**, viscosity of epoxy, desired depth of penetration, etc.).

(29) In some embodiments, the injection barrel **80** and the cable clamp **60** may be removed before the epoxy has fully cured. For example, after an initial setting time of the epoxy, the injection barrel **80** and the cable clamp **60** may be removed (e.g., for cleaning) and the electrical cable **12** may be allowed to sit until the epoxy fully cures. FIG. 7 is a perspective view of the electrical cable **12**, after the epoxy has cured, including an epoxy-solidified portion **100** of the insulating material **46** that penetrates (shown via arrows **102**) a distance into the end face **50** of the insulating material **46**, according to an embodiment of the present disclosure. After curing, the epoxy-solidified portion **100** of the insulating material **46** may provide structural integrity to the insulating material **46** and

act as a moisture barrier between the potentially hygroscopic insulating material **46** and the environment.

(30) Additionally, in some embodiments, the epoxy-solidified portion **100** of the insulating material **46** may be shaped via a cutting tool **110**, such as shown in FIG. **8**. As should be appreciated, cutting may occur after full curing of the epoxy or before full curing if the epoxy has set enough to be handled. In some embodiments, the cutting tool **110** may include abrasive edges **112** (e.g., diamond, corundum, silicon carbide, etc.) to cut into the epoxy-solidified portion **100** of the insulating material **46**. Moreover, the cutting tool **110** may have an opening **114** through which the conductor **42** may be fed to facilitate radially symmetric cutting of the epoxy-solidified portion **100** of the insulating material **46** about the axial axis **40** without damaging the conductor **42**.

Additionally, in some embodiments, the cutting tool **110** may include one or more topological characteristics **116** such as chamfers or bevels to generate different geometries in the epoxy-solidified portion **100** of the insulating material **46**. For example, the epoxy-solidified portion **100** of the insulating material **46** may be shaped to match one or more connection profiles associated with a desired connection of the electrical cable **12**. As should be appreciated, any suitable cutting tool **110** may be used to generate any desired shape for facilitating a particular termination/connection.

(31) FIG. **9** is a schematic cross-sectional view of an example cable connection **120** utilizing an electrical cable **12** prepared with an epoxy-solidified portion **100** of the insulating material **46**, according to an embodiment of the present disclosure. In one embodiment, the cable connection **120** may be an electrical connection described in U.S. Pat. No. 7,731,515, which is incorporated herein by reference in its entirety. In the depicted embodiment, a connector geometry **122** has been cut into the epoxy-solidified portion **100** of the insulating material **46** to form a basis for interfacing (e.g., seating, sealing, etc.) with another insulator **124** with reduced or eliminated air gaps, which may improve tracking resistance and/or other electrical properties/characteristics of the connection. As should be appreciated, the cable connection **120** is shown as an example and is, as such, non-limiting. Indeed, the systems and methods of the present disclosure may be utilized for any connection utilizing an electrical cable **12** that may benefit from epoxy resin injection preparation.

(32) FIG. **10** is a flowchart of an example process **130** for preparing an electrical cable **12** for termination/connection via epoxy resin injection, according to embodiments of the present disclosure. In some embodiments, to prepare the electrical cable **12** for termination/connection via epoxy resin injection, a length **48** of the outer casing **44** and insulating material **46** may be removed, exposing a portion of the conductor **42** (process block **132**). Additionally, a cable clamp **60** may be coupled to the outer casing **44** of the electrical cable **12** (process block **134**), and an injection barrel **80** may be coupled to the cable clamp **60** such that a chamber **88** of the injection barrel **80** is in fluid contact with the insulating material **46** (process block **136**). The chamber **88** may be filled with a dielectric epoxy resin (e.g., via one or more ports **86**) and air may be evacuated from the chamber (process block **138**). Furthermore, the chamber **88** may be pressurized such that the dielectric epoxy resin is forced to permeate into the insulating material **46** (process block **140**). Pressure may be maintained until the epoxy has reached a desired depth into the insulating material and/or reached a desired setting point (i.e., an amount of curing) (process block **142**). The injection barrel **80** and the cable clamp **60** may be removed, and the epoxy may be allowed to cure (process block **144**). After curing, the epoxy-solidified portion of the insulating material **46** may be shaped (e.g., via a cutting tool **110**) as desired to facilitate termination/connection of the electrical cable **12** (process block **146**).

(33) The technical effects of the systems and methods described in the embodiments of FIGS. **1-10** include the injection of a solidifying material into a porous and/or powdered insulating material **46** that forms an annulus around a conductor **42** of an electrical cable **12**. The insulating material **46** may include one or more of polymers, ceramics, porcelains, glass, fabrics, or any combination, wherein the insulating material **46** may be porous or distributed as a plurality of insulating elements

(e.g., powder, fibers, particles, etc.). The solidifying material may include one or more epoxy resins, polymers (e.g., thermosetting polymers), polyester, vinyl, polyimides, polyurethane, nylon, or any combination thereof. For example, the solidifying material may include a dielectric epoxy resin. The epoxy injection may provide for a more stable, physically shapeable, and sealed terminal end of the electrical cable 12, which may further provide improved electrical properties such as improved tracking resistance. Furthermore, although the above referenced flowchart is shown in a given order, in certain embodiments, process blocks may be reordered, altered, deleted, and/or occur simultaneously. Additionally, the referenced flowchart is given as an illustrative tool and further decision and process blocks may also be added depending on implementation.

