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Bayles et al.

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[54] **HIGH TEMPERATURE ELECTRICAL CABLE**

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[51] **Int. Cl.**..... **H01b 7/18**; H01b 3/04

[58] **Field of Search**..... 174/102 R, 102 A, 110 S, 174/110 R, 120 R, 120 C, 121 A, 122 R, 122 G, 124 R, 124 G, 124 GC, 126 R, 126 CP, 128, 25 C, 105 R, 106 R

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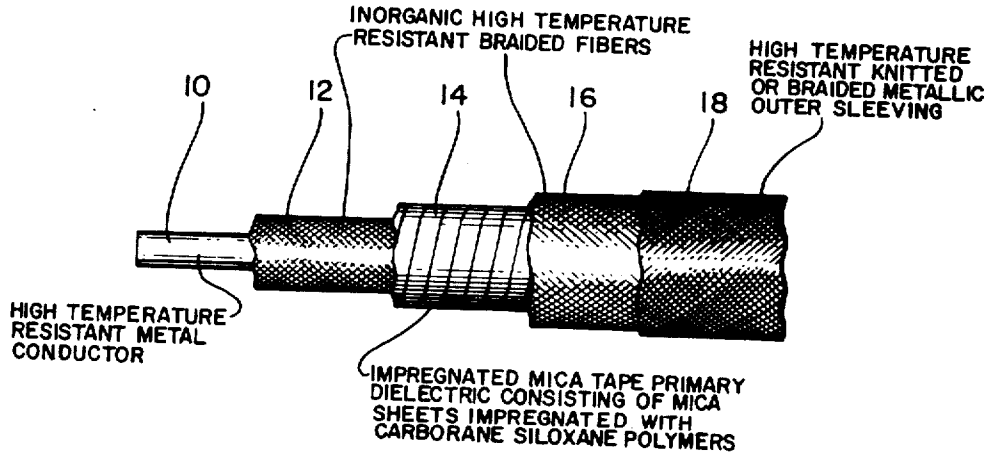
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[57] **ABSTRACT**

A high temperature electrical cable comprising generally three parts is disclosed, namely a central conductor, a covering of insulating material applied over the central conductor and an outer protective sleeving applied over the covering of insulating material. The central conductor is made of stranded or solid metal capable of essentially maintaining its useful service at high temperature. The covering of insulating material consists of at least one inner layer of inorganic high temperature material providing essentially complete coverage of the conductor and a smooth base for the subsequent layers, at least two layers of primary dielectric material consisting of mica tapes made from reconstituted mica sheets impregnated with carborane siloxane polymers, and an outer layer of inorganic high temperature material over the mica tapes such as to provide essentially complete coverage of the primary dielectric layers. The outer protective sleeving is achieved either by knitting or braiding one or more fine high temperature resistant wires onto the covering of insulating material.

