Primer On Electrical & Electronic Cable Jacket Types: RF, Data, and Power

White Paper

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Introduction

The ongoing electrification of a wide range of technology and the expansion of electrical/electronic systems to almost every application means that there is a growing demand for electrical/electronic interconnect. Even with the advances of wireless technology to use as extra-system and intra-system wireless links, there is still an explosion of uses of conductive and waveguide interconnect. Wires and cables are still, and will continue to be, the dominant form interconnect for electrical/electronic systems for decades to come. These interconnects are the backbone of the modern world and are literally used to connect virtually every modernized human population on the globe.

As the conductive and waveguide materials used with electrical/electronic interconnect are typically sensitive to external environments and would readily be damaged or degraded by handling, these wires and cables are generally coated or otherwise encapsulated in a protective jacket material. The jacketing materials and methods of construction for these wires and cables have evolved as electrical/electronic technology has evolved to provide enhanced performance or features at various price points and for numerous environments.

This whitepaper aims to illuminate readers on the key properties of wire and cable jacketing materials and dive into the details of individual materials that are used for wire and cable jackets.

Cable Jacket Key Properties

Electrical/electronic wires and cables are used in virtually every environment where human technology is employed. This means everywhere from the deepest oceans to the furthest reaches of space. These interconnects are also used in a wide range of applications with various requirements and cost points. Hence, there are a plethora of variations of wire and cable types, and the jacketing material is a major contributing factor to a long list of wire and cable capabilities and features.

The main role of a wire/cable jacket is to protect the interior conductor and/or waveguide from damage or degradation to environmental factors. This includes protecting wire/cable internals during thermal, chemical, mechanical, electrical, radiation, humidity/moisture, and during installation/handling conditions. A given wire/cable will have several characteristics that are nearly entirely controlled by the jacketing material and manufacturing process of the jacketing.

Cable Jacket Key Properties/Characteristics

- Tear resistance
- Abrasion resistance
- Flexibility at various temperatures
- Maximum/minimum bend radius
- Flex cycle life
- Deformation resistance
- Temperature stability
- Flame resistance
- Oil resistance
- Moisture absorption
- Chemical resistance

- Oxidation resistance
- Ultraviolet and radiation resistance
- Electrical resistivity
- Dielectric breakdown voltage
- Surface texture/roughness and other handling dynamics
- Shock/vibration resilience
- Color and color retention/aging
- Elastic memory
- Specific gravity
- Compliance
- Toxicity

Cable Jacketing Manufacture & Assembly

Some jackets are manufactured as a single monolithic material that is extruded over the internal wire or cable structures. In this process the core materials are run through a fixture that has the extruded material simultaneously run through a surrounding funnel or die. Typically, this type of process is used for thermoplastic or thermoset cable jacket materials. Hence, the jacket material may be extruded molten or cold but requires a later curing process step.

One of these methods is called tube extrusion, where a thermoplastic material is extruded through a tube that ensures a smooth and uniform thickness around the core. Tube extrusion is preferred as a method of jacket manufacturing as it typically saves weight and materials compared to other methods. Moreover, tube extrusion leads to a much smoother and uniform jacket material that is easier to strip and mitigates ribbing or sugaring twist effects that impact other methods of extrusion.

Cable manufacturing/jacketing process

There are also pressure or tightly extruded jacket methods that hold the core materials tightly in place during manufacture. In these processes, the jacketing material is also extruded into the interstice's gaps around the core bundle or stranding. This method is most often used for flexible cables or wire/cable bundles that may be exposed to harsh environments. These types of cables are generally better sealed, and the internal cores are maintained in a desirable pattern. However, this method results in a jacketing that is more difficult to strip, wire/cable weight may be higher than other methods, costs may be higher, and the outer cable appearance and dimensions are determined by the core structures and twisting/ribbing effects may be observable. Aside from aesthetics this could cause issues in certain handling, installation, and even operation scenarios.

For extreme environmental cable, a multi-material process may be used where a jacket bedding process is first extruded around the cores followed by the outer jacketing material. This can result in the use of multiple jacketing processes with a desirable outer jacket finish, clearly at increased cost and complexity of wire/cable manufacture.

Other processes include braiding, taping, wrapping, or other methods of winding a jacketing material around a cable. In some cases, multiple processes steps are involved to make composite or multi-material and multi-construction method wire/cable jackets. A wire/cable may even have an additional outer wire/cable jacket added for aesthetic or handling performance as a later stage prior to installation or attachment to a system. An example of this is braiding nylon and/or rubber/elastomer threads around an already jacketed wire/cable to enhance the abrasion resistance and handling of the wire/cable.

