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VANJSKI ZAŠTITNI PLAŠT ENERGETSKIH KABELA - SISTEMSKE PREDNOSTI KORIŠTENJA BIMODALNOG POLIETILENA VISOKE GUSTOĆE

SAŽETAK

Vanjski zaštitni plašt energetskih kabela prijeko je potreban sastavni dio konstrukcije kabela. On štiti izolaciju i vodič energetskog kabela od mehaničkih oštećenja i ulaska vlage u kabel za vrijeme transporta, polaganja i upotrebe kabela. Kod odabira materijala za vanjski zaštitni plašt energetskih kabela, najvažnije je upotrijebiti materijal koji osigurava najbolje značajke obzirom na: pouzdanost, cijenu i zaštitu od vatre (gdje se traži).

U refratu se fokusiramo na detaljiziranje ukupnih sistemskih koristi upotrebom bimodalnog HDPE materijala za vanjski zaštitni plašt energetskog kabela tijekom proizvodnje kabela, njegovog polaganja i ukupne životen dobi kabela.

Ključne riječi: vanjski zaštitni plašt kabela, energetski kabel, bimodalno HDPE materijal, sistemske koristi

SYSTEM BENEFITS OF USING BIMODAL HIGH DENSITY POLYETHYLENE COMPOUND IN POWER CABLE JACKETING

SUMMARY

The jacket is an essential component of cable construction. It protects power cable insulation and conductor from mechanical damage and moisture in-take during transportation, installation and operation. When selecting jacketing material for power cables, the key objective is to use material which provides the best performance with regard to: reliability, cost and fire protection (where specified).

This paper focuses on detailing the total system benefits of using bimodal HDPE as the power cable jacketing material in cable production, cable installation and lifetime.

Key words: jacket, power cable, bimodal HDPE compound, system benefits

1. INTRODUCTION

A cable jacket provides the outer protection of the cable. It is an essential component to provide cable system functionality through cable lifetime. Choosing the right cable jacketing compound not only has a major influence on in-service performance, it can also have a significant impact on the total cost of cable systems including cable production, transportation, handling, installation, operation, and even system maintainability.

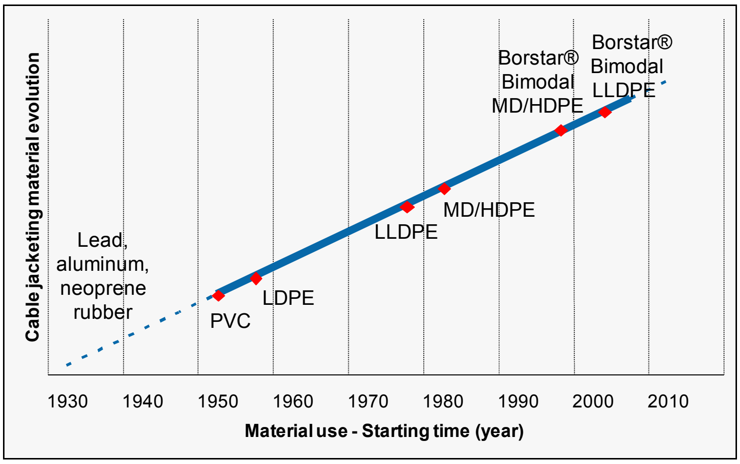

Figure 1. Evolution of jacketing materials

Figure 1 demonstrates the evolution of the jacketing materials in the past 80 years. Lead represents the oldest type of the jacket for the power cables. Then aluminum jacket has been used in Germany since 1940s. The most frequently specified jacketing materials for low voltage cables and building wires are PVC and PE [1]. Since its introduction in the 1950s the most significant technical evolution has been in the polyethylene (PE) field where new polymerization technologies have made possible the development of jacketing products with enhanced key properties with over 30% lower weight (density) (Figure 2). Polyethylene (PE) has a long history of use for jacketing in wire and cable applications. Conventional high-pressure LDPE was widely used in the early years, but it has been largely replaced by linear materials. These polyethylenes, LLDPE, MDPE and HDPE, have much improved jacketing mechanical and physical properties than LDPE and PVC.

