
Fields of application of nickel plated copper conductor

By Selcuk Harput

Sarkuysan Electrolytic Copper Co.

Turkey

Abstract:

Increasing experience in nickel coating techniques on copper wire has been an important factor encouraging its use in the form of cables for high temperature applications. Unfortunately, the expected amendments in related standards lagged behind, or simply neglected, are essential for correct material selection for cable producers and end users. To compare the properties of nickel plated copper wire to those of tin and silver plated copper wires and highlight the outstanding properties gained by nickel plating in regard to their high temperature applications are the aims of this paper. The main topics taken under consideration are physical, electrical and thermal properties of nickel coated copper wire, its standard specifications and wire geometries, its comparison with other coating metals (i.e. tin and silver) and giving information about special thermally resistant insulation materials, and the bases of selection for best wiring material under different environmental conditions at certain temperatures.

Selcuk Harput is R&D Manager in Sarkuysan Electrolytic Copper Co., Turkey. He is responsible for all research and development activities of Sarkuysan. He joined Sarkuysan in 1988. He was previously primary aluminium production superintendent in Etibank Aluminum Plant, Turkey. He holds a diploma in metallurgical engineering from The Middle East Technical University, Ankara, Turkey. He is a member of WAI, AESF and Chamber of Metallurgical Engineers in Turkey.



Nickel plating: a short history

Nickel can be expressed as good high and low temperature strength, high oxidation resistance, corrosion resistant, highly desirable material. Nickel was discovered in 1751 by Cronstedt in Sweden. Nickel and copper were electrochemically deposited after silver until 1830's. In 1840, Shore filed a patent for electrochemical nickel deposition, followed in 1842 by Böttger who actually plated nickel from a nickel ammonium sulphate solution. Around 1870, chloride and boric acid additions are described. There was not significant development between 1870 and 1940 from the electroplating point of view, except in 1916 when Watts developed his formulation which is still known as "Watts bath". In the 1950's, new acid baths started replacing the cyanide formulations thus improving safety.

The years between 1870 and 1940 were rather tame. Only one improvement can be mentioned. In 1916 Watts developed his formulation, still known as the Watts bath. This increased current densities tenfold, from 0.5 to 5 Adm². In the 1950's, new acid baths started replacing the cyanide formulations thus improving safety and increasing current densities up to 40 Adm². Part of wire and cable sector entered nickel plating area after the development of high speed electroplating processes. Because nickel plated wire and cable is an unrivalled material especially in high temperature corrosive applications.

Nickel plated wires

It is estimated that over 10 000 tones of copper wire are plated worldwide per year with silver or nickel. These plated wires are used principally for stranded conductors in high performance electric cable for the aerospace, airframe, defense, computer, telecommunication and professional electronics industrial sectors. In addition, plated wire is used for high temperature cable, spark ignition leads and fuses. Nickel plated copper wires can resist temperatures up to 750°C. They are corrosion resistant and weld easily. Stranded conductors in this material are coated with suitable temperature resistant materials for cables. This coating process is requiring high temperatures, makes it unsuitable for silver plated wires which would oxidize. A drawback with nickel plated copper is its reluctance to solder easily without special fluxes and the need to plate the nickel under carefully controlled conditions in order to give a pore - free and suitably ductile deposit for drawing.

Parallel to the developments in Nickel electroplating technology and exploring new insulating materials, silver plated wires left temperature dependent areas to Nickel plated wires and cables. Nickel plated copper cables are now an undoubted materials in aviation and aerospace industry. Because nickel plated wires can resist thermal shocks, continuous high temperature exposure and temporarily very high temperatures higher than the melting temperature of copper substrate. Plating metals other than nickel over copper limit the working temperature of cable. But, in most cases the working temperature of nickel plated copper cables can only be limited by insulating materials.

Nickel plated copper wires are also used in other industrial applications than aviation and aerospace such as, iron, steel, aluminum, glass, petrochemical and pyrometallurgical plants.

Basic Components of High-Temperature Insulated Wire

As mentioned before, nickel plated high temperature cables are generally resistant to temperatures where insulation materials can. In general, high temperature cables consist of five basic components which are conductor, insulation, protective braid, jacketing and shielding. Not all elements are appropriate for each construction. Simpler constructions may require only a conductor and extruded insulation. Usually, unprotected insulation is a tough thermoplastic or synthetic rubber with good electrical insulating (i.e. dielectric) properties. When severe service

is expected at elevated temperatures, more complex constructions may be required.