Additionally, armoring or crush-resistance methods may be used as outer jacketing material. Some armor or crush members may even have an insulated outer coating for enhanced environmental performance. Armor may be made of high strength braided materials, segmented, or even corrugated materials. Braided protective outer members are typically called sheathing, and may be made of polymers, metals, or even natural materials such as leather or twine.

As an example, metal clad (MC) cable is a common type of armored cable used in electrical installations. Armored cable jackets may be made of plastics, composites, or metals, but are typically constructed using stainless steel, aluminum, or galvanized steel. In some cases, the armor may be added by a technician during installation, or it can be integrated as part of the original manufacturing of the wire/cable.

Cable Jacket Materials

Though there are many types and variations of jacketing material and manufacture, the most common type of jacketing material is polymer jacketing. This type of jacketing is often even used with other types of external protective jackets, such as armor, crush members, or sheathing. Thermoset and thermoplastic are both types of polymers. They have different properties and behaviors when heated and are used in many different applications. Thermoplastics can be melted and reshaped repeatedly without altering their chemical structure. Thermosets undergo a chemical reaction when heated, forming a rigid, three-dimensional network of bonded molecules. They are irreversible, cannot be melted or reshaped, and retain their form and stay solid under heat.

Thermoplastic vs. Thermsot

	Thermoplastic			Thermoset		
	PVC	Polyurethane	CPE	Neoprene	EPR	CPE
Oxidation Resistance	Excellent	Excellent	Excellent	Good	Excellent	Excellent
Heat Resistance	Excellent	Good	Excellent	Good	Excellent	Excellent
Low-Temperature Flexlbillty	Poor to Good	Good	Excellent	Fair to Good	Good to Excellent	Fair
Weather/Sun Reslstance	Good to Excellent	Good	Excellent	Good	Excellent	Excellent
Abrasion Resistance	Fair to Good	Outstanding	Excellent to Outstanding	Good to Excellent	Good	Good to Excellent
Flame Resistance	Excellent	Poor	Excellent	Good	Poor	Good

	Thermoplastic			Thermoset		
	PVC	Polyurethane	CPE	Neoprene	EPR	CPE
Water Resistance	Fair to Good	Poor to Good	Outstanding	Excellent	Good to Excellent	Good to Excellent
Underground Burial	Poor to Good	Good	Excellent to Outstanding	Good to Excellent	Excellent	Excellent

Thermoplastic

Thermoplastics are one of the lowest cost and most used types of polymer wire/cable insulation and jacketing materials. This family of polymers includes PVC and polyurethane. A thermoplastic is a polymer that substantially changes hardness as a function of temperature such that heating to reasonable processing temperatures allows for forming and reforming. Though this makes for easier processing, thermoplastics also may become deformed, less abrasion resistant, or otherwise degrade in mechanical, environmental, or electrical performance in the presence of high ambient or internal temperatures.

For applications where temperatures will stay within an acceptable range for thermoplastic materials, cable/wire with these jackets can be made much more economically, often lower weight, in a wide variety of colors/patterns, and may even exhibit better electrical properties than other polymers.

Common Thermoplastic Polymers for Wire/Cable Insulation/Jacketing

- Polyvinyl Chloride (PVC)
- Polyurethane (PUR)
- Polyethylene (PE)
- High Density Polyethylene (HDPE)
- Low Density Polyethylene (LDPE)
- Chlorinated Polyethylene (CPE or PE-C)
- Chlorosulfonated Polyethylene (CSPE)
- Polypropylene (PP)
- Thermoplastic Elastomer/Rubber (TPE/TPR)
- Ethylene Propylene Diene Monomer (EPDM)

Thermoplastic					
Resistance:	PVC	TPE/TPV	Fluoropclymer	Polyurethane	CPE
Ozone	Good	Good	Excellent	Excellent	Excellent
Heat	Good	Good	Excellent	Good	Good
Extreme Cold Temperatures	Poor	Excellent	Excellent	Good	Good
UV	Good	Good	Excellent	Good	Good
Abrasion	Good	Good	Good	Excellent	Excellent

Thermoplastic					
Resistance:	**PVC**	**TPE/TPV**	**Fluoropclymer**	**Polyurethane**	**CPE**
Flexing	Good	Excellent	Poor	Excellent	Good
Fluid	Good	Good	Excellent	Excellent	Excellent
Tear	Good	Good	Good	Excellent	Excellent
Chemicals	Poor	Good	Excellent	Good	Good
Nuclear Radiation	Poor	Good	Poor	Good	Good
Dieletric Strength	Good	Good	Excellent	Good	Good
Oil	Good	Good	Excellent	Excellent	Good