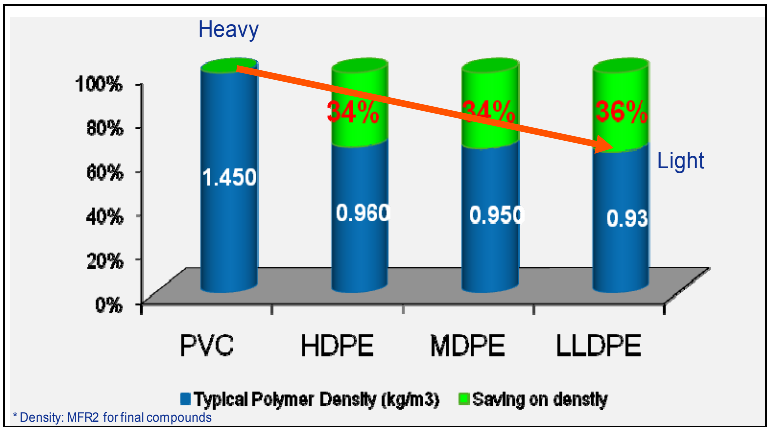

Figure 2. Material weight (density) comparison

However, a quantum developmental leap was the introduction of bimodal materials based on the proprietary technology Borstar® in the late 1990s. Unlike the conventional unimodal PE technology, it allows the tailoring of the molecular structure of polymers, which has led the path to a new generation of cable jacketing materials with the optimal balance of all jacketing key properties. Although Borstar® technology can provide the full range of PE (LLDPE, MDPE, and HDPE), the bimodal HDPE compounds have proven to perfectly match requirements of modern power cables jacketing.

2. BIMODAL TECHNOLOGY PLATFORM

Borstar is a bimodal technology combining a supercritical propane slurry loop and a gas phase reactor utilising a proprietary catalyst to produce polyolefin (Figure 3). The reactor principle is unique. Together with the catalyst it creates a process which gives a high degree of flexibility for the production of enhanced PE materials. Unlike some other bimodal processes, which are limited to MDPE and HDPE products, the Borstar process, employing a unique configuration, can also produce LLDPE resins. In the loop reactor, which is placed first, the fraction with little or no co monomer is produced. The melt flow rate is high (ie. short molecules). The material is transferred to the gas phase reactor without additional catalyst feed. The polymer chain continues to grow on the same catalyst particle, which means that both short and long chains derive from the same particle. This produces superior homogeneity which cannot be obtained with a polymer mix. Processability is determined both by ratio of materials between reactors and MFR of the materials in the two reactors. Simply stated, good processability requires higher MFR and a larger amount produced in the first reactor. For unimodal materials produced in one reactor, a particular catalyst gives a specific molecular weight distribution, which cannot be changed. Only the molecular weight can be adjusted. This certainly limits the potential for modifying the material. Finally, the Borstar process permits the tailoring of products for a given requirement (e.g. processability).

A comparison of unimodal PE and Borstar PE highlights the advantages of the Borstar process. The Borstar process makes it possible to combine the good properties of various conventional PE types into one product, thereby creating new products which set new standards. ESCR is closely related to the number of tie molecules formed during the crystallisation process, and which link the crystalline lamellae together. The distribution of the co monomer is important, since a co monomer on the chain works as a disturbing point and starts the growth into another lamella. The optimal distribution is the location of the co monomer on the long chain to create a maximum number of links among the lamellae. On short chains, the effect of the co monomer is of little importance. For some catalysts used in unimodal production, most of the co monomer tends to be located on the short chains. As a result, melt flow rate (MFR) has to be kept low in order to achieve acceptable ESCR properties. This means that processing properties will suffer from high melt pressure, limited output, etc.

