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B1 Insulated cables
PS1/Learning from experiences

Practical experience and modelling of the corrosion behaviour of the Aluminium metallic cable sheath

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SUMMARY

For cross-border TSO, conservation, maintainability and loading capabilities are key for operating the 150 kV underground cable (UGC) grid successfully. The TSO is eager to get better insight into optimizing specifications and maintenance activities of HV cable systems, in order to manage remaining lifetime aspects and fine-tune the asset management practices.
Because of the high groundwater level in the Netherlands, a watertight (in longitudinal and axial direction) metallic cable sheath is recommended in UGC to prevent internal failure mechanisms during its lifetime. More than 10 years ago, the TSO started using aluminium instead of lead for the metallic sheath. Since then, around 800 km of (E)HV power cable with aluminium welded sheath have been installed in the Netherlands with good service record, i.e. no problems related to corroded metallic sheaths have been reported until today.

In this paper, the results of intensive literature, practical, modelling and laboratory studies dealing with the degradation of power cables with an aluminium welded sheath are presented. In parallel to this study, the TSO launched a program to measure on-line cable sheath and conductor currents. This method can be a way to detect any early abnormality of the jacket condition.
Degradation on the aluminium sheath has been observed in the laboratory, depending on variables such as: the tension voltage applied on the metallic sheath, the cable environment (e.g. soil composition, pH level), the system design, etc. However, both literature and experiments demonstrate that without any aging of the cable outer jacket, degradation of the aluminium sheath is negligible during the cable operational lifetime.

All the gathered results and knowledge are used to develop a risk assessment model to estimate the maximum repair time following the detection of a jacket failure during the periodic maintenance tests. As no aluminium sheath failure has been reported on the TSO grid up to now, and no aging of the aluminium sheath is expected if the outer polymer jacket is intact, it was decided to keep the interval of the periodic measurements of the cable sheath unchanged.

KEYWORDS
Aluminium Metallic Sheath - Condition Assessment - Condition-Based Maintenance - Corrosion Oversheath - On-line Monitoring - Sheath Current - Underground Cable

1. INTRODUCTION

The cross-border grid operator has about 1800 km of 110 and 150 kV cable and 80 km of 220 and 380 kV cable circuit in the on-land power grid of the Netherlands. In the coming years the cable length will continue to grow. The forecasted tracé grid expansion is about 3000 km.
Due to the high-water level in the Netherlands, it is common to apply a water barrier in the underground cable in order to prevent early aging of the polymer insulation. A radial water barrier made of metal has shown to be a good option. Besides to ensure waterproofness, the metallic sheath conducts the single-phase short circuit in case of a single phase to ground fault.
The use of lead inner sheaths is widely known, but the TSO changed over to a sheath of aluminium about 10 years ago. Compared to lead, aluminium offers the following advantages:

- Less density, which reduces the weight of the whole cable, allowing longer cable lengths and reducing the risk of cable sinking in low density soils
- High conductivity, allowing higher short circuit currents
- Much higher mechanical strength
- Lower environmental impact.

However, aluminium is more vulnerable than lead to electrochemical and electrolytic corrosive action [1]. In addition, the actual corrosion risk when used in underground power cable is internationally insufficiently known. No cases of the metallic sheath degradation have been reported up to now in the Netherlands, when using aluminium welded metallic sheath (referred to as “AluWeld”) since the introduction in 2010. Nevertheless, because of (i) the large installed assets base, (ii) the required work force to install and to maintain all the future forecasted cable projects, it is necessary to get more insight on the AluWeld actual corrosion risk and associated corrosion kinetics. These insights are also needed to define the maintenance strategy and repair actions in the future.
The aim of this study is to investigate aging mechanisms, degradation process and hence develop a set of knowledge rules to predict the maximum repair time and maintenance interval. Variables whereto the cable is exposed, and which may affect the degradation of the sheath are taken into account, such as: the soil composition, the type of outer jacket failures and the induced voltage on the sheath. Depending on the results, possible changes to the system design could be considered.