(34) As used herein, the terms “inner” and “outer”; “up” and “down”; “upper” and “lower”; “upward” and “downward”; “above” and “below”; “inward” and “outward”; and other like terms as used herein refer to relative positions to one another and are not intended to denote a particular direction or spatial orientation. The terms “couple,” “coupled,” “connect,” “connection,” “connected,” “in connection with,” and “connecting” refer to “in direct connection with” or “in connection with via one or more intermediate elements or members.”

(35) The foregoing description, for purpose of explanation, has been described with reference to specific embodiments. However, the illustrative discussions above are not intended to be exhaustive or to limit the disclosure to the precise forms disclosed. Many modifications and variations are possible in view of the above teachings. Moreover, the order in which the elements of the methods described herein are illustrated and described may be re-arranged, and/or two or more elements may occur simultaneously. The embodiments were chosen and described to best explain the principals of the disclosure and its practical applications, to thereby enable others skilled in the art to best utilize the disclosure and various embodiments with various modifications as are suited to the particular use contemplated.

(36) Finally, the techniques presented and claimed herein are referenced and applied to material objects and concrete examples of a practical nature that demonstrably improve the present technical field and, as such, are not abstract, intangible or purely theoretical. Further, if any claims appended to the end of this specification contain one or more elements designated as “means for [perform]ing [a function] . . .” or “step for [perform]ing [a function] . . .,” it is intended that such elements are to be interpreted under 35 U.S.C. § 112(f). However, for any claims containing elements designated in any other manner, it is intended that such elements are not to be interpreted under 35 U.S.C. § 112(f).

Claims

1. A method for preparing an electrical cable, comprising: coupling an injection barrel to the electrical cable, wherein the electrical cable comprises one or more conductors surrounded by a porous insulating material within an outer casing; injecting, via one or more ports, epoxy resin into a chamber of the injection barrel, wherein the chamber surrounds the one or more conductors and is fluidly coupled to an end face of the porous insulating material; pressurizing the chamber such that the epoxy resin is forced to penetrate into the end face of the porous insulating material; and removing the injection barrel to expose an epoxy-injected portion of the porous insulating material.
2. The method of claim 1, comprising waiting for the epoxy-injected portion of the porous insulating material to cure to generate an epoxy-solidified portion of the porous insulating material.
3. The method of claim 2, comprising shaping, via a cutting tool, the epoxy-solidified portion of the porous insulating material according to a connection profile.
4. The method of claim 3, wherein the cutting tool comprises a diamond abrasive cutting tool.
5. The method of claim 1, comprising coupling a cable clamp to the outer casing of the electrical cable, wherein the injection barrel is coupled to the electrical cable via the cable clamp.
6. The method of claim 5, wherein the cable clamp comprises a compression fitting configured to

secure the cable clamp to the outer casing of the electrical cable.

7. The method of claim 1, wherein the porous insulating material comprises powdered magnesium oxide (MGO).

8. The method of claim 1, comprising removing a length of the outer casing of the electrical cable and the porous insulating material, leaving an exposed portion of the one or more conductors.

9. The method of claim 1, wherein the injection barrel comprises a piston configured to actuate into the chamber, wherein pressurizing the chamber comprises actuating the piston into the chamber.

10. The method of claim 1, wherein the injection barrel comprises a plurality of ports configured to evacuate air from the chamber and fill the chamber with the epoxy resin.

11. The method of claim 1, wherein the one or more conductors comprise nickel alloy or copper cores.

12. A method for connecting a prepared electrical cable, comprising: inserting the prepared electrical cable into a cable connection, wherein the cable connection comprises a first geometry and the prepared electrical cable comprises a shaped epoxy-solidified portion of a porous insulating material comprising a second geometry complementary to the first geometry, wherein the prepared electrical cable is prepared by: coupling an injection barrel to an unprepared electrical cable, wherein the unprepared electrical cable comprises one or more conductors surrounded by the porous insulating material within an outer casing; injecting, via one or more ports, epoxy resin into a chamber of the injection barrel, wherein the chamber surrounds the one or more conductors and is fluidly coupled to an end face of the porous insulating material; pressurizing the chamber such that the epoxy resin is forced to penetrate into the end face of the porous insulating material; removing the injection barrel to expose the epoxy-injected portion of the porous insulating material; and cutting into the epoxy-injected portion of the porous insulating material to generate the second geometry.

13. The method of claim 12, wherein coupling the injection barrel to the unprepared electrical cable comprises securing a cable clamp to the outer casing of the unprepared electrical cable and mechanically coupling the injection barrel to the cable clamp.

14. The method of claim 12, wherein the epoxy resin comprises a dielectric epoxy resin.

15. The method of claim 12, wherein the insulating material comprises an inorganic mineral material.