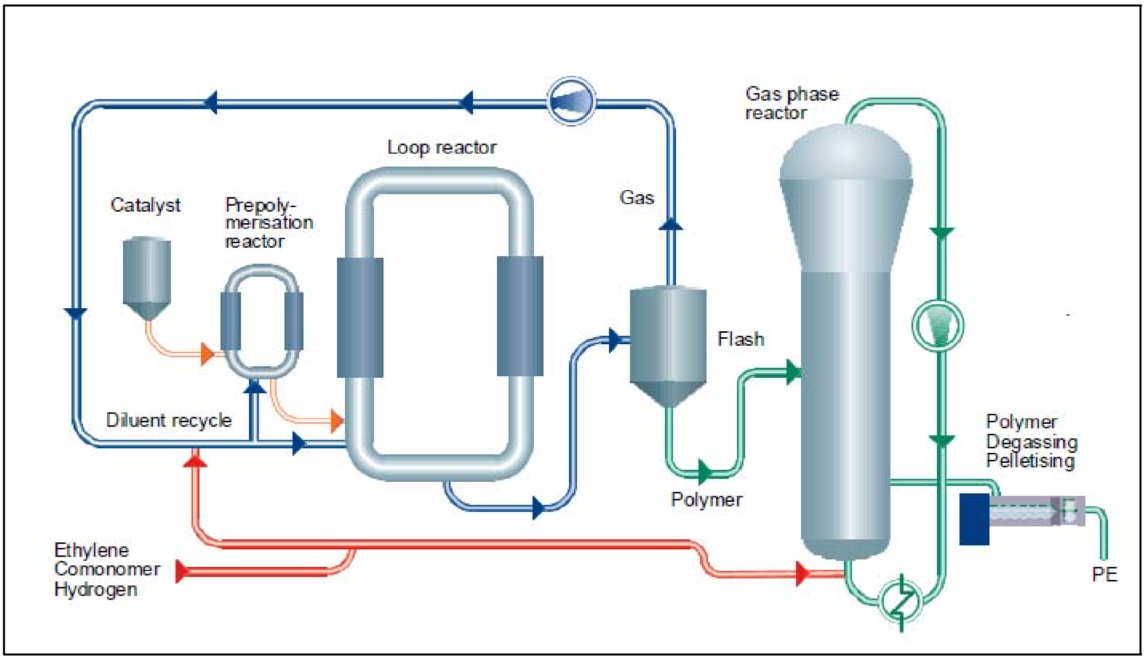

Figure 3. Borstar process flow chart

Figure 4 illustrates how product properties are linked to different areas of the molecular weight distribution (MWD) for a PE resin. The graph indicates the differences between MWD for conventional unimodal PE and a bimodal material. Due to overlapping peaks actual MWD curves for bimodal grades do not necessarily show two well-separated peaks. Co monomer distribution is another important tool for optimising polymer structure and material characteristics. The curve shows how polymers can be engineered thanks to the Borstar bimodal technology. Not only the bimodal curve cuts the left area of MWD which is responsible for odour, smell, smoke during extrusion, but also it strengthens the right area of MWD which is responsible for better processing, melt strength, swelling.

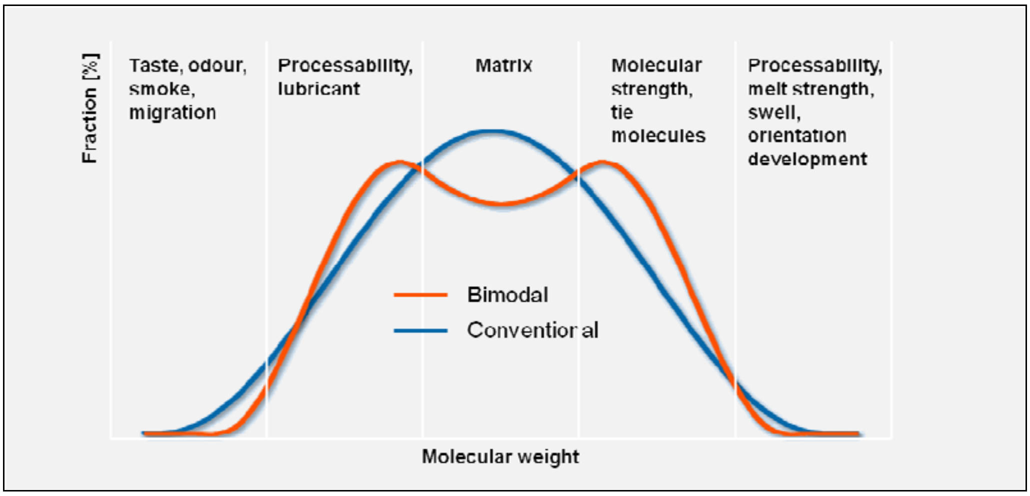

Figure 4. Molecular weight distribution curves for unimodal and bimodal PE resins

3. SYSTEM BENEFITS OF USING BIMODAL HDPE COMPOUNDS FOR POWER CABLE JACKET IN

Choosing bimodal HDPE compounds for power cable jacketing can improve cable production efficiency, make installation easier at reduced costs and ensure a long cable lifetime.

3.1. Improve cable production efficiency

A highly efficient cable production can be contributed by a high extrusion line speed, low energy consumption and long production operation cycles. This helps cable producers to increase the cable output, reduce the production costs and the working capital.