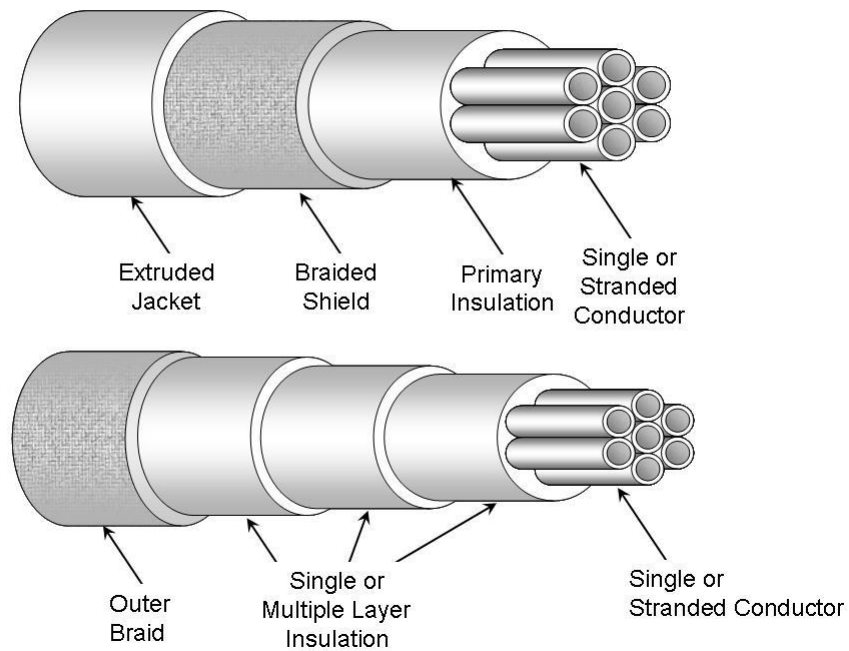


Figure-1: Basic components of high-temperature insulated cables

Conductor

Critical conductor selection variables are a composition of conductor material, conductor diameter and stranding. Expected service temperature should be considered first because conductor materials vary in heat resistance. Next to be evaluated should be the conductor's capacity to carry current without surpassing the temperature rating of the conductor and insulation. Material and conductor circular mil area are key determinants of this capacity. Finally, the decision should be made on how much flexibility is required, for this determines the stranding configuration. According to the standard ASTM B 355, nickel layer thicknesses have been classified as nickel percentages and nickel layer thickness as $1,27\mu$ ($50\ \mu\text{in}$) depending on the conductor diameter. Various nickel thicknesses are shown in Table-1. For extreme cases such as, cable can be exposed temporarily in very high temperatures; nickel layer thickness will be higher than normal working thickness i.e. 10% or 27%.