19 Claims, 5 Drawing Figures



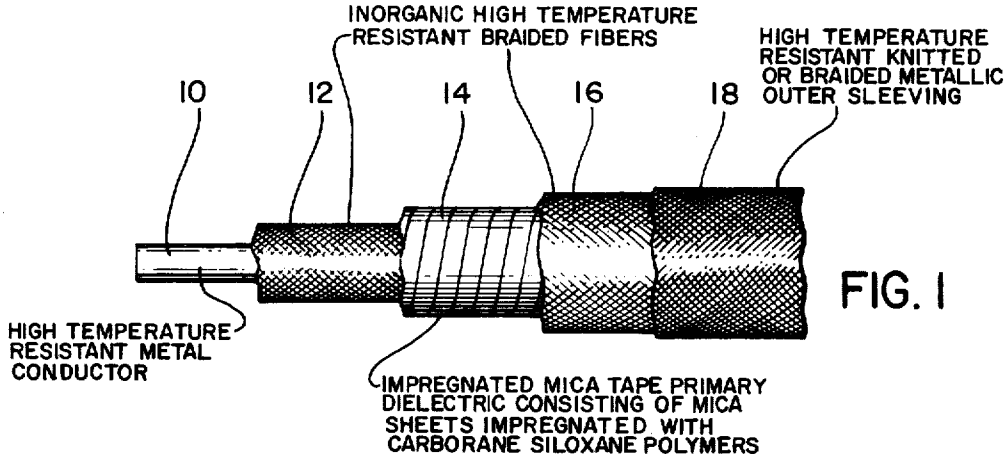


FIG. 1

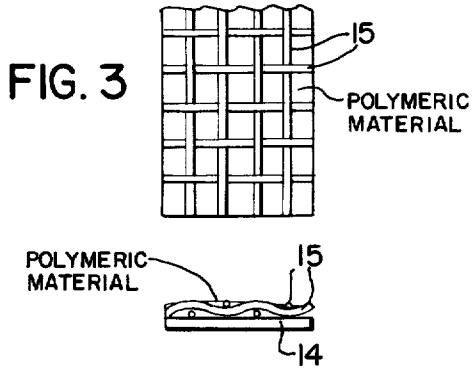


FIG. 3

FIG. 3a

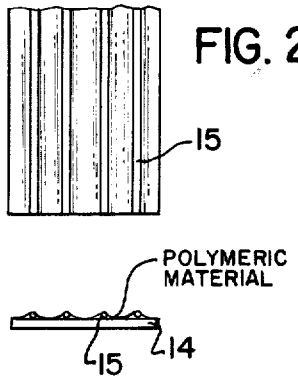


FIG. 2

FIG. 2a

HIGH TEMPERATURE ELECTRICAL CABLE

This invention relates to a high temperature electrical cable.

With the advent of more severe aircraft environments, expected to be encountered in supersonic transports and tactical aircraft operating considerably in excess of the speed of sound, there is an increasing need for large volumes of economically produced flexible cable which is small in diameter, lightweight, capable of carrying 600 volts or more, and capable of performing at 1,000°F or higher for extended periods of time.

Additionally, the operational conditions are such that the electrical cable should exhibit little or no tendency to smoke or fume, be relatively insensitive to moisture absorption, shock and impact and exhibit a minimum of abrasion destruction of the insulating layer or layers during vibration and flexing, all of these both before and after exposure to 1,000°F and greater.

Prior art insulated cable allegedly useful for this purpose has been successful in only some of the requirements, showing, for example, embrittlement, evolution of degradation products and loss of flexibility upon exposure to 1,000°F and greater.

Some of the prior art high temperature cables, such as the one disclosed in Canadian Pat. No. 870,247 issued May 4, 1971, are covered with an armoured sheathing which greatly reduces the flexibility of such cables.

It is therefore the object of the present invention to provide a high temperature cable which overcomes the above disadvantages of the prior art cables.

The high temperature cable, in accordance with the invention, comprises generally three parts: a central conductor, a covering of insulating material over the central conductor, and an outer protective sleeving over the covering of insulating material. The central conductor is made of stranded or solid metal capable of essentially maintaining its useful service at high temperature. The covering of insulating material consists of at least one inner layer of inorganic high temperature material providing essentially complete coverage of the conductor and a smooth base for the subsequent layers, at least two layers of primary dielectric material consisting of impregnated mica tapes made from reconstituted mica sheets impregnated with carborane siloxane polymers, and an outer layer of inorganic high temperature material over the mica tapes such as to provide essentially complete coverage of the primary dielectric layers. The outer protective sleeving is achieved either by knitting or braiding one or more fine high temperature resistant wires onto the covering of insulating material.

The central conductor may consist of a central metal core cladded with a dissimilar metal, selected from the group consisting of nickel clad copper, nickel clad silver, nickel alloy clad silver, nickel alloy clad copper, and stainless steel clad copper. It may also be made of rhodium or other suitable refractory metal.

The inner and outer layers of inorganic high temperature material may advantageously be braided fibers selected from the group consisting of quartz, leached glass, boron free glass and the like or combinations of them.