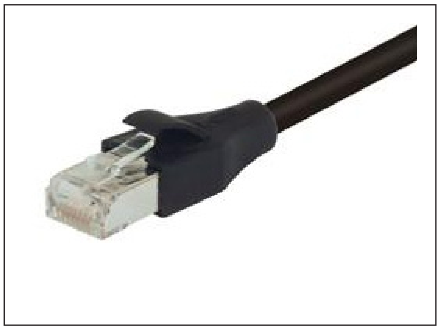
Polyvinyl Chloride (PVC)

PVC is one of the most common cable/wire insulation and jacketing materials. It has reasonably good performance in virtually all categories, except for extreme cold, chemical resistance, and nuclear radiation resistance. It is, however, widely available, relatively low cost for low-voltage range applications, moisture/salt corrosion resistant, and provides good electrical insulation with decent material strength.

There are high temperature and low temperature variations of PVC, and other formulations that result in trade-offs for the material performance with a focus on certain properties. Hence, there is also a wide range of costs with various types of PVCs.

Polyurethane (PUR/TPU)

PUR/TPU exceeds PVC in virtually all categories and is also halogen-free when burning. PUR/TPU also has a high tensile strength and good mechanical performance compared to other polymers, mainly abrasion, cut-through, and tear resistance. This polymer isn't as flexible as some other thermoplastic polymers, but does exhibit good "memory" performance, so it can be used in coil cord or retractable cord applications. PUR/TPU can be used in a wide range of temperatures in relatively high wear applications. This includes oil/gas, paint, or automotive applications. PUR also does not contain chlorine, iodine, fluorine, bromine, or astatine.



Industrial Ethernet Cable with PUR Jacket

Polyethylene (PE), High Density Polyethylene (HDPE), Low Density Polyethylene (LDPE) Polyolefin

PE tends to surpass other thermoplastics in electrical performance, specifically with a relatively low dielectric constant that is stable over a wide frequency. This is why PE is often a choice thermoplastic for communications and data wire/cable. PE materials tend to be highly resistant to moisture. These materials also tend to off-gas less than PVC and polystyrenes, so are considered less toxic. PE materials are not as flexible as other polymers and also tend to be more flammable. Less flammable PE versions tend to sacrifice electrical properties for enhanced flame retardance.

PE materials can be made in various molecular weights, such as low weight, high weight, and even ultra-high molecular weight (UHMWPE). Typically, the higher the molecular weight the denser the PE and the greater material strength, specifically tensile strength. LDPEs tend to be made into low weight films and foams with good electrical properties, and higher molecular weight PEs are used in higher strength and durability applications.

Chlorinated Polyethylene (CPE or PE-C) & Chlorosulfonated Polyethylene (CSPE) *Polyolefin

CPEs/CSPEs are much like other PEs but exhibit much better temperature resistance and some are even flame retardant. These materials are also extremely moisture, UV, nuclear radiation, and oil resistant compared to other thermoplastic polymers. CPEs/CSPEs tend to exceed PVCs in virtually every performance category but are more expensive to produce.

CPE surface textures tend to be mildly rough but do exhibit a low coefficient of friction compared to other thermoplastic polymers. CPEs are often used when oil, moisture, UV, and chemical resistance is needed at a lower cost point than thermoset or fluoropolymer materials. CPEs can also be colored over a wide range and retain color well after aging.

Polypropylene (PP) *Polyolefin

PP is very similar to PE but is typically harder than PE. This means that PP is good for high wear applications. PP also has a low and stable dielectric constant, like PE, but has a relatively low maximum temperature with the UL listing indicating a rating to 60 or maybe 80 degrees C.

Thermoplastic Elastomer/Rubber (TPE/TPR)

TPE/TPR demonstrates excellent low temperature performance, which is often why it is preferred for cold climate applications. These polymers also are extremely flexible and resistant to radiation, oxidation, ozone, and UV. This material also retains most of the desirable mechanical and electrical properties when exposed to harsh environmental conditions, such as highly corrosive salt environments. Some TPE/TPR materials are rated for use as high as 125 degrees C, which is higher than many other thermoplastics. These materials are also halogen-free and are recyclable.

Ethylene Propylene Diene Monomer (EPDM)

EDPM is a very flexible and durable polymer. This material is also resistant to moisture even at high temperatures and medium voltages. This is why EPDM is often used for wire and cable jacketing for high temperature and medium voltage applications, such as welding cables, appliance wiring, solar, and automotive. EPDM suffers from low oil resistance and poor chemical resistance to common solvents, such as kerosene and gasoline.