2. DESCRIPTION OF THE CABLE SYSTEM IN THE POWER GRID

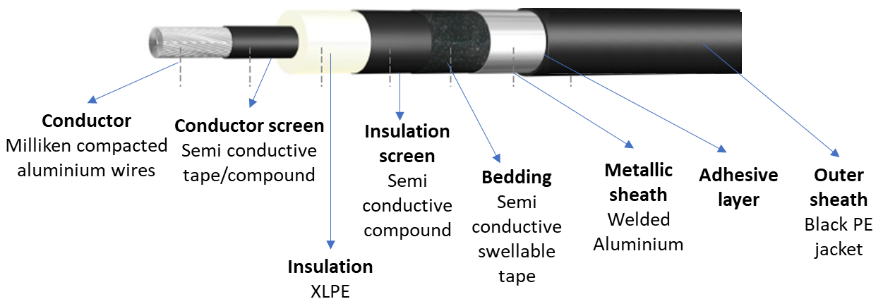


Figure 1: Design of a Alu weld HV cable “EYAKrvlwd 87/150kV” (according to NEN-HD-632)

The design of a typical “AluWeld” HV cable is presented in Figure 1. The smooth welded aluminium sheath (alloy type 1050A) consists of an aluminium sheet, longitudinally applied over the cable core, shaped around it and welded in longitudinal direction. An outer polyethylene sheath (also referred as “jacket”) is firmly bonded to the aluminium sheath resulting in a cable with a impervious water barrier and resistance to fatigue strain. The jacket provides mechanical protection to the metallic sheath as well as protection of direct contact with the metallic sheath which is important from safety point of view. In addition, the adhesive part of the waterproof layers ensures that moisture which may have penetrated the protective covering does not spread along the surface of the sheath, extending the areas of corrosion.

A cable system includes typically sheath cross-bonding to minimise the currents through the metallic sheaths (Figure 2). Therefore, the cross-bonding system consists of major section(s) that are subdivided in 3 minor section lengths, ideally of equal length an laying configuration. The cable orientation is flat or trefoil arrangement with typical minor section lengths of about 1000-1500 m (depending on the cable cross section, ranging between 2000 and 3500 mm^2). The aim is to reduce the number of joints, which argues for longer sectional lengths (obeying safety).
The cables are mostly directly buried in the ground. A backfill around the cables is applied when required for the transport capacity. Drillings are used wherein the cables are installed in ducts. If needed, the cables can be installed in pre-installed ducts in open trench.

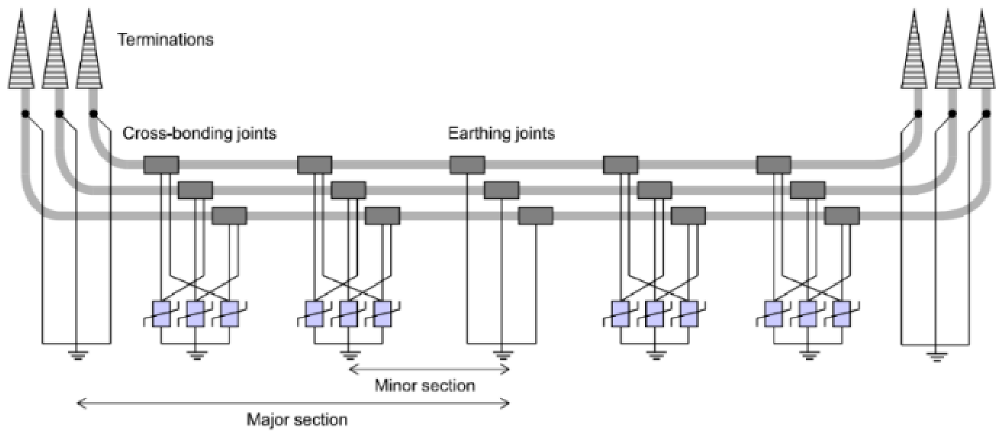


Figure 2: Cable cross-bonding system configuration [2]