The mica tapes used in the primary dielectric layers may optionally be reinforced with a backing of any one of the above mentioned braided fibers applied as unidirectional thread or woven construction and impregnated with a polymeric material. Such polymeric material may be selected from the group consisting of carborane siloxane polymers, poly(siloxanes), or any other flexible inorganic polymers.

The mica tapes are preferably applied as lapped, open helically wound tapes in the same or opposite lay in different layers in order to give essentially complete coverage of the inner layer of high temperature material and a functional dielectric strength of 1,000 volts or more.

The metallic wires used in the outer protective sleeving may advantageously be made of stainless steel, nickel alloy or any other high temperature resistant material.

The invention will now be disclosed, by way of example, with reference to preferred embodiments thereof illustrated in the accompanying drawing wherein:

FIG. **1** illustrates an electrical cable in accordance with the invention;

FIGS. **2** and **2***a* illustrate an elevation and a side view respectively of a portion of the tape which may be used for making the cable of FIG. **1**; and

FIGS. **3** and **3***a* illustrate another configuration of a tape which may be used for making the cable of FIG. **1**.

Referring to the drawing, there is shown a high temperature electrical cable comprising a central conductor **10** which may be a solid metal conductor or made of a plurality of metal wires stranded together. As mentioned previously, the metal of the conductor must be capable of maintaining its useful service at high temperature. It may consist of a central core cladded with a dissimilar metal, such as nickel clad copper, nickel clad silver, nicekl alloy clad copper, nickel alloy clad silver and stainless steel clad copper. It may also be made of rhodium or any other suitable refractory metal. In a preferred but not limitative embodiment of the invention, the conductor was a solid conductor made of a fine silver core cladded with a nickel alloy sheath representing a cross-section area for the sheath of between 25 and 50 percent, and preferably in the range of 40–50 percent of the total cross-section area. The nickel alloy used was one known under the Trademark Inconel 600 sold by International Nickel Company. It is to be understood that other conductor configurations capable of maintaining their useful service at high temperature may be used.

The conductor **10** is then covered with at least one layer of inorganic high temperature material **12**. The purpose of the inorganic high temperature material is to give essentially complete coverage of the conductor and provide a smooth surface for subsequent layers and thus improve the flexibility of the cable. In a preferred embodiment of the invention, such high temperature material was in the form of braided fibers selected from the group consisting of quartz, leached glass, boron free glass and the like or combinations of them. Some commercial sources of these fibers include the ones known under the trademarks "S" glass of Owens Corning, Refrasil of Hitco, Sil-Temp of Haveg, and AstroQuartz of J.P. Stevens. Braiding is achieved at between 10 and 18 fiber picks per inch, for a nominal 0.03 in. cord on a 12 AWG conductor. One or two layers of braided fibers were found to be sufficient but it is to be understood that plural layers may be used if necessary, more particularly if other materials than braided fibers are employed. It is to be understood that other inorganic high temperature materials could be

used in place of braided fibers.

At least two layers of primary dielectric materials consisting of impregnated mica tapes **14** made of reconstitued micaceous sheets impregnated with carborane siloxane polymers are then helically wound over the layer **12.** In the preferred, but not limitative, embodiment of the invention, the primary dielectric layer consisted of three layers of lapped, open helically wound impregnated mica tapes, **2** thousandths of an inch thick by ¼ inch wide which had been previously impregnated with a cured decaborane-siloxane polymer known under the trademark Dexsil 300 sold by Olin Mathieson Company at an approximate loading of 2 to 25 percent, preferably 6 to 12 percent by weight on weight of mica paper. These tapes were laid in the same direction or in opposite directions in different layers so as to achieve essentially complete coverage of the inner layer **12** and a dielectric strength of 1,000 volts or more, under a variety of environmental exposure conditions. It is to be understood that the number of layers of mica tapes may be higher than two. It is also to be understood that other carborane siloxanes may also be used as impregnants for reconstituted mica sheets. Some of the carborane siloxane materials that have been found particularly good as impregnating materials for reconstituted micaceous sheets include decaborane siloxane polymers such as the ones known under the trademark Dexsil and sold by Olin Mathieson Company, pentaborane siloxane polymers such as the ones known under the trademark Pentasil and sold by Chemical Systems Inc., and mixed meta - and para - decaborane siloxane polymers such as the ones known under the trademark Ucarsil and belonging to Union Carbide Corporation. Copolymers of deca- and pentaborane siloxane polymers as well as physical combinations of deca- and penta-borane siloxane polymers have also been advantageously used. These mica-impregnant combinations result in a primary dielectric material showing excellent initial flexibility and tensile strength, excellent dielectric strength, low weight change and moisture pick-up and significantly better retention of these properties after high temperature exposure, in comparison to other commercially available materials. Further references to specific properties and methods of construction of these composites may be found in U.S. application No. 488,408 filed July 15, 1974.