| Conductor Diameter | | | According to Ni Layer Thickness | | | According to Percentage | |
|--------------------|--------|-------|---------------------------------|-----------|------|-------------------------|-------|
| AWG | in | mm | (μ in) | (μ) | (%) | Class | % |
| 18 | 0,0403 | 1,024 | 50,00 | 1,27 | 0,50 | 2 | 2,00 |
| 19 | 0,0359 | 0,912 | 50,00 | 1,27 | 0,56 | 2 | 2,00 |
| 20 | 0,0320 | 0,813 | 50,00 | 1,27 | 0,62 | 2 | 2,00 |
| 21 | 0,0285 | 0,724 | 50,00 | 1,27 | 0,70 | 2 | 2,00 |
| 22 | 0,0253 | 0,643 | 50,00 | 1,27 | 0,79 | 2 | 2,00 |
| 23 | 0,0226 | 0,574 | 50,00 | 1,27 | 0,88 | 2 | 2,00 |
| 24 | 0,0201 | 0,511 | 50,00 | 1,27 | 0,99 | 2 | 2,00 |
| 25 | 0,0179 | 0,455 | 50,00 | 1,27 | 1,11 | 2 | 2,00 |
| 26 | 0,0159 | 0,404 | 50,00 | 1,27 | 1,25 | 2 | 2,00 |
| 27 | 0,0142 | 0,361 | 50,00 | 1,27 | 1,40 | 2 | 2,00 |
| 28 | 0,0126 | 0,320 | 50,00 | 1,27 | 1,58 | 2 | 2,00 |
| 29 | 0,0113 | 0,287 | 50,00 | 1,27 | 1,76 | 2 | 2,00 |
| 30 | 0,0100 | 0,254 | 50,00 | 1,27 | 1,99 | 2 | 2,00 |
| 31 | 0,0089 | 0,226 | 50,00 | 1,27 | 2,23 | 4 | 4,00 |
| 32 | 0,0080 | 0,203 | 50,00 | 1,27 | 2,48 | 4 | 4,00 |
| 33 | 0,0071 | 0,180 | 50,00 | 1,27 | 2,80 | 4 | 4,00 |
| 34 | 0,0063 | 0,160 | 50,00 | 1,27 | 3,15 | 4 | 4,00 |
| 35 | 0,0056 | 0,142 | 50,00 | 1,27 | 3,54 | 4 | 4,00 |
| 36 | 0,0050 | 0,127 | 50,00 | 1,27 | 3,96 | 4 | 4,00 |
| 37 | 0,0045 | 0,114 | 50,00 | 1,27 | 4,40 | 7 | 7,00 |
| 38 | 0,0040 | 0,102 | 50,00 | 1,27 | 4,94 | 7 | 7,00 |
| 39 | 0,0035 | 0,089 | 50,00 | 1,27 | 5,63 | 7 | 7,00 |
| 40 | 0,0031 | 0,079 | 50,00 | 1,27 | 6,35 | 7 | 7,00 |
| 41 | 0,0028 | 0,071 | 50,00 | 1,27 | 7,01 | 10 | 10,00 |
| 42 | 0,0025 | 0,063 | 50,00 | 1,27 | 7,86 | 10 | 10,00 |
| 43 | 0,0022 | 0,056 | 50,00 | 1,27 | 8,80 | 10 | 10,00 |
| 44 | 0,0020 | 0,050 | 50,00 | 1,27 | 9,86 | 10 | 10,00 |

Table-1: Nickel layer thicknesses of some finished copper conductors according to ASTM B 355

Three types of 0,25mm copper conductors have been exposed into very high temperatures for the examination of the final conditions of conductors (Figures 2, 3, 4 and 5). It was found that 10% and 27% nickel plated copper wires can resist temporarily up to the temperatures of minimum 1100°C and 1200°C respectively. At this stage copper substrate melts and nickel layer acts as a tube for liquid copper and conductor can still continue current transfer to give vital chance to user.

4% nickel plated copper wire could not maintain its shape because of less nickel at 1100°C (Figure-3).

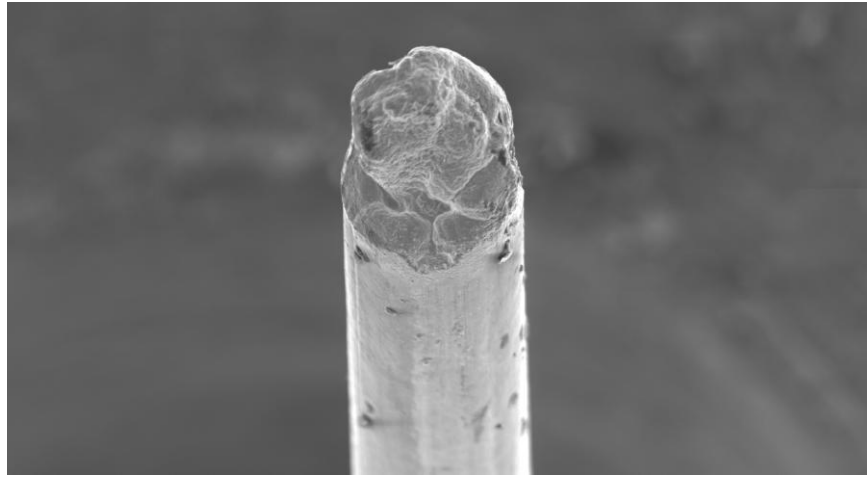


Figure-2: SEM photo of 4% 0,25mm nickel plated copper wire after 20 minutes exposure at 1000°C



Figure-3: SEM photo of 4% 0,25mm nickel plated copper wire after 5 minutes exposure at 1100°C