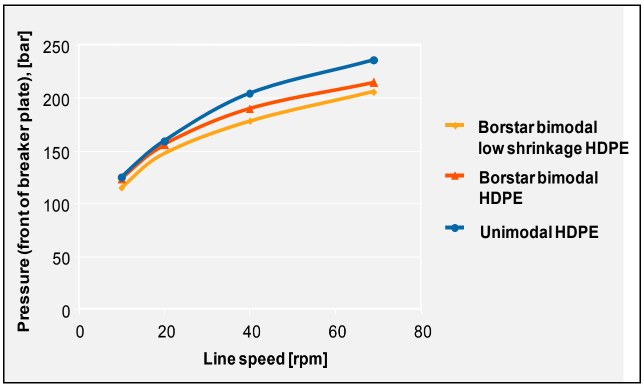

Figure 5. Melt pressure versus line speed comparison with PVC screw, 150 mm / 25 D

Zones	Borstar® bimodal low shrinkage HDPE	Borstar® bimodal HDPE	Unimodal HDPE
Zone 1	140°C	150°C	170°C
Zone 2	160°C	170°C	180°C
Zone 3	170°C	180°C	190°C
Zone 4	170°C	180°C	200°C
Neck	180°C	190°C	210°C
Die	180°C	190°C	220°C

Figure 6. Extrusion temperature setting

Due to the uniqueness of the molecular distribution, bimodal HDPE jacketing compounds provide wider processing window than conventional unimodal HDPE compounds as shown in Figure 5. This allows for the higher throughput when keeping the same extrusion pressure, which can result into the higher productivity of cable production.

Bimodal HDPE compounds also can reduce the energy consumption during extrusion. This is clearly shown on the extrusion temperature setting comparison (Figure 6), in which bimodal HDPE compounds can be extruded at lower temperatures than unimodal.

3.2. Make installation easier at reduced costs

3.2.1. Surface properties

Cable laying into the ground is the process where the cable jacket is exposed to possible mechanical damages. Cables with damaged jackets need to be repaired or replaced either on site or back to the cable production plant. If not repaired, the damaged jacket may significantly reduce lifetime of the cable due to non-protection of the cable core. That is why hard and tough material should be chosen for cable jackets to reduce the repairing costs due to damage and risks for cable failure. As seen in Figure 7 and 8, bimodal HDPE compounds ensure the best protection of the cable core. They make it possible to lay power cables using smaller trenches and sometimes even without sand bedding or direct plugging techniques.

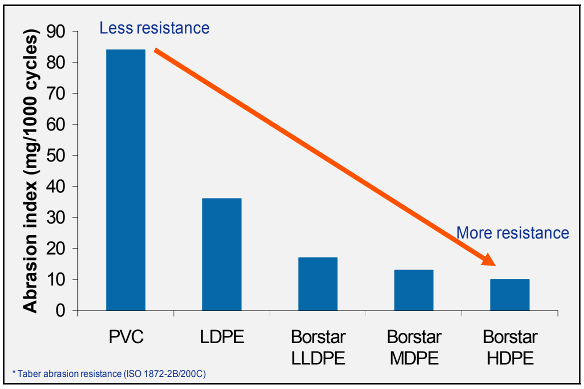

Figure 7. Abrasion resistance comparison

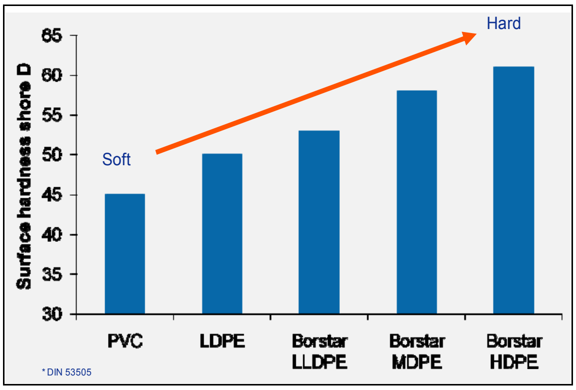

Figure 8. Shore D hardness comparison

3.2.2. Cable laying costs

During the laying of power cables, it is important that automatic mechanical laying techniques like plugging can be used. In certain areas, the removed soil can immediately be used to backfill the trench. However, in most parts of Europe, the soil is too rocky to be used for this method. Therefore, the cable has to be specially protected. In this situation, the use of high-performance HDPE, with high hardness property (i.e. >58 Shore D) for jacketing, should be applied. Typical laying costs of 0.4 kV cable in one European country is represented in Figure 9 [2].

By using HDPE jacketing with sufficient hardness properties, the laying costs can be reduced significantly. The trenches can be smaller and the risk that the cables are damaged during installation is lower. Additionally, the soil that is obtained by digging the trenches can be used to fill them again instead of sand, further reducing the costs. In Figure 10, the costs are outlined from a German utility that introduced a hardness specification in 1985 [3]. They were able to keep their installation costs under control and improve the performance of their grid.