Layer **14** of primary dielectric insulating material is covered with a further layer **16** of inorganic high temperature material similar to inner layer **12** so as to give essentially complete coverage of the primary dielectric layer **14.**

FIGS. **2** and **2***a* illustrate an elevation and side view respectively of a portion of a tape **14** reinforced with a backing of braided fibers **15** applied as unidirectional threads whereas FIGS. **3** and **3***a* illustrate corresponding views of a tape **14** reinforced with a backing of braided fibers **15** applied as a woven construction.

Finally, an outer sleeving **18** achieved by knitting or braiding one or more fine, high temperature resistant metal wires, is applied over the previously assembled configuration. As mentioned previously, such a wire could be made of stainless steel or nickel alloys. In a preferred embodiment, the sleeving was a knitted sleeve made of Inconel 600 wire. It is to be understood that other high temperature resistant wires would be suitable. It is important to note that this type of outer protection allows greater flexibility of the wire, smaller wire diameter, and lighter weight than other armoured sheathings known in the prior art such as the one disclosed in Canadian Patent No. 870,247 issued May 4, 1971.

Testing was carried out on the above mentioned preferred embodiment consisting of a 12 AWG conductor of a fine silver core oversheathed with Inconel 600, a first inorganic layer of braided fibers known as Refrasil C-**100-2,** a primary dielectric insulation consisting of three layers of lapped, open helically wound impregnated mica tapes of 0.002 of an inch thick by ¼ inch wide previously impregnated with a cured decaborane-siloxane polymer (Dexsil 300) at an approximate loading of 10 percent by weight on weight of mica paper, another inorganic layer of braided fiber of Refrasil C-**100-2,** and a protective sleeving of knitted 0.0045 inch diameter Inconel 600 wire.

The results given in the Table have been obtained against a performance requirement noted in brackets:

TABLE

PERFORMANCE PROPERTIES OF PREFERRED EMBODIMENT

Test Condition	Dielectric[1] Withstand (Requirement 2.2 KV for 5 sec.)	Dielectric[1] Breakdown in Kilovolts (Requirement 1.2 KV)	Insulation[2] Resistance in megohms/ft (Requirement >1.0 megohm/ft.)
Mandrel and thermal shock	passed	4.1	
As fabricated	passed		1.3×10^7
76°F/50% RH	passed	>5.0	
76°F/100% RH	passed	4.4	
At 1250°F	passed	2.4	8.0
76°F/50% RH	passed	>5.0	11.4×10^6
At −65°F	passed	4.8	
76°F/100% RH			8.3×10^2
At 1250°F			3.5
After 800 hrs. at 1250°F		2.0	

[1]Test performed in accordance with ASTM D149
[2]Test performed in accordance with ASTM D257
Vibration: (20 g, 10–2000 cps) passed
Mechanical shock: (50 g, 11 ± millisecond) passed
Abrasion resistance: Janco Abrader, 30 in. of garnet tape (12 in. garnet tape)
Mandrel flexibility: (wind ⩾ 20 × wire diameter) passed 10 ×

This construction also carried an electrical load in 1,200 volts R.M.S. without breakdown for three hours in a direct flame of approximately 1,000°C. Furthermore, the insulation did not burn or smoke throughout the duration of the exposure.

