# AGEING AND IMPROVEMENT OF LV UNDERGROUND EXTRUDED CABLES SYTEMS

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## *ABSTRACT*

*Extruded Low Voltage (LV) cables systems are ageing and an assessment of their condition is now necessary to build up a strategy regarding the management of this asset. This paper describes on the one hand the symptoms observed on faulty LV cables and branching joints by means of visual examination, material and electrical measurements in Laboratory. On the other hand, the paper describes the different investigations done in order to control and improve the quality of new LV extruded cable systems.*

## INTRODUCTION

By analysing the recent LV failure statistics, Belgian DNOs have observed that the service life of newly installed underground polymeric cables and branch joints are far shorter than expected. Taking into account the importance of those failures to the total cost of the LV network exploitation, a project was launched in order to determine the reasons for the premature faults and to build up a strategy regarding the management of this asset.

The first part of this paper presents the results of the examinations and tests, carried out on about thirty faulty LV extruded cables and branching joints taken from the field. The mechanical ageing of the insulation and the outer sheath is investigated mainly by performing tensile tests. The electrical ageing of the insulation is determined by carrying out a dielectric spectroscopy measurement, a resistance test and a breakdown voltage test. The results obtained on faulty cables are compared to those obtained on new reference cables stored in the LV cable library of Laborelec.

Based on the results of these analyses, it was decided to perform quality check on some new LV cables by controlling the resistance against impact, measuring the outer sheath thickness and testing the adhesion of the XLPE insulation with different cast resins used for branching joints. The results of these additional tests are presented in the second part of the paper.

## VISUAL EXAMINATION OF FAULTY LV EXTRUDED CABLES & BRANCHING JOINTS

Visual examinations performed on faulty branching joints have shown that, most of the times, the faults are due to bad mounting and water ingress (Fig.1). Most of the water issues are related to a poor adhesion between the XLPE insulation of the cable and the resin (Fig.2). Due to this lack of adhesion and under the influence of the load cycling, the joints become vulnerable to water infiltration.

**Fig. 1** : Resin not correctly poured

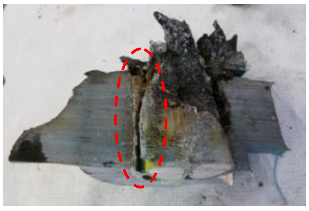

**Fig. 2** : Poor adhesion between the resin and the XLPE insulation

Most of the faults that occurred on cables are due to mechanical degradation of the outer sheath and water ingress. Severe degradation by corrosion of the aluminum solid conductor is often observed (Fig. 3 to 6). The efficiency of the swelling tapes did not appear sufficient to avoid longitudinal water diffusion.

**Fig. 3** : Corrosion on the PVC filler

**Fig. 4** : Corrosion on the PVC filler

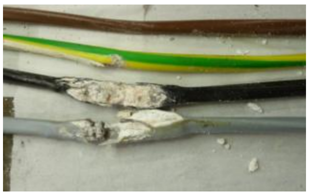

**Fig. 5** : Corrosion of conductors

**Fig. 6** : Degradation due to water ingress

## AGEING OF EXTRUDED LV CABLES

### Mechanical ageing of the insulation

The decrease in elongation at break and tensile strength of the insulation were analyzed by performing tensile test on 11 faulty XLPE insulations. As shown in Fig. 7, the obtained values are higher than the requirements of CENELEC HD 603 for unaged XLPE insulation (min. 12,5 MPa and 200 % ).