3. CORROSION OF ALUMINIUM IN SOIL AND INFLUENCE OF ALTERNATIVE CURRENT

In case of damage to the outer cable jacket, the aluminium sheath may be directly exposed to soil. Possible causes of damages on the cable jacket are, among others, excavation campaigns around the power cables and aging of the plastic material, which could eventually lead to sheath cracking.
Aluminium is in general quite resistant to a large variety of chemical agents. This resistance is due to the inert and protective character of the aluminium oxide film which forms on the metal surface and reforms rapidly if damaged. Due to the progressive growth of the film oxide, the rate of corrosion of aluminium decreases rapidly with time in most environments. The aluminium oxide film is stable at neutral pH, but can dissolve spontaneously in very acid (pH<3) or strong basic (pH>9) environments. As a consequence, the aluminium should not be used in alkaline environments and many acid solutions [3]. In neutral environments, the corrosion attack is usually localised (pitting). Chlorides as well as other halides can trigger the local break down of the film oxide, leading to the formation of corrosion pustules covered with white, voluminous and gelatinous deposit of alumina. Salts of heavy metals (Cu, Au, Ag, Hg, Pb, Ni, Co) are particular aggressive towards aluminium. In aqueous solutions or in presence of humidity, those salts may lead to severe pitting corrosion [3].
The corrosion resistance is also influenced by the alloy composition. It is generally acknowledged that the commercial pure aluminium (series 1000) offers a better resistance to corrosion attack than any other alloys containing different alloys elements, as for instance copper [4]. The actual corrosion behaviour of buried aluminium (i.e. the sheath without protective covering) is very difficult to predict, because of the great diversity in the composition of soils [3], [5]. The main tendencies are depicted in Table 1. As pH in soils ranges generally between 5,5 and 8 (i.e. the stability range of the oxide film), the corrosion resistance of buried aluminium is in general acceptable, in absence of stray currents. Usually aluminium does not suffer corrosion in drained and well aerated soils, as for instance sand. Higher corrosion rates can occur in acid soils, for example in peat, or in strong alkaline soils. Moderate pitting can occur in moist and marshy soils, even with low chloride concentrations. Specific attention should be paid to industrial or contaminated soils. Severe attack of aluminium structure has been reported in cinders embankment [6].

Table 1: Main parameters affecting the corrosion of aluminium in soil

Parameter	Behaviour of Alu in soil - risk
Soil pH	pH between 5,5 and 8 in most of the soils considered = passivation zone
Soil water content	No corrosion in sandy (good aerated) and well drained (dry) soils
Chlorides concentration	Moderate pitting (moderate) in moist/marshy soils
Presence of heavy metals salts	Very aggressive corrosion in contaminated soils (ex. aluminium buried in cinder embankment)
Soil resistivity	Low resistivity promote corrosion. No corrosion expected above 10000 Ω·cm

Careful attention should be given to stray currents present in soil or current flowing from the sheath to earth, as they may have a considerable influence on the corrosion process. In fact, whenever an electric current (AC or DC) leaves an aluminium surface to enter soil, aluminium is corroded at the area of current passage. In case of DC, the material loss is proportional to the amount of current passed. At low current densities, corrosion may take the form of pitting, whereas at higher current densities considerable destruction of the metal can occur.

AC has in general a negligible influence on corrosion in most metals, as for instance carbon steel and lead. The estimated impact of AC is only 2% compared to DC. Conversely, the influence of AC on aluminium can be appreciable [4]. The expected impact of AC is about 50% of that caused by DC [7]. However, the corrosion of aluminium is not directly proportional to the AC intensity. There is a threshold current density at which corrosion is initiated (Figure 3). This threshold depends on the exposure time: it is approximately 1 to 10 A/m² for a duration of at least 100 h, and on the order of 100 A/m² for a duration of a few minutes [3].

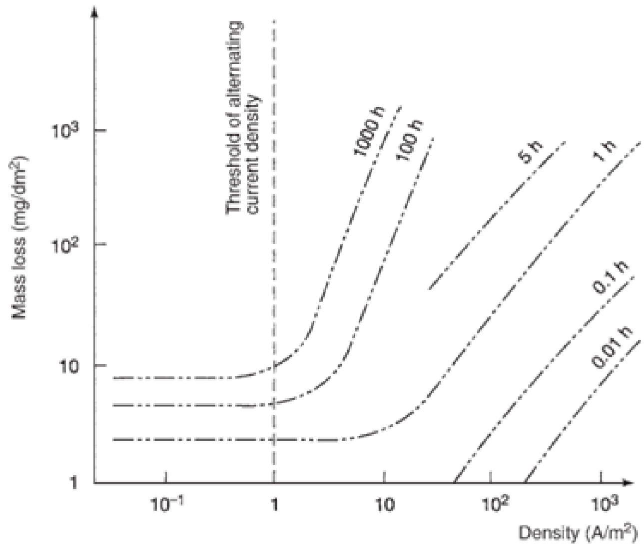


Figure 3: Influence of AC on aluminium corrosion [3]

4. SIMULATIONS EARTH LEAKAGE CURRENTS IN CASE OF DIRECT EXPOSURE ALUMINIUM SHEATH TO SOIL

To quantify the earth leakage currents, firstly the voltage on the aluminium sheath of a major section of an existing cable link was calculated by means of a FEM software. The cable model in FEM was validated by comparing induced voltages/currents values in some typical cases calculated with a software based on standards. For the considered cable section, the maximum voltage on the aluminium sheath is about 150 V (Figure 4).