What is claimed is:

1. A high temperature electrical cable comprising:

a. a central conductor made of a metal capable of essentially maintaining its useful service at high temperatures;

b. a covering of electrical insulating material applied over said conductor and consisting of at least one inner layer of inorganic high temperature material providing essentially complete coverage of said conductor and a smooth base for subsequent layers, at least two layers of primary dielectric material consisting of impregnated mica tapes made of reconstituted mica sheets impregnated with carborane siloxane polymers, and at least one outer layer of inorganic high temperature material over said impregnated mica tapes; and

c. an outer layer protective sleeving applied by knitting or braiding over said outer layer of inorganic high temperature material and consisting of at least one high temperature resistant metal wire.

2. A high temperature electrical cable as defined in claim **1**, wherein the central conductor is made of solid metal.

3. A high temperature electrical cable as defined in claim **1**, wherein the central conductor is made of plural strands of metal.

4. A high temperature electrical cable as defined in claim **1**, wherein the central conductor consists of a central metal core cladded with a dissimilar metal.

5. A high temperature electrical cable as defined in claim **4**, wherein the central conductor is made of a metal selected from the class of metal consisting of nickel clad copper, nickel clad silver, nickel alloy clad copper, nickel alloy clad silver and stainless steel clad copper.

6. A high temperature electrical cable as defined in claim **1**, wherein the central conductor is made of rhodium.

7. A high temperature electrical cable as defined in claim **1**, wherein the conductor consists of a silver core protected by a nickel alloy sheath representing a cross-sectional area for the sheath of between 25 and 50 percent of the total cross-section area of the conductor.

8. A high temperature electrical cable as defined in claim **7**, wherein the nickel alloy sheath represents a cross-sectional area for the sheath of preferably between 40 and 50 percent of the total cross-section area of the conductor.

9. A high temperature electrical cable as defined in claim **1**, wherein the inner and outer layers of inorganic high temperature material are made of braided fibers selected from the group consisting of quartz, leached glass, boron free glass and the like and combinations thereof.

10. A high temperature electrical cable as defined in claim **1**, wherein the impregnated mica tapes are reinforced with a backing of fibers applied as unidirectional thread or woven construction and impregnated with a polymeric material.

11. A high temperature electrical cable as defined in claim **10**, wherein the polymeric material used for impregnation of the backing may be selected from the group consisting of carborane siloxane polymers and poly (siloxanes).

12. A high temperature electrical cable as defined in claim **1**, wherein the impregnated mica tapes are made of reconstituted mica sheets impregnated with decarborane siloxane polymers.

13. A high temperature electrical cable as defined in claim **1**, wherein the impregnated tapes are made of reconstituted mica sheets impregnated with pentaborane siloxane polymers.

14. A high temperature electrical cable as defined in claim **1**, wherein the impregnated mica tapes are made of reconstituted mica sheets impregnated with mixed meta-and para-decarborane siloxane polymers.

15. A high temperature electrical cable as defined in claim **1**, wherein the impregnated mica tapes are made of reconstituted mica sheets impregnated with copolymers of deca- and penta-borane siloxane.

16. A high temperature electrical cable as defined in claim **1**, wherein the impregnated mica tapes are made of reconstituted mica sheets impregnated with physical combinations of deca- and penta-borane siloxane polymers.

17. A high temperature electrical cable as defined in claim **1**, wherein the impregnated mica tapes are applied as lapped, open helically wound tapes applied in the same or opposite lay in the different layers in order to give essentially complete coverage of the wire and a functional dielectric strength of 1,000 volts or more.

18. A high temperature electrical cable as defined in claim **1**, wherein the metallic wires of the outer sleeving are selected from the group consisting of stainless steel and nickel alloys.

19. A high temperature electrical cable as defined in claim **1**, wherein the central conductor is made of nickel alloy clad silver, the inner and outer layers of inorganic high temperature insulative material made of braided fibers, the primary dielectric layers made of lapped open helically wound tapes of reconstituted mica sheets impregnated with cured carborane siloxane polymers to approximately 10 percent weight loading on weight of mica tapes, and the protective sleeving made of nickel alloy high temperature resistant wire.

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