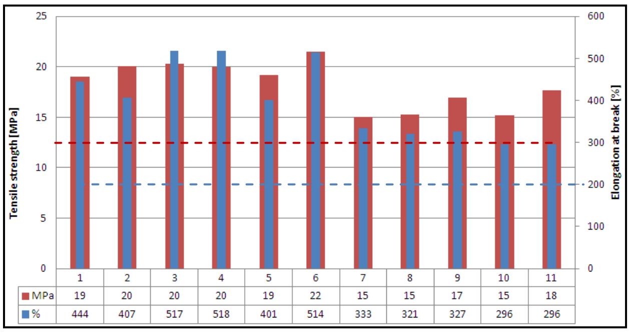


**Fig. 7** : Tensile test of 11 faulty insulations

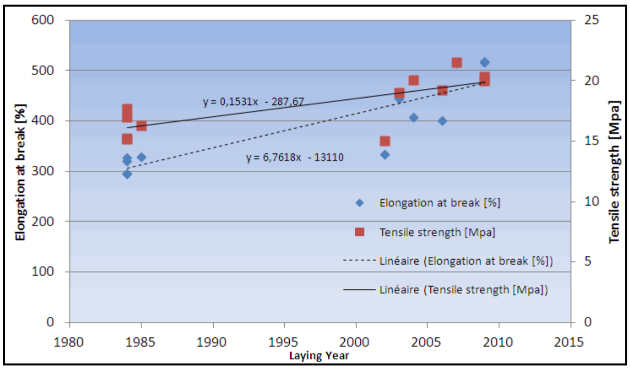


**Fig. 8**: Elongation and tensile strength in function of laying year

The decrease in elongation and tensile strength are presented in Fig. 8 in function of the laying year. On the assumption that the decrease in mechanical properties is a linear function of time [1], we get two trend lines. According to the first trend line, cables laid before 1968 (45 years) have an elongation at break below the criterion standard (200%). According to the second trend line, cables laid before 1962 would have a tensile strength less than the standard criterion (12.5 MPa). More tests on older cables need to be carried out in order to confirm this ageing model.

### Mechanical ageing of the outer sheath

Tensile test were also performed on four faulty outer sheaths. The obtained values of tensile strength and elongation at break are higher that the requirement of the CENELEC HD 603 for PVC sheath (min. 12,5 MPa and 125 % ). The outer sheath in PVC contains phthalates to make the cable flexible. By varying the quantity of plasticizer, manufacturers can select precisely the degree of flexibility necessary to meet the mechanical requirements of the end product. Thermal aging can lead to the evaporation of plasticizers. The percentage of plasticizer has been measured by Pyrolysis GCMS on a new outer sheath and on aged outer sheaths from the field. The results of this analysis (Fig. 10) show that the remaining percent of plasticizer is still high enough to avoid cracking of the outer sheath at low temperatures (> 18 % [1]).

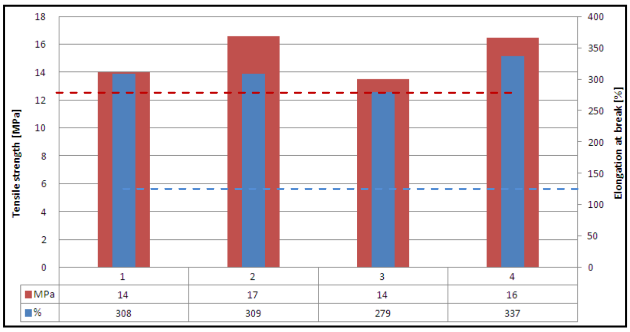


**Fig. 9** : Tensile strength of faulty outer sheaths

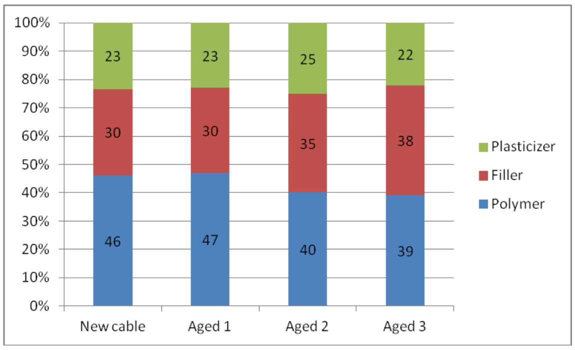


**Fig. 10** : Percentage of polymer/plasticizer/filler

### Electrical ageing

Most of the dielectric spectroscopy measurements on aged cables showed that the tangent delta increased over the years. Figure 11 compares the results obtained on an aged cable with those obtained on a reference from the cable library. In that case, Tan delta at 50 Hz ($200V_{peak}$) increases from 0.04 to 0.0494 (+19%).

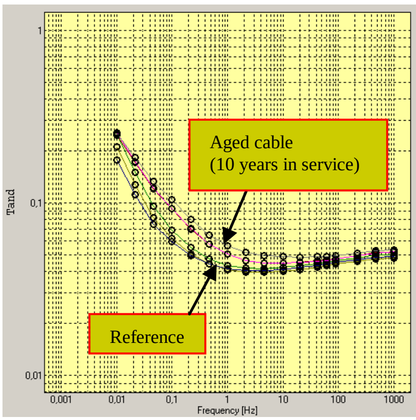


**Fig. 11** : Increase in Tg delta after 10 years service

Dielectric spectroscopy measurements were also used as a quality control (Finger print) of new LV cables in order to quickly check that manufacturer did not change their insulation compound.
The insulation resistance tests carried out at 1 kV on both new and aged cables show similar results. The resistance of the phases of the aged cable is systematically lower than the resistance measured on the same core color from the reference (Fig. 12).