This value is applied on the sheath for the current calculation. Without any damage on the outer jacket, the current flowing through the soil is negligible.

A simplified model in 3D was built to calculate the current flowing through the sheath fault. The influence of some parameters as the surface of the exposed aluminum sheath and the electrical resistivity of the soil were studied. This simplified model shows clearly the obvious linear relation between the electrical conductivity and the earth leakage currents (Figure 5). Conversely, the area of the fault has a minor impact on the current density through the damage (Figure 6), meaning that the expected corrosion rate will not be influence by the size of the damage.

It should be noted that any contact resistance due to aluminum oxidation or to an imperfect surface contact between soil and the aluminum sheath is included in the model. The actual values are therefore expected to be lower and the present results should be considered as a worst case.

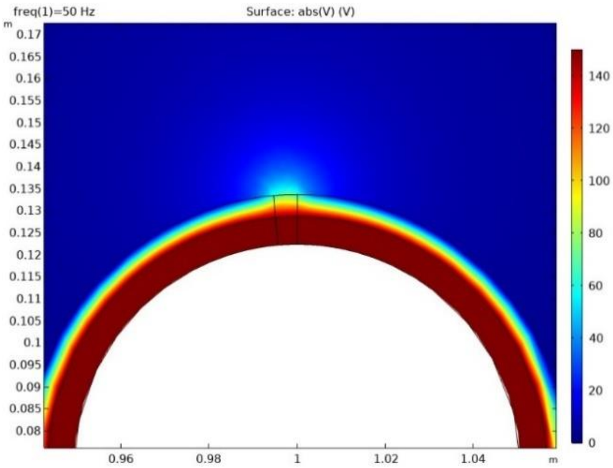


Figure 4: 3D simulation of induced voltage on the aluminium sheath, with a fault on the outer jacket

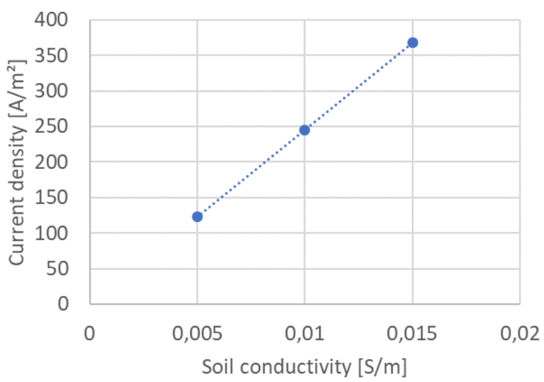


Figure 5: Influence of the soil conductivity on the earth leakage currents (150 V)