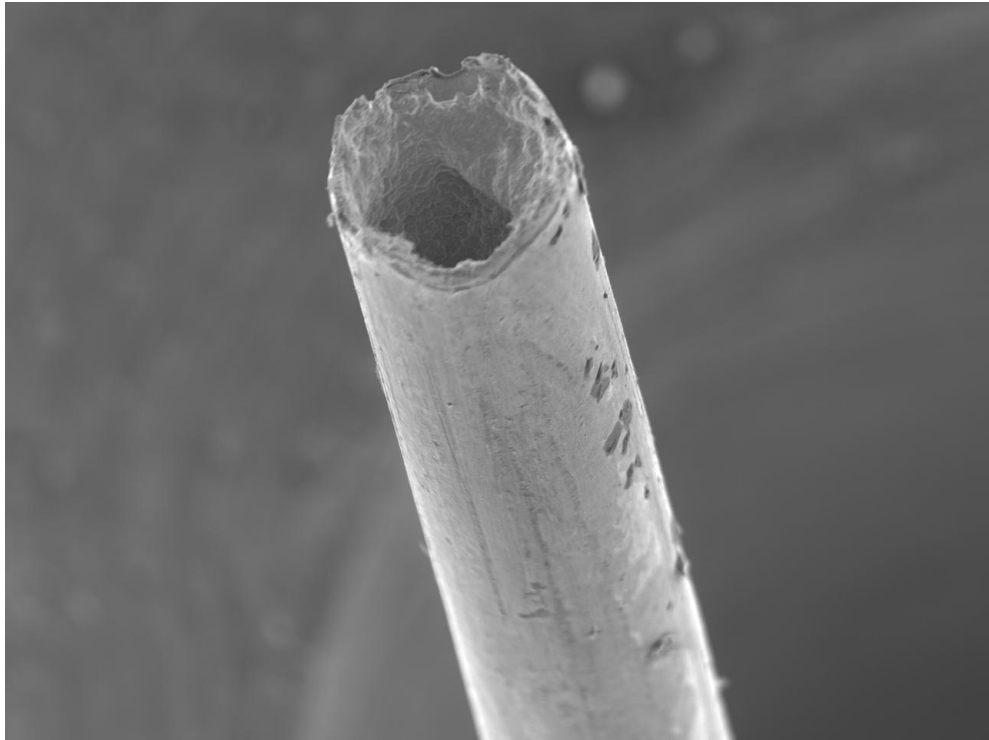


Figure-4: SEM Photo of 10% 0,25mm nickel plated copper wire after 20 minutes exposure at 1100°C

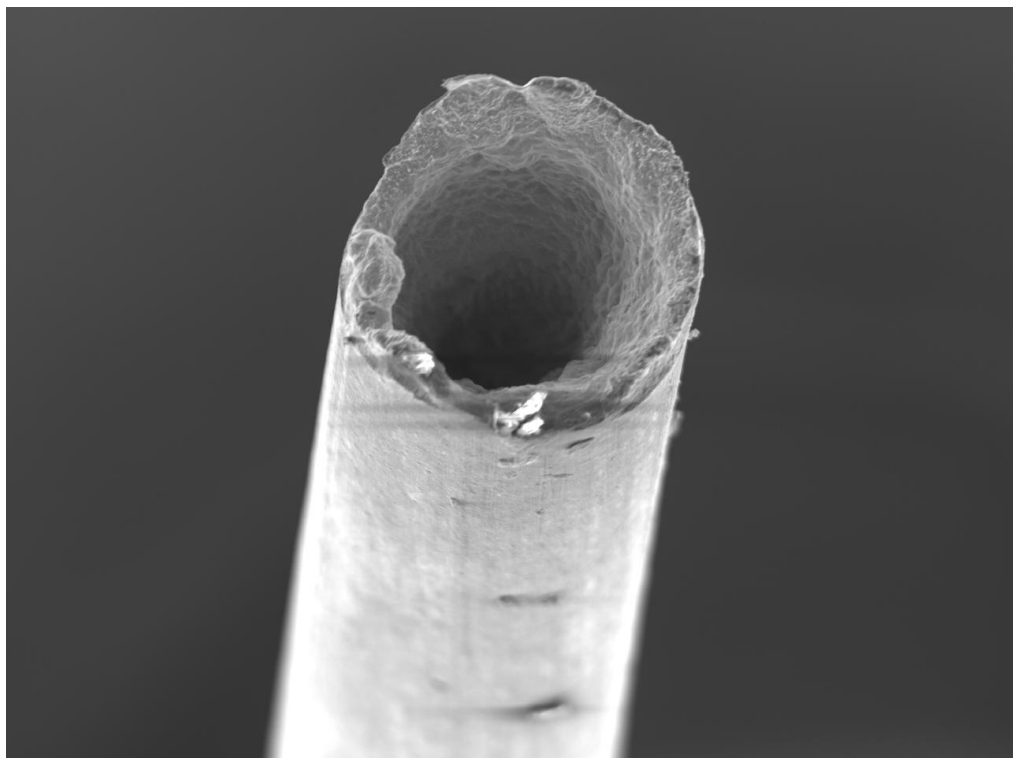


Figure-5: SEM Photo of 27% 0,25mm nickel plated copper wire after 20 minutes exposure at 1200°C