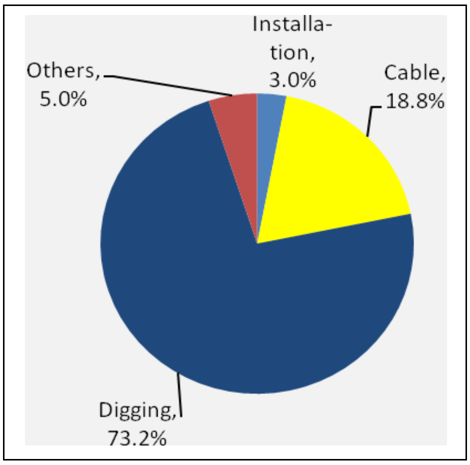

Figure 9. Laying costs for a 0.4 kV cable [2]

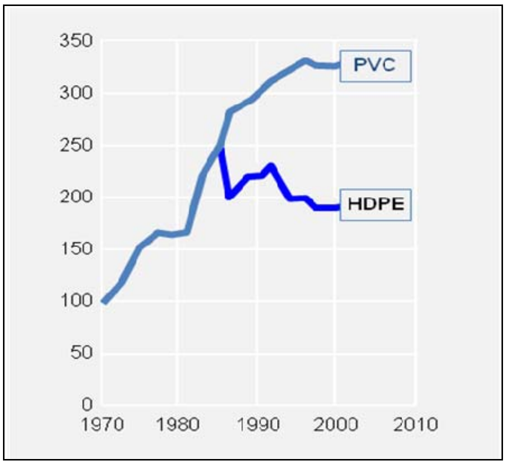

Figure 10. Standardized cost of laying 20 kV cables in the Bavarian area in Germany [3]

3.3. Ensure a long cable lifetime

3.3.1. ESCR

ESCR is an important long term property of many plastics in contact with different media such as detergents, oils, and insect repellent. Laboratory measurement of ESCR is usually carried out in such media to accelerate crack initiation and propagation. In the case of PE, it is well known that the cracking phenomenon is easily accelerated in the presence of detergents such as IGEPAL for example.

The ESCR of semi-crystalline polymers such as PE is less severe than in amorphous polymers. However, exposing PE to stress-crack agents results in unexpected brittle fracture. Crazes (or white spots) are commonly found as a precursor to this type of fracture in PE. However, this cannot be determined by conventional mechanical properties of the polymer but rather by the ESCR tests. Factors governing ESCR are those related to the environment such as the exposure time to the stress cracking agent, exposure temperature, concentration of the stress cracking agent, and level of strain on or in the polymer. Combination of mentioned parameters may lead to the shortening of the time to failure. Measurement of ESCR is an important way to characterize mechanical strength of plastics, also those used for cable jacketing. The environmental test media is selected based on the plastic type and end use application. As mentioned previously in the case of HDPE and MDPE, the cracking phenomenon is readily accelerated in the presence of detergents such as IGEPAL [4]. IEC60811-4-1/B and ASTM D1693 are the most frequently used methods in determination of ESCR for cable jacket materials.

As seen in Figure 11, bimodal HDPE gives significantly better results in the ESCR test according to ASTM D1693 than unimodal HDPE. Bimodal HDPE compounds, regardless MFR, showed no cracks during testing, whereas 20% of conventional unimodal HDPE sample was cracked before 2000 hours.

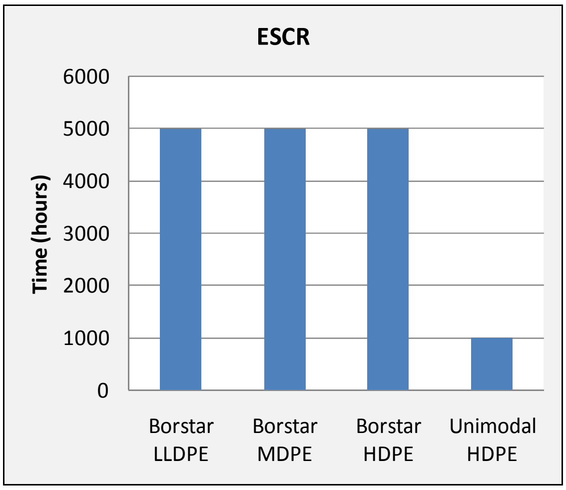

Figure 11. ESCR F0 (hours) (ASTM D 1693A)