Thermoset

Thermoset materials must be cured after shaping to take on their final properties. The thermal curing process for these materials is non-reversible with temperature, which is why thermoset materials are often used in higher temperature applications than thermoplastics. Thermoset materials tend to be higher weight and rubbery compared to thermoplastics.

Common Thermoset Jacketing Materials

- Polychloroprene (Neoprene) Or Chloroprene
- Silicone
- Ethylene Propylene Rubber (EPR)
- Thermoset CPE
- Cross-linked Polyethylene (XLPE)

Thermosets					
Resistant to:	Rubber		Silicone	Crosslinked Fluroelastomer	Crosslinked Polyolefin
	CSPE	NBR/PVC			
Ozone	Excellent	Poor	Excellent	Excellent	Good
Heat	Good	Good	Excellent	Excellent	Good
Extreme Cold Temperatures	Good	Poor	Excellent	Excellent	Good
UV	Excellent	Good	Excellent	Excellent	Good
Abrasion	Excellent	Good	Poor	Good	Good
Flexing	Good	Good	Excellent	Excellent	Good
Fluid	Excellent	Good	Good	Excellent	Excellent
Tear	Excellent	Good	Poor	Good	Excellent
Chemicals	Good	Good	Excellent	Excellent	Good
Nuclear Radiatin	Excellent	Good	Good	Excellent	Excellent
Dieletric Strength	Excellent	Good	Excellent	Excellent	Excellent
Oil	Good	Good	Excellent	Excellent	Excellent

Polychloroprene (Neoprene) Or Chloroprene

As a vulcanized synthetic rubber, Neoprene exhibits high resilience to permanent deformation under heat and load, and does not readily embrittle at lower temperatures. These materials provide good mechanical performance all around, especially abrasive wear, impact, crushing, and chipping, which is why neoprene jacketing cables are often used in mining, dredging, and other harsh industrial environments.

Neoprene is also highly resistant to aging from UV/radiation exposure and oxidation and is extremely resistant to atmospheric ozone degradation. Neoprene has good flame resistance and is self-extinguishing. Neoprenes can be made to be flexed without damage below -40 degrees C and will even pass a mandrel wrap test down to -45 degrees C. These polymers are also resistant to chemicals found in soil, such as acids and alkalis, and are also resistant to breakdown from biological agents.

Silicone

Silicone is a non-toxic and soft/rubbery material with a very high temperature range of operation (-80 degrees C to 200 degrees C). Moreover, silicone exhibits good radiation, UV, ozone, and weather resistance while also offering good moisture absorption performance. Though very environmentally rugged and with good electrical properties, silicones tend to suffer from poor abrasion resistance, low mechanical strength, poor cut resistance, and poor scuff resistance.

Ethylene Propylene Rubber (EPR)

EPR is used in high voltage applications, welding, and mining/control equipment. EPR is considered a synthetic rubber, and is often used for highly flexible cables. This material demonstrates good dielectric strength, though less than that of PE and XLPE. Formulations of EPR demonstrate good abrasion resistance and are suitable for use in temperatures down to -60 degrees C. Flame retardant (FREP) EPR versions are available, and EPRs can often withstand high operating temperatures as high as 150 degrees C.

Thermoset CPE

Thermoset CPE exceeds thermoplastic CPE in ozone and UV resistance. Specifical thermoset formulations of CPE can also be made to be extremely solvent, base, and acid resistant as well as withstanding long-term water immersion. Thermoset CPE can also be made to maintain flexibility at temperatures as low as -18 degrees C and not to become brittle until -40 degrees C. Moreover, thermostat CPEs have excellent cold temperature impact resistance.

Cross-linked Polyethylene (XLPE)

XLPE is a good performing jacketing material but is especially used in high voltage applications due to its high insulation resistance, high dielectric strength, and relatively low dielectric constant (~2.3). This material is also very tough at temperatures below 100 degrees C and exhibits good low-temperature performance below -40 degrees C. Flame retardant additives are needed to realize flame retardant XLPE, which degrades some of the materials performance properties. XLPE tends to be lower cost than EPR materials.

Fluoropolymer

Fluoropolymers are polymer materials that contain fluorine in their molecular composition and are often used to make high performance and rugged cable insulation and jacketing. These materials tend to exhibit high chemical, mechanical, and thermal resistance and excellent electrical properties. Specifically, fluoropolymer jackets are known for their resistance to corrosion, chemicals, and extreme temperature stability compared to other polymers. These polymers can be thermoset or thermoplastic, but some require specialized handling and processing procedures to be developed as an insulator or jacketing material. Most fluoropolymers are thermoplastics that can be extruded, PTFE requires a special process. This is why fluoropolymers are often considered different from other thermoset or thermoplastic polymers. Some fluoropolymers can be used at temperatures that exceed 200 degrees C.