Insulation

The purpose of insulation is to maintain the electrical insulation. It is normally extruded over the conductor or applied as a wrapped tape. Materials selected for the primary insulation (plastics, synthetic rubbers and mica) have good dielectric properties as well as heat resistance. For severe applications, it should be determined whether or not a secondary insulation may be required for protection against cutting, tearing or other damage.

Insulation, jacketing, and metallic shields give their electrical and physical advantages to high temperature cables. They are an important part of wire and cable. Primary insulation must be a good electrical insulator to contain and channel the voltage, while the secondary insulation is used to protect the primary insulation and conductor against physical damage. The outer layers, braiding and jacketing, provide additional mechanical protection to the insulation with jacketing providing environmental protection as well. Finally, metallic shielding can be used to provide heavy-duty physical protection in harsh environments and to prevent electrically generated interference that may be caused by motor ignition and shut-off, fluorescent tubes in lighting ballasts, and relays.

Many insulation, jacketing, and metallic shield materials, which may be considered individually or in combination as a composite, are available for high-temperature wire and cable applications.

Choosing an appropriate insulating material is a process of weighing the balance of desirable characteristics against those that may be undesirable for a particular application. For example, mica is an excellent insulation material for 450°C temperature exposure, but not for a traveling cable which will be continually bent and flexed. Mica would probably fail very quickly in this application due to its embrittlement after exposure to heat. Another construction alternative would be to use layers of PTFE protected by layers of a fiberglass serve. This construction would allow the cable to remain flexible, but it would not have the heat resistance of mica, resulting in a relatively short life span.

Braiding

Fiber glass is widely used in braided outer covers for limited mechanical protection. Glass braid almost always is saturated with an appropriate high-temperature finish to prevent fraying or moisture penetration and to improve fiber bonding.

Jacketing

Also called sheathing, jackets generally are extruded from thermoplastics or thermoset materials for mechanical, thermal, chemical and environmental protection. It is also used as a supplemental electrical insulation over metallic shields.

Shielding

Metal shielding, applied as a corrugated or flat tape or as a woven braid used to protect insulation from severe operating conditions. Additionally, it prevents power-generated interference from escaping to the surrounding environment. Metallic shielding is also commonly used in low-voltage communications wiring to protect signal integrity.

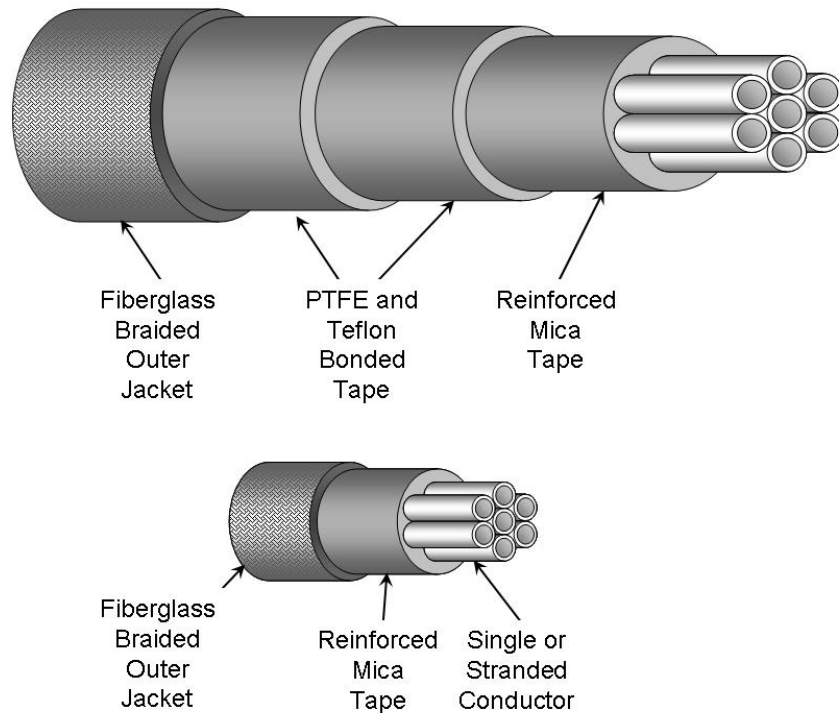


Figure-6: Some insulating materials used for high-temperature cables.