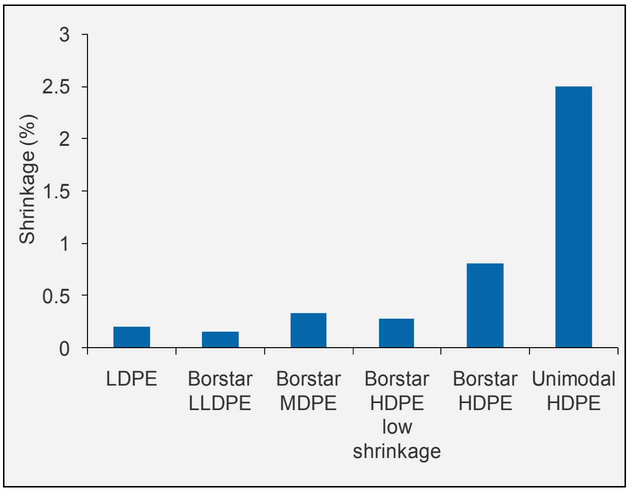

Figure 12. Shrinkage of cable jackets at 100^{o}C/24 (IEC 60811-1-3)

3.3.2. Shrinkage

Shrinking or shrink back influences the performance of cables. In joints or terminations of the cables excessive shrinkage can open the access of the environmental surrounding (especially moisture) to the cable core, thus leading to an early breakdown of the cable.

PE resins show tendency to shrinking or shrink back. During the cable extrusion process, the orientation of molecules takes place already in the die. Process starts at the entrance of the die. Relaxation continues after the jacket has been extruded on the cable. This post-shrinkage causes various problems. The long molecules cause most of the shrinkage. They orient in the melt, and their size restricts them to relaxing between the die and the cooling bath. Due to the type of catalyst, unimodal PE normally contains a small amount of very long molecules, which cause most of the shrinkage.

The catalyst for the Borstar bimodal process does not produce this fraction of very long molecules, ensuring much lower shrinkage for bimodal PE (Figure 12). For stringent shrinkage requirements, a very low shrinkage Borstar bimodal HDPE (Figure 12) is often used such as for fibre optic cables. All standard requirements are fulfilled with bimodal HDPE compounds with a great safety margin.

3.3.3. Weather resistance

Both cables installed and stored outdoors may be exposed to sunlight and strong UV exposure. As UV radiation can cause rapid degradation, a cable jacket has to be properly protected. Superior UV stabilization is obtained by the incorporation of properly dispersed special carbon black in the PE compound.

A number of cable makers are today offering products to the market where the incorporation of the carbon black master batch is carried out during the extrusion of the cable jacket. The analysis of commercial cable jackets produced in this way has shown that in some cases these products meet neither the established absorption coefficient requirements nor dispersion standards. Cables not meeting these standards could be liable to failure within 5-10 years [5].

Colored cables must also be protected against UV degradation and all natural Borstar HDPE jacketing compounds contain a hindered amine light stabilization which has been demonstrated to give 5 years protection in outdoor Florida ageing experiments. This equates to 10 years exposure in Central Europe. However for indefinite outdoor exposure the use of black ready-made jacketing compounds is recommended.

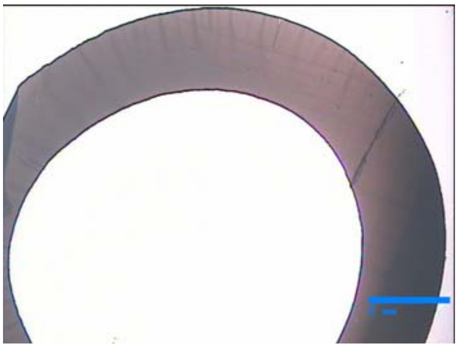

Figure 13. Dispersion quality of fully formulated compound [5]

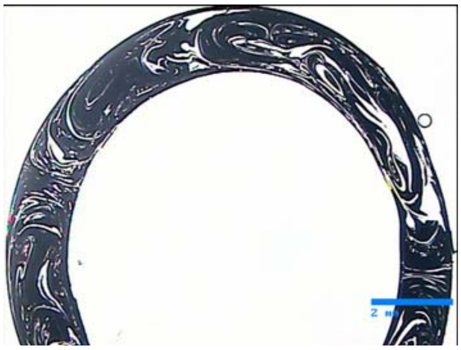

Figure 14. Example of dispersion quality by inline of carbon black during extrusion [5]

3.3.4. Water barrier

As shown in Figure 15, PVC absorbs more water than PE. The water absorption leads to the weakening of the material's insulation properties and eventually to the breakdown of the cables. Cables with PVC jacketing are subject to this phenomenon, while cables with HDPE jacketing are far more resistant to the presence of moisture (Figure 16). Experience has shown that very low moisture transmission rate significantly reduces degradation in MV cables, thus maintaining breakdown strength on the high level and extending cable life time [6].