Polytetrafluoroethylene (PTFE)

PTFE, commonly referred to as Teflon (PTFE Teflon), exhibits excellent wire/cable insulation and jacketing properties across the board, but with a few exceptions. These exceptions include that PTFE demonstrates relatively poor nuclear radiation resistance and does not have adequate dielectric strength for high-voltage applications. Typically, PTFE Teflon is applied as a paste around wires and then sintered, though PTFE can also be used as a wrap. PTFE Teflon can be used in continuous service to 260 degrees C and does not melt like other polymers. PTFE is substantially more expensive compared to the common thermoplastic polymers.

Fluorinated Ethylene Propylene (FEP)

FEP, which is also called FEP Teflon/Teflon FEP, is a thermoplastic material that can be extruded to make long runs of cable using conventional methods. FEP can operate to 205 degrees C continuously and is valued as a nonflammable jacketing material for multi conductor cables. This material also exhibits very low moisture absorption and can be used to make very high current and high-temperature wire with very small diameters.

Perfluoroalkoxy (PFA)

PFA, also known as Teflon PFA, and has similar operating temperatures as PTFE. This material also exhibits good low-temperature mechanical properties and good flame resistance. PFA demonstrates a lower melt viscosity than PTFE but is also reactive to fluorine and molten alkalis. This polymer does provide good non-stick performance and a very low coefficient of friction. PFA is comparable to FEP in terms of mechanical properties, but PFA exceeds FEP in electrical properties and service temperature range (-200 degrees C to 260 degrees C).

Hi-temp Aerospace Rated Ethernet Cable

Ethylene tetrafluoroethylene (ETFE)

Like other fluoropolymer cable insulation/jacketing materials, ETFE is very versatile and demonstrates good resistance to harsh environmental conditions. ETFE exhibits superior mechanical strength compared to FEP and PTFE, though comparable insulation properties and temperature stability. ETFE also provides excellent heat-aging, high-voltage, and radiation resistant properties. ETFE can be made to conform with MIL-W-22759 for hook-up wire construction and MIL-C-27500 for multi-conductor cables.

Thermostat vs. Thermoset vs. Fluoropolymer

	Thermoplastics (PE, pvc, PP)	**Thermosets** (XLPE, Silicone Rubber, Neoprene)	**Fluoropolymers** (PTFE, PFA)
Heat Resistance	Lower	High	Very High
Electrical Properties	Good, varies depending on the material	Good, low dielectric constant and high volume resistivity	Excellent, high dielectric strength, low dielectric constant, and high electrical resistivity

	Thermoplastics (PE, pvc, PP)	Thermosets (XLPE, Silicone Rubber, Neoprene)	Fluoropolymers (PTFE, PFA)
Thermal Properties	Soften when heated, can deform under high temperatures	Excellent heat resistance, does not soften or melt when heated	Exceptional heat resistance, maintain insulating properties at both very high and very low temperatures
Mechanical Properties	More flexible, can be reshaped multiple times	Excellent rigidity and strength once cured, cannot be reshaped or remolded	Lower strength and rigidity compared to thermosets, but offer exceptional chemical resistance and dimensional stability
Enviromantal Impact	Recyclable, not all types are biodegradable	Not recyclable due to their cross-linked structure, generally not biodegradable	Not typically recyclable and not biodegradable, high environmental impact
Weight	Varies	enerally denser and heavier than thermoplastics	High molecular weight, but can result in overall lighter components due to their strength
Price	Less Expensive	More expensive than thermoplastics	Most expensive
Chemical Resistance	Varies, generally lower than thermosets and fluoropolymers	Good	Exceptional
Weather Resistance	Varies, generally lower than thermosets and fluoropolymers	Good	Superior
UV Resistance	Varies, generally lower than thermosets and fluoropolymers	Generally superior to thermoplastics	Superior

Conclusion

In conclusion, selecting the right cable jacket for electrical and electronic cabling is critical to ensuring system performance, longevity, and safety. The wide range of cable jacket materials, such as PVC, Teflon, rubber, and polyethylene, each offer distinct properties tailored to specific environments and applications. Understanding these materials' resistance to environmental factors such as moisture, chemicals, abrasion, and temperature is key to making informed decisions that align with the operational needs of your application. As technology continues to advance and the demands on cabling systems increase, choosing the appropriate cable jacket will play an ever-important role in optimizing reliability, enhancing safety, and reducing maintenance costs across a variety of industries.