When selecting high-temperature wire or cable, all the basic requirements must be also taken into consideration when selecting normal wiring materials such as current carrying capacity, voltage rating, dielectric strength of insulation materials, and ambient temperature. The insulation materials must be considered and evaluation must be done how they are affected by the application environment as the next step. When selecting insulation materials for a high-temperature application, the first consideration is usually the relative heat resistance of the material.

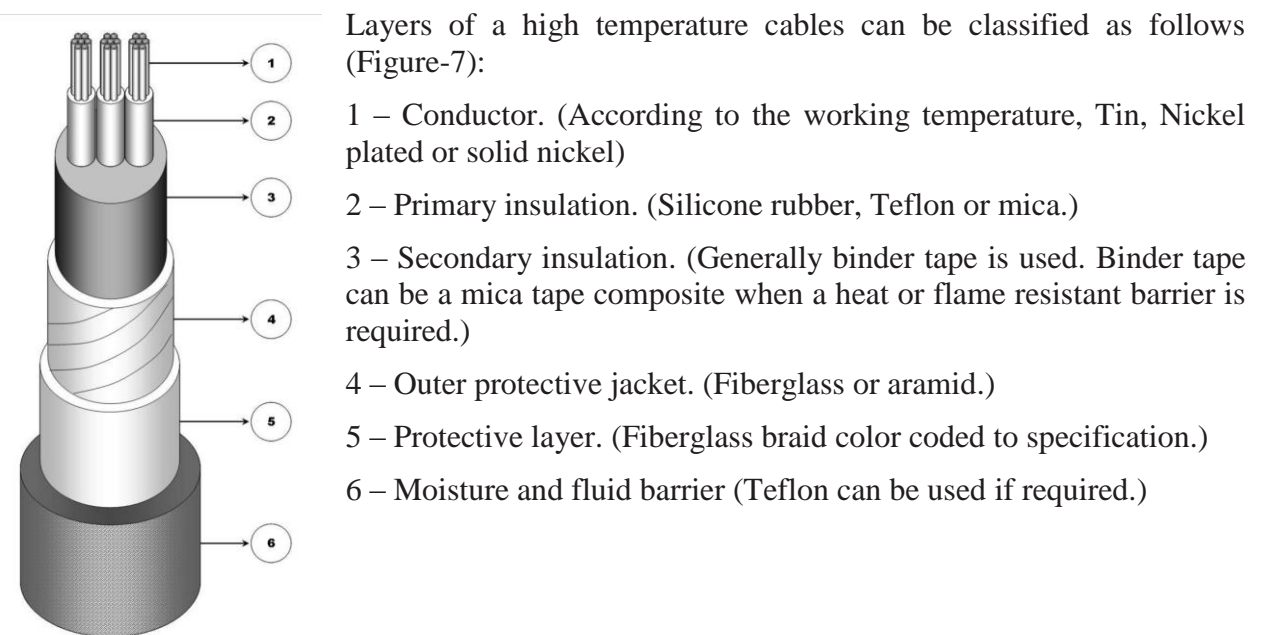


Figure-7

Insulation Materials

Select a composite of mica with intermediate layers of fiberglass braid, mica, and more fiberglass braid. This choice provides the heat resistance of mica and extends the cable's service life by diminishing the effects of flexing upon the cable. But, when considering a composite cable, it is important to remember that it is ultimately only as strong as its weakest component, and the components need to be compatible.