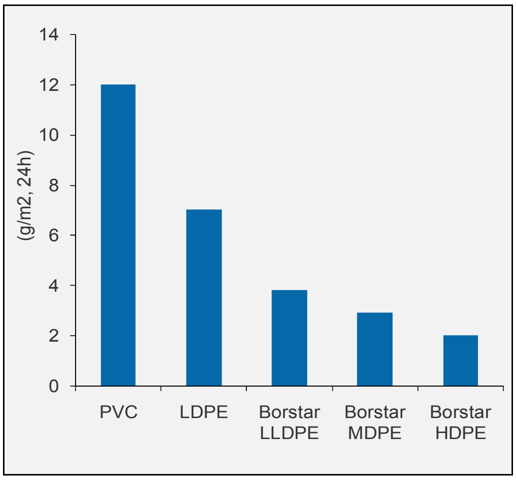

Figure 15. Water absorption for 100 my film, 38°C, 95% RH

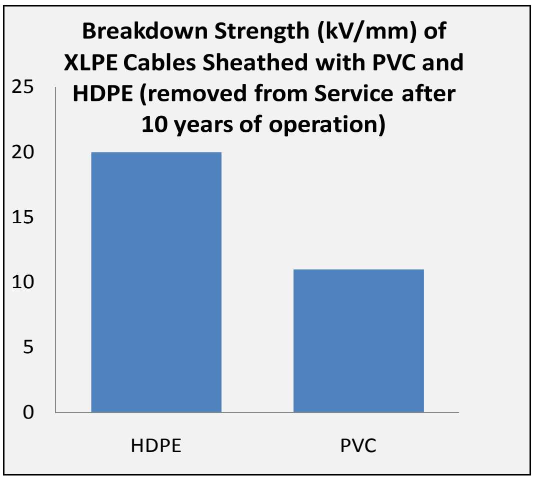

Figure 16. Breakdown strength of MV XLPE cable [6]

3.3.5. Termite resistance

Underground cables are not only exposed to the treatment of weather conditions and mechanical damages, but also to the attack of animals such as rodents or termites. In some world areas it is very important that a cable jacket gives protection against termites. Here PVC is not recommended as the cable jacket (Figure 17). A possible solution is the addition of special anti-rodent additive or applying additional metallic outer sheet over a standard PE jacket. However, according to the results presented at JiCable 2007, the addition of biocide or repulsive products to PE is not really necessary. Especially HDPE based materials are very resistant to termite attacks [7].

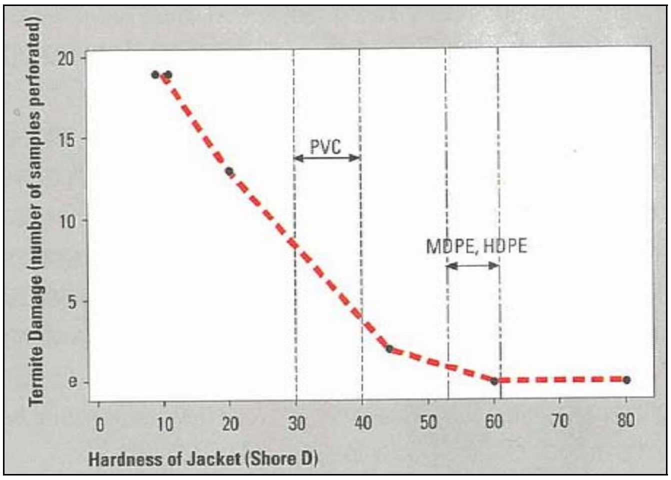

Figure 17. Relation of termite attack to jacket hardness [6]

In the below Table I, results of experiments using three types of termites with HDPE black and coloured jacket are given. Each type of material was tested in three parallel tests with the following termite species according to EN 117: Reticulitermes santonensis (European termite, f.ex. in France), Coptotermes formosanus (South East Asia: Japan, perhaps also in China, South America and New Orleans region). For each test 250 workers were used. Two specimens of each type of material were placed in breading basins of species of Coptotermes formosanus and Mastotermes darwiniensis between feeder wood blocks (to resemble real life). Climatic conditions were: 26 ºC, relative humidity 92 %. Test time: 8 weeks.

