CABLE OVERSHEATH MATERIALS: THE FIRST LINE OF DEFENCE FOR IMPROVED CABLE RELIABILITY

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ABSTRACT

The reliability of newly installed cables is expected to be as high as possible from commissioning to replacement. The cable oversheath (jacket) provides the first line of defence for the cable during transportation, installation and throughout its life in the laying environment. As such choosing the most appropriate oversheath material is essential to protect the cable at all stage of its life.

INTRODUCTION

Since the introduction of MV XLPE cables in the 1960s many design modifications have led to increased cable reliability, such as extruded semiconducting screens and cleaner insulation. Although protective jackets are common today they were not so in the past; a North American study showed that only in the 80’s did the use of polymeric jackets increase to over 80% of all cables installed. Investigations have shown that the introduction of cable jackets has significantly reduced cable failure rates.

Increasing demand for cable is being driven by (i) asset replacement in developed economies and (ii) network expansion in developing economies. At the same time public opposition to disruption caused during cable laying is increasing. This, along with pressure to lower project costs and reduce installation time, is driving utilities to consider alternative laying methods to those which they may have used for many years.

Installation methods vary regionally, e.g. duct systems are common in North America but less so in Europe. Also some techniques may be relatively new to the industry or pushing the limits of previous applicability, e.g. ploughing-in or directional drilling methods.

Examples include;
1. Duct systems only require a short length of trench to be open at any time. Ducting can be installed at the most convenient time, minimising disruption and the cable pulled into the ducts at a later date.
2. Tunnels are also increasingly popular in major conurbations. Although an expensive option, multiple circuits can be installed in the same space, access is easy and disruption to the public can often be minimal during excavation.
3. Ploughing-in techniques have gained popularity in open-ground (non-urban) due to the speed at which cables can be installed.
4. Directional drilling is being used over short and long distances to avoid breaking ground at the surface.

The reliability of newly installed cables is expected to be as high as possible from commissioning to replacement. Although much attention is given to the electrical performance of the cable core, the oversheath provides the first line of defence for the cable during transportation, installation and throughout its life in the laying environment. Choosing the appropriate oversheath material is essential to protect the cable at all stage of its life.

KEY OVERSHEATH PROPERTIES

Cable norms prescribe the minimum requirements for jackets. In the case of polyethylene jackets, standards such as IEC 60502 or CENELEC’s HD 620 define the functional requirements for the jacket material.

Some properties such as tensile strength and elongation are of general importance, whereas others should depend strongly on the installing technique of the cable and laying environment. Some properties may even be geographically important, for example in southern Europe and the tropics, termite resistance is required.

Cables pulled into ducts or through directionally drilled ground may suffer abrasion to the oversheath, whereas cables which are ploughed-in or pulled-in following directional drilling may come to rest on hard sharp objects (e.g. rocks) and need good puncture resistance.

Impact resistance is important parameter for cables in open ground which may be damaged during ground works in the vicinity of the cable. Similarly the jacket should be resistant to, and act as a barrier against, chemicals in the ground. In other situations, cables:
- Pulled into ducts benefit from a low coefficient of friction and flexibility,
- In tunnels benefit if the jacket has some flame retardant characteristics,
- Which have a wet design, benefit when the jacket reduces water diffusion into the cable’s interior,
- Which are bent or flex significantly benefit from superior stress crack resistance.
Specialized jacket layers

In addition to physically protecting the cable the oversheath can provide extra functionality, e.g. flame retardancy or an improved conducting path.

The benefit of applying a semiconductive jacket in MV cable is grounding is provided over the entire cable length providing additional protection from lightning surges. For HV and EHV cables, an outer semiconductive jacket layer allows simpler diagnostics after production and installation, particularly for cables laid in air. Such layers provide easier application, which does not rub or wash off, and better performance than graphite paint.

Flame retardant jacket materials for cables in tunnels offer important safety benefits such as allowing personnel extra time to evacuate the tunnel in case of fire. These HFFR materials can be applied as outer layer over a traditional jacket resulting in the combined benefits of both materials.

JACKET MATERIALS

Polymeric materials used for cable jackets include PVC, polyethylenes, polypropylene, rubber, nylon, HFFR grades and some other plastics for more specialized applications.

Plasticized PVC is widespread in cable jackets offering good resistance to ozone, oils, acids, bases, alcohols, waxes and greases and flame retardancy in a cost effective manner. The disadvantages of PVC are higher water diffusion, lower abrasion resistance, poor resistance to low temperatures and generation of noxious gases when ignited.

Polyethylenes are becoming increasingly popular as the jacket material for underground power cables because they offer certain advantages over PVC. The polyethylene density is one of the determining factors besides the polymer molecular weight (expressed as melt index) and resin design which controls the properties of the material. However, polyethylenes are usually just classified according to their density:

- LDPE and LLDPE: density from 0.910 to 0.925 g/cm³
- MDPE: density from 0.925 to 0.940 g/cm³
- HDPE: density above 0.940 g/cm³

LDPE jacket materials are generally no longer used for energy cable jackets, but are still used widely in telecommunication cables. Linear polyethylenes offer improved properties compared to LDPE, while modern extrusion lines can process linear polyethylenes without limitations in motor load, melt temperatures or melt pressure. Depending on the requirements LLDPE, MDPE and HDPE are all used in energy cable jackets.