| Properties | Nuclear radiation | Water resistance | Acid resistance | Alkali resistance | Gasoline Kerosene etc. | Benzol, Toluol etc. | Degreaser solvents | Alcohol resistance | Underground burial | Oxidation resistance | Heat resistance | Oil resistance | Low temp. Resistance | Weather, sun resistance | Ozone resistance | Abrasion resistance | Electrical properties | Flame resistance |
|------------------------|-------------------|------------------|-----------------|-------------------|------------------------|---------------------|--------------------|--------------------|--------------------|----------------------|-----------------|----------------|----------------------|-------------------------|------------------|---------------------|-----------------------|------------------|
| PVC | F | F-G | G-E | G-E | P | P-F | P-F | G-E | P-G | E | G-E | F | P-G | G-E | E | F-G | F-G | E |
| LDPE | G-E | E | G-E | G-E | G-E | P | G | E | G | E | G | G-E | E | E | E | G | E | P |
| Cellular PE | G | E | G-E | G-E | G | P | G | E | F | E | G | G | E | E | E | F | E | P |
| HDPE | G-E | E | E | E | G-E | P | G | E | E | E | E | G-E | E | E | E | E | E | P |
| Polypropylene | F | E | E | E | P-F | P-F | P | E | E | E | E | F | P | E | E | F-G | E | P |
| Cellular Polypropylene | F | E | E | E | P | P | P | E | F | E | E | F | P | E | E | F-G | E | P |
| Polyurethane | G | P-G | F | F | P-G | P-G | P-G | P-G | G | E | G | E | G | G | E | O | P | P |
| Polyimides | | E | E | P | E | E | E | | | E | O | E | | E | | E | O | |
| Nylon | F-G | P-F | P-E | E | G | G | G | P | P | E | E | E | G | E | E | E | P | P |
| CPE | O | O | E | E | E | G-E | E | E | E-O | E | E | E | E | E | E | E-O | E | E |
| Plenum PVC | F | F | G | G | P | P-F | P-F | G | P | E | G-E | F | P-G | G | E | F-G | G | E |
| FEP | P-G | E | E | E | E | E | E | E | E | O | O | O | O | O | E | E | E | O |
| PFA | P-G | E | E | E | E | E | E | E | E | O | O | O | O | O | E | E | E | O |
| ETFE | E | E | E | E | E | E | E | E | E | E | E | E | E | E | E | E | E | G |
| PTFE | E | E | E | E | E | E | E | E | E | O | O | E-O | O | O | O | O | E | E |
| PVDF | E | E | G-E | E | E | G-E | G | E | E | O | O | E | O | E-O | E | E | G-E | E |
| ECTFE | E | E | E | E | E | E | E | E | E | O | O | O | O | O | E | E | E | E-O |
| Butadiene rubber | | | | | | | | | | F | F-G | P | F-G | F | P | G-E | E | P |
| SBR | F-G | E | F-G | F-G | P | P | P | G | G | G | F | P | E | F | P | E | E | P |
| TPR | | E | F-G | F-G | G | G | G | G | | | F | E | | | | E | E | |
| Polybutadiene | P | E | F-G | F-G | P | P | P | F-G | G-E | G | F | P | E | F | P | E | E | P |
| Neoprene | F-G | E | G | G | G | P-F | P | F | G-E | G | G | G | F-G | G | G | G-E | P | G |
| Hypalon | E | E | E | E | F | F | P-F | G | E | E | E | G | F | E | E | G | G | G |
| NBR | F-G | G-E | G | F-G | E | G | P | E | G | F | G | G-E | F | F-G | P | G-E | P | P |
| NBR/PVC | P | E | G | G | G-E | G | G | G | G | E | G | G | F | G | G | E | F | G |
| ERP | G | G-E | G-E | G-E | P | F | P | P | E | E | E | P | G-E | E | E | G | E | P |
| XLPE | E | G-E | G-E | G-E | F | F | F | E | E | E | G | G | O | G | G | F-G | E | P |
| CPE | G | G-E | E | E | F | F | P | G-E | E | E | E | G-E | F | E | G-E | G-E | F-G | G |
| MICA | O | O | | | | | | | | O | O | O | O | O | O | | E | O |
| SILICON | E | G-E | F-G | F-G | P-F | F | P-G | G | G | E | O | F-G | O | O | O | P | G | F-G |

P=POOR F=FAIR G=GOOD E=EXCELLENT O=OUTSTANDING

Table-2: Properties of some insulation materials.

| Insulating Material | Max Working temp (°C) | Brittleness temp (°C) | Specific gravity (g/mL) | Water absorption (%) |
|----------------------|-----------------------|-----------------------|-------------------------|----------------------|
| LDPE | 80 | -100 | 0,92 | <0,01 |
| POLYBUTADIENE RUBBER | 80 | -70 | | |
| NYLON | 90 | 0 | | |
| XLPE | 100 | -118 | 0,93 | <0.01 |
| PVC | 105 | -30 | 1,2 | 0,03 |
| POLYURETHANE | 108 | -68 | 1,21 | |
| PVDF | 110 | -62 | 1,75 | 0.05 |
| HDPE | 120 | -100 | 0,95 | <0.01 |
| THERMOPLASTIC RUBBER | 125 | | | |
| POLYPROPYLENE | 135 | 0 | 0,9 | <0,02 |
| ECTFE | 150 | -105 | 1,7 | <0.03 |
| NEOPRENE | 150 | | | |
| HYPALON | 160 | | | |
| KEVLAR | 180 | | | |
| FEP | 200 | -270 | 2,15 | <0.01 |
| NOMEX | 220 | | | |
| PFA | 250 | -270 | 2,15 | <0.03 |
| SILICON RUBBER | 250 | | 1,85 | 0,2 |
| PTFE | 260 | -267 | 2,15 | 0.01 |
| POLYIMIDES | 390 | | 1,55 | 0,1 |
| MICA | 1000 | | | |