Table I. Termite tests results

Test method	Similar to EN117				Breading basin			
Termite species	R. santonensis		C. formosanus		C. formosanus		M. darwiniensis	
Area	Edge	Surface	Edge	Surface	Edge	Surface	Edge	Surface
Borstar HDPE black&red	0	0	0	0	2	0	0	0

Assessment: 0 - No attack
1 - Traces of gnaw on the surface or edge
2 - Light attack: < 1 mm depth
3 - Medium attack: > 1 mm depth
4 - Heavy attack: holes or specimen destroyed

Based on the above results, bimodal HDPE can be classified as termite resistant towards European termite R. santonensis and Australian M. Darwiniensis. The South-East Asian termite species C. formosanus is more aggressive and the tested materials are not resistant to attack of this termite species.

3.3.6. System outages

Increased evidence proves that cable jacketing has an important influence on the service life of power cables. The failure rate depends largely on the jacketing material. Table II shows clearly the differences between HDPE and PVC.

Table II. Chosen properties of jacketing materials

Sheathing material	HDPE	PVC	Unit	Method
Impact resistance	18	9	kJ/m²	-
Hardness	60-63	37	Shore D	ISO 868
Water absorption	≤0.2	10	mg/cm^2	14 days, 85°C
Brittleness temperature	<-76°C	-15°C	min. °C	ASTM D 746
Handle ability temperature	-15°C	0°C	min. °C	-
Pressure test at high temperature	<10% at 115°C/6h	10-30% at 90°C	%	IEC 60811-3-1
ESCR	>2000	No data available	FO, h	IEC 60811-4-1/B
Fungicide	Very good	Low	-	-
Termites resistance	Very good	Low	-	-

Furthermore, the system outages using an XLPE/HDPE (insulation/jacket) cable can be reduced significantly. In Figure 18, the outages from a European grid are highlighted. It can clearly be seen that using an XLPE cable together with a tough jacket reduces the outages by more than 50%, further increasing the reliability of the power grid [8, 9].

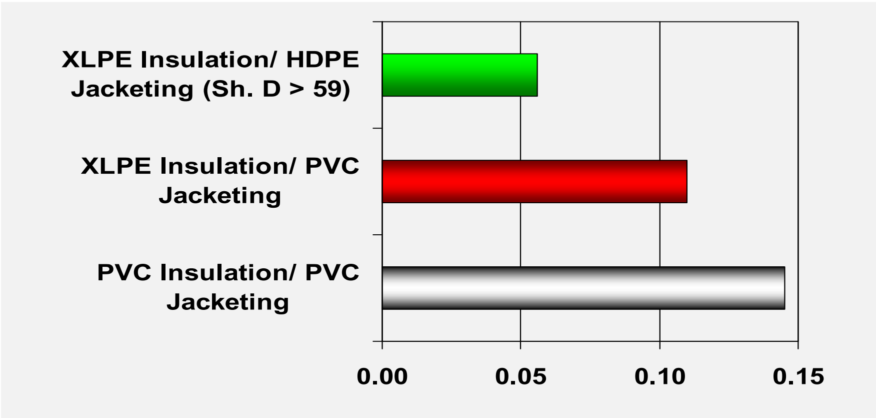

Figure 18. System outages per system kilometer and year [8], [9]

4. CABLE JACKETING STANDARDS AND SPECIFICATIONS

There are many cable standards specifying jacketing material for power cables. These include HD603, HD620, HD632, IEC60502, IEC60840, and IEC62067. Specific requirements to the cable jacket material are included in mentioned standards, which are mechanical properties before and after aging, ESCR, pressure test at high temperature, shrinkage, Shore D hardness, carbon black content and different tests at low temperatures. However, the carbon black dispersion and absorption coefficient are not specified in most Energy cable standards in Europe and it is recommended this omission should be corrected [5].

In some countries, the power cable standards are directed towards overall end cable performance and less specify on material properties, which encourages the innovative solutions in the cable industry.

5. CONCLUSIONS

The jacket is an essential component of the power cable construction. Choosing the right jacketing material has a significant influence on cable production, installation and laying costs, and cable lifetime.

HDPE provides much better protection than PVC as the power cable jacketing material. By combining a HDPE with bimodal polymerization technology, bimodal HDPE compounds offer the optimal balance of all key jacketing properties including improved processability, reduced shrinkage and yet with excellent physical toughness and environmental stress crack resistance (ESCR).

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