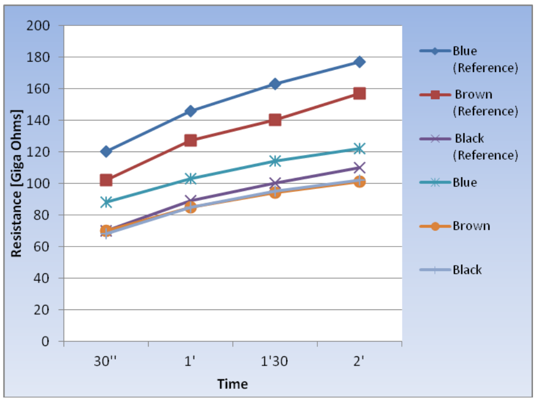


**Fig. 12** : Decrease of the insulation resistance after 10 years service

Breakdown voltage tests were also performed on both new and aged cables. LV cables aged by 3 years of service have broken down during a dielectric voltage test at 30 kV, while a new cable can support a voltage reaching 63 kV. Although all these electrical results are acceptable, it still shows that the dielectric strength tends to decrease rapidly once the cable is in service.

## QUALITY CHECK OF EXTRUDED LV CABLES

### Control of the impact resistance

The EN 50393 on LV accessories requests to perform an impact test at ambient temperature with a steel block of 4 kg dropped on to the accessory from a height of 1m. It seems surprising that no impact test at ambient temperature is required in the standard HD 603 on LV cables, where the risk of impact is certainly higher on the cable than on the accessory. The standard HD 603 asks for an impact test at low temperature according to the EN 60811-506 but the impact test apparatus using a hammer does not correspond at all with the impact test of the standard EN 50393. Therefore, whether the used LV cables have the same impact resistance as the cable accessories is currently unknown. For this reason, impact tests were performed on LV cables at ambient and low temperatures by using the impact test set-up of the EN50393. These tests were performed on cables with PVC and LLDPE outer sheath. For the cables with LLDPE outer sheath, the impact at ambient temperature damaged the outer sheath and slightly degraded the insulation (Fig. 13 and 14). The damage is higher for cables of the same cross-section but with PVC sheath. For these cables, the insulation was torn after the impact (Fig. 15 and 16).

**Fig. 13** : LLDPE sheath after impact test (Outer side)

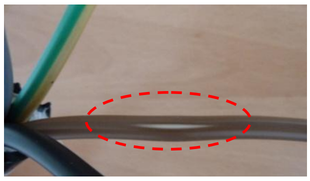

**Fig. 14** : Insulation under the LLDPE sheath (after impact)

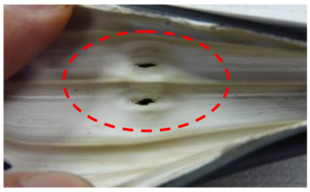

**Fig. 15** : PVC sheath after impact (Inner side)

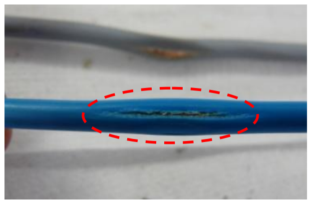

**Fig. 16** : Insulation under the PVC sheath (after impact)

The impact tests at low temperature (-15 °C) have shown that PVC sheath with armour can be very sensitive to impacts (Fig. 17).

**Fig. 17** : Impact test performed on LV cable with PVC outer sheath cooled at – 15°C

### Outer sheath thickness

The outer sheath thickness of unaged cables fabricated between 1997 and 2011was measured in accordance with the EN 60811-202. Since the revision of the NBN HD 603 in 2007, the nominal thickness of the outer sheath of the Belgian 4*150 mm² 1 kV cable (EAXeVB) is 3 mm (instead of 3,2 mm) and the minimal value is 2,45 mm. The thickness measurements have shown a tendency of the cable manufacturers to decrease the average thickness in order to be close to the minimum value of 2,45 mm (Fig. 18). This decrease of the thickness could partially explain the increase of the breakdowns of newly installed cables.