Table-3: Properties of some insulation materials

Application of high temperature cables

There are many areas where cables are continuously or temporarily exposed to high temperatures. Some applications are given below:

- Aircraft interconnecting wire: (2% Nickel plated copper wire)

Document: MIL-W-22759/2 Voltage rating: 600V; Rated wire temp.:260°C Fluoropolymer insulated TFE and TFE coated glass

- Aircraft interconnecting wire: (2% Nickel plated copper wire)

Document: MIL-W-22759/3 Voltage rating: 600V; Rated wire temp.:260°C Fluoropolymer insulated TFE –glass- TFE

- Aircraft interconnecting wire: (2% Nickel plated copper wire)

Document: MIL-W-22759/6 Voltage rating: 600V Rated wire temp.:260°C Fluoropolymer insulated extruded TFE.

- Aircraft interconnecting wire: (2% Nickel plated copper wire)

Document: MIL-W-22759/8 Voltage rating: 600V Rated wire temp.:260°C Fluoropolymer insulated extruded TFE.

- Aircraft interconnecting wire: (2% Nickel plated copper wire)

Document: MIL-W-22759/10 Voltage rating: 1000V Rated wire temp.:260°C Fluoropolymer insulated extruded TFE.

- Aircraft interconnecting wire: (2% Nickel plated copper wire)

Document: MIL-W-22759/41 Voltage rating: 600V Rated wire temp.:200°C Fluoropolymer insulated crosslinked modified TFE.

- Aircraft interconnecting wire: (2% Nickel plated copper wire)

Document: MIL-W-22759/8 Voltage rating: 600V Rated wire temp.:260°C Fluoropolymer insulated extruded TFE.

- Aircraft protected wire: (2% Nickel plated copper wire)

Document: MIL-W-22759/12 Voltage rating: 600V Rated wire temp.:260°C Fluoropolymer insulated extruded TFE

- Aircraft protected wire: (2% Nickel plated copper wire)

Document: MIL-W-22759/45 Voltage rating: 600V Rated wire temp.:200°C Fluoropolymer insulated crosslinked modified ETFE

- Aircraft protected wire: (2% Nickel plated copper wire)

Document: MIL-W-22759/18 Voltage rating: 600V Rated wire temp.:200°C Fluorocarbon polyimide insulation

- Aircraft cables for fire zones: (Heavily nickel plated copper 10% and 27%)

Some Federal Aviation Regulations refer mostly FAR 25 for flammability requirements. All wire insulations must meet FAR 25.1359 (d), and those located in fire zones must also meet FAR 25.1359(b)

- High temperature lead wire for use in iron, steel, aluminum, glass, and petrochemical plants: (Heavily nickel plated copper 27%)

For use in circuits which have severe, high temperature environment. 1- Flexible stranded 27% nickel plated copper; 2- Reinforced mica insulation tape wraps; 3- Closely woven fiberglass braid conductor jacket, color coded with high temperature abrasion and moisture resistant finish; 4- Flame barrier of reinforced mica tapes; 5- Moisture and fluid barrier of heat sealed PTFE tape; 6- Heavy duty braided fiberglass jacket with high temperature finish.

Continuous working temperature: 450°C (UL); 530°C (NON-UL)

- Motor lead and apparatus cable: (2% Nickel plated flexible stranded copper.)

These types of cables consist of three insulation layers. 1- PTFE tape insulation; 2- Additional served fiberglass insulation; 3- Fiber braid jacket with durable high temperature finish. Continuous working temperature: 250°C; 600V.

- High temperature lead cable: (27% Nickel plated flexible stranded copper.)

These types of cables are used in extreme environments and reduce the costs of added thermal protection (glass sleeve, ceramic insulator, etc). These types of cables consist of three insulation layers. 1- Mica Glass Composite; 2- Glass braid; 3- Modified silicone jacket.

Continuous working temperature: 550°C

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