Mechanical strength

The mechanical strength of a jacket is often defined by the tensile properties. Figure 1 shows a comparison of tensile properties of PVC and various polyethylenes. HDPE offers the highest ultimate tensile strength while maintaining high elongation (to break) values. PVC has lower values.

Flexibility

Flexibility is often expressed as flexural modulus and affects the force required to bend cable. Plasticized PVC jackets are very flexible. Within the polyethylene family, LLDPE offers the good flexibility (Figure 1); for this reason it is the preferred material in colder regions. Stiffer polyethylene jacket materials have higher densities.

Hardness and abrasion resistance

The hardness of a jacket material, often expressed as Shore D or Shore A determines properties such as abrasion resistance and termite resistance. Studies have shown that European termite species will not attack jackets having a Shore D hardness above 60, meaning MDPE and HDPE jackets are suitable in this region. In other geographies where termite species can chew harder materials, a nylon (polyamide) outer jacket offers additional protection.

Figure 1. Property balance of PVC and PE jacket grades.

Figure 2. Abrasion resistance of various jacket materials.
A comparison of abrasion resistance is shown in Figure 2. Although suitable for duct systems, first generation semiconducting jackets were softer than unfilled materials and more likely to suffer abrasion when pulled over rough surfaces than modern formulations. New, second generation, semiconductive jacket grades show abrasion resistance more typical of an LLDPE. These are suitable for pulling into ducts or through directionally drilled ground where the conditions can be unknown.

**Temperature resistance**

An important thermal property of a jacket is the puncture resistance as measured by the pressure test at elevated temperatures (Figure 3). This test simulates the resistance of the jacket to resting on sharp stones pushing into the jacket when the cable heats up during operation and subsequent thermo-mechanical movement. The test is clearly relevant to directly buried cables and in particular, ploughed in cables, where no attempt is made to avoid this situation. The indentation of HDPE jacket grades is the lowest of all polyethylene based jackets and offers the best puncture resistance for both MV and HV cable jackets.

Another common measure for temperature resistance is the Vicat softening point of a plastic. As Figure 1 shows, this property is highly dependent on material density. However control of the polymer structure allows this property to be fine tuned whilst maintaining other parameters.

**Environmental stress crack resistance**

ESCR is an important property which indicates if a cable jacket will undergo cracking when subjected to high stresses eg bending. LLDPE jackets exhibit very high stress crack resistance and were therefore the material of choice for energy cable jackets, although MDPE were used when higher abrasion resistance was required.

The previous generation of HDPE jackets could only guarantee a high ESCR level, with high molecular weight polymer, which caused extrudability and shrinkage issues. However, with the new generation of HDPE jacket resins the issues have been designed out of the materials and such grades do not show any failures after 4000 hours in a 10% Igepal solution; the most severe test. This level of performance is typical of LLDPE jacket grades.

**Barrier properties**

Not only does the oversheath protect and prevent corrosion of the neutral wires and metallic sheath (if present), but also limits water diffusion into the interior of the cable when no radial water barrier is present. XLPE insulations will develop water trees when water diffuses into the insulation layer (which can act as a failure mechanism). Use of water tree retardant XLPE combined with a low vapour transmission oversheath will minimise water tree growth when no radial water barrier exists. Figure 4 compares the water vapour transmission of a flexible PVC jacket versus polyethylene jackets. Such results have also been confirmed by measurements on actual cable jackets at different temperatures.

Since the diffusion of water molecules is controlled by the packing of the polymer molecules, high crystallinity HDPE will have the lowest vapour transmission. Nevertheless, the latest (second) generation of semiconducting jackets offers similar vapour transmission to HDPE.

**Coefficient of friction**

The coefficient of friction of the oversheath material determines the pulling forces required to pull a cable through a duct. This characteristic of polyethylene jackets is also related to the density. An HDPE jacket has the lowest coefficient of friction within the polyethylene group and the value is lower than that of plasticised PVC.

**Low temperature behaviour**

Unfilled polyethylenes have a brittleness temperature below -78 °C whilst PVC has a higher brittleness temperature which depends on the level of plasticisation. Tensile elongation values measured for HDPE1 and HDPE2 at
HDPE jackets offer an excellent mix of properties to meet the criteria of the most stringent requirements such as DMP2 or DMP9 for black or DMP13 for natural MV cable jackets in HD 620.

**CONCLUSIONS**

The properties of an energy cable oversheath need to be matched to the installation method and laying environment of the cable. Polyethylene jackets offer benefits over PVC jackets such as reduced water diffusion, higher abrasion resistance and increased toughness.

Advances in polymerisation and catalyst technologies have created polyethylene materials which although having the same nomenclature, e.g. HDPE, can have differing properties. Consequently, modern materials can have improved performance over their predecessors.

Where flexibility is a key performance item, LLDPE jackets are a good choice. New generation HDPE jacket grades provide a combination of high abrasion resistance, superior moisture barrier properties, and excellent thermal and stress crack resistance. For utilities developments in PE jacketing have led to cables with improved reliability.

Advanced jacketing options such as semiconducting jackets offer utilities additional advantages for testing energy cables after manufacturing, installation and during the use.

**REFERENCES**