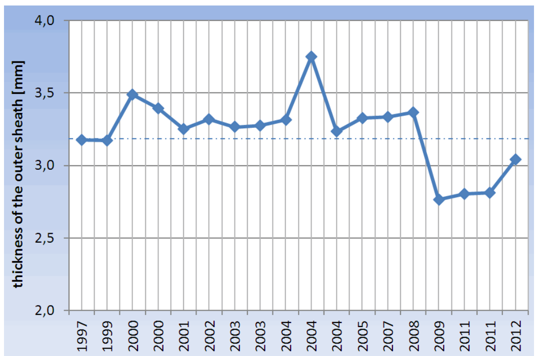


**Fig. 18** : Outer sheath thickness of new cables fabricated between 1997 and 2011

## Adhesion between XLPE insulations and resins

Although research and progress have been made in order to improve the adhesion between the XLPE insulation of the cable and the cast resin, branching joint manufacturers still meet difficulties to pass the cycling tests according to the EN50393 standard (63 load cycles in air followed by 63 load cycles in water with direct penetration of water under the cable sheath). Due to the lack of adhesion and under the influence of the load cycling, the joints become vulnerable to water infiltration. Belgian DNOs asked Laborelec to performed adhesion test as described in the HD603 part 5 Section G on four resins (A, B, C and D) in association with three cables (a, b and c) from different manufacturers. It consists of traction tests on samples of core insulation moulded with cast resin. The results of these tests have shown that, even if the adhesion is higher than in the past [2] and if the average peeling resistance is high for cables b and c (Fig. 19), the obtained minimum peeling resistances were, for some of the 10 tested samples of cables a, b and c, still lower than the required value specified in HD 603 Part 5-G (1N/mm).

| | Black phase | | | Brown phase | | | Gray phase | | | Yellow/Green | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cable / Resin | a | b | c | a | b | c | a | b | c | a | b | c |
| **A** | 0,3 | 3,0 | 9 | 0,2 | 1,5 | 4,9 | 0,2 | 4,2 | 0,0 | 0,0 | 2,7 | 13 |
| **B** | 0,1 | 2,5 | 8,7 | 0,2 | 1,5 | 3,4 | 0,1 | 2,1 | 6,3 | 0,3 | 2,2 | 6,8 |
| **C** | 0,0 | 1,8 | 9,8 | 0,1 | 1,1 | 4,7 | 0,2 | 2,9 | 13 | 0,3 | 2,0 | 8 |
| **D** | 0,1 | 3,4 | 5,4 | 0,2 | 1,5 | 3,7 | 0,2 | 3,1 | 4,9 | 0,6 | 3,5 | 5,4 |

**Fig. 19** : Average peeling resistance (N/mm) on four resins (A, B, C and D) in association with three cables (a, b and c)

A complementary chemical analysis was performed on 4 resins in order to discover the nature of the resins by XRF and infra red spectroscopy and to detect the resin composition changes. The resins are a two component polyurethane-type casting material consisting in a mixture of polyols, with fillers and special additives, and a hardener which is always MDI (diphenylmethane-di-isocyanate). The main difference between the resins is to find in the percentage of filler and additive component (fig. 20).

| Resin | Polyol | Filler | Isocyanate |
|---|---|---|---|
| **A** | Polyester | Andalusite<br>Potassium silicate<br>(Calcium carbonate) | MDI |
| **B** | Polyester | Calcium carbonate<br>(Andalusite) | MDI |
| **C** | Polyester | Calcium carbonate<br>Andalusite | MDI |
| **D** | Polyester | Calcium carbonate<br>(Andalusite) | MDI |

**Fig. 20** : Composition of the tested resins

## CONCLUSION

Most of the premature breakdowns of LV cable systems appear to be caused by local water tightness problems, due to mechanical degradations on the outer sheath (for the cable) and to a bad mounting or a poor adhesion between the resin and the XLPE insulation (for the branching joint). Radial and longitudinal water absorption induces corrosion of the sector shape conductor and leads to failure.

Most of the material and electrical tests performed on faulty extruded LV cables show that, although decreasing, the dielectric strength and mechanical properties of the insulation and the outer sheath are still in accordance to the requirements for new cables. Given the number of defects on newly installed LV cable systems due to water absorption and mechanical damage, the question might arise if the current specification and standards cover adequate requirements and tests regarding the main causes of branching joints and cable failures. Several options may be considered, in order to improve the quality of LV cables:

- Change the criterion of the water penetration test
- Require long-term tests with cables directly buried
- Require an impact test based on the test setup of the EN 50393
- Increase the average outer sheath thickness
- Require an LLDPE outer sheath and/or a more resistant PVC filler.
- Improve the quality of sector shape conductor by requiring additional tests to the EN 60228 that only gives requirements on resistance and tensile strength but no requirement on hardness or corrosion resistance.

## REFERENCE

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[2] A. Déom, Y. Tits, E. Engel, A François, D. Vangulick, 2003, LV Underground branching joints – Compatibility between cable insulation and cast resin. CIRED 2003 1/23

[3] CENELEC HD 603 S1/A2, Distribution cables of rated voltage 0,6/1 kV, 2003