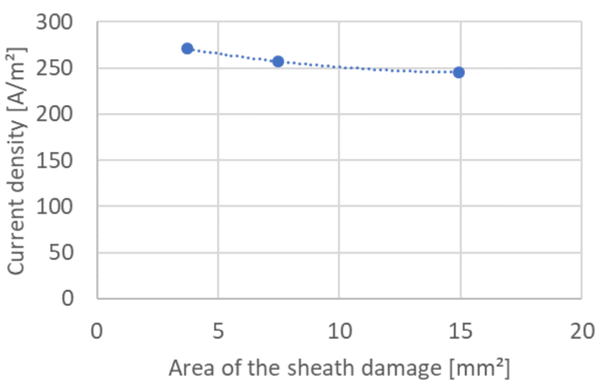


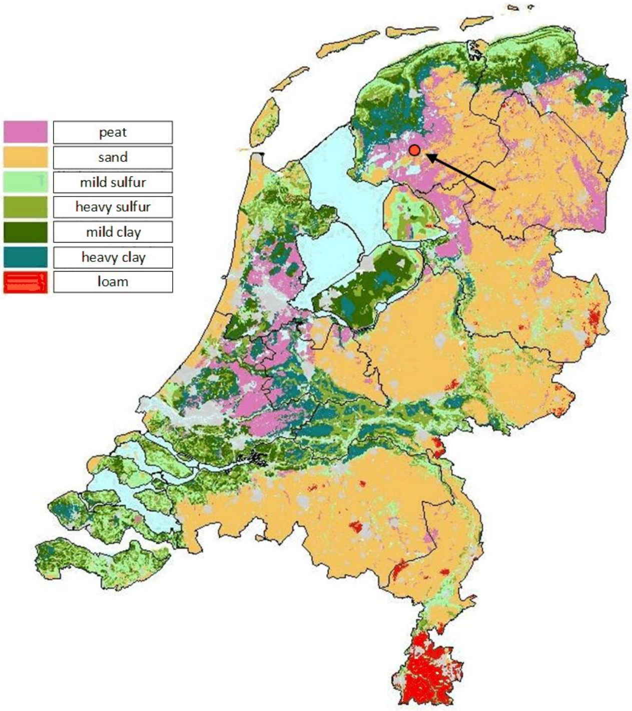
Figure 6: Influence of the area on the current density through the damage (150 V, ρ= 10000 Ω · cm)

5. EXPERIMENTAL ASSESSMENT OF ALUMINIUM SHEATH CORROSION

5.1 Methodology

To investigate the actual effect of soil composition and induced voltage on the aluminium sheath degradation, an experimental campaign was started. A location in the north of Netherlands, where the soil consists mainly of peat, was selected for the field tests (Figure 7a and 7b). Among all the soil types present in the Netherlands, peat is considered as a harmful condition due to its low pH and high moisture content. Cable samples and aluminium reference plates were directly buried, but for practical reason no tension could be applied on the aluminium sheath. The effect of induced voltage on corrosion was therefore studied on a separate experimental set-up (refer to the next section), using samples of soil extracted on field.

a)



b)

Figure 7: Soil maps of the Netherlands (a) and location of the test field, field location at the red dot (b)

5.2 Samples preparation

The samples of about 100 cm long were cut from cables (EYAKrvlwd 64/110kV 1x2500mm2 AlMil) used in an ongoing TSO's project. This means that the manufactured cable samples were conforming the cable specification. In order to assess the AluWeld degradation when directly exposed to soil, as for instance after excavation damages, the following artificial defects were machined on the PE outer sheath (Figure 8):

- a longitudinal defect 10 cm long and 0,1 cm wide
- a radial defect 10 cm long and 0,1 cm wide
- 3 holes with diameter 10 mm, machined at 12h, 3h and 6h positions, respectively
- 3 holes with diameter 4 mm, machined at 12h, 3h and 6h positions, respectively
- 3 holes with diameter 1 mm, machined at 12h, 3h and 6h positions, respectively

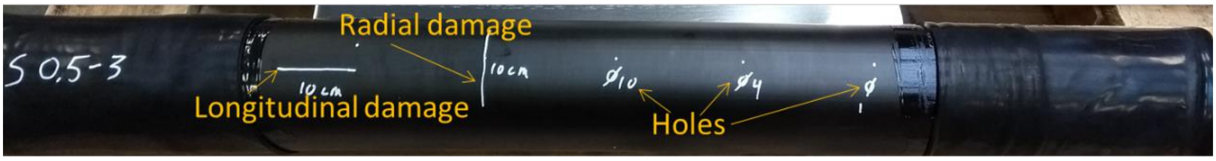


Figure 8: Cable sample with artificial defects machined on the outer PE jacket

In addition, plates with dimension 35 cm * 18 cm were cut from the same 1 mm-thick aluminium sheet (grade 1050A) used to manufacture the cable and buried as reference samples. Both surfaces, which have a conventional cold rolled finishing, were exposed to soil.

5.3 Field tests

A set consisting of 5 cable samples and 5 aluminium plates samples were buried directly in peat (without backfill) on the field location. A second set of samples were buried surrounded in backfill sand. The laying arrangement of the samples buried in backfill is illustrated in Figure 9. The two different sets of samples are being dug up after 6 month and in year 1, 2, 3 and 5. This sequence reflects to the maintenance sheath measurement interval (3 years, or even longer due to grid unavailability). The tests are ongoing, and the results of the 0,5- and 1-year sample analyses are available.

Figure 9: Arrangement of the samples in backfill, before covering and compaction

5.4 Soil properties

The pH and the electrical resistivity of the natural surrounding soil (peat) and the used backfill on the field test location were measured. The results are shown in Table 2. Peat is found to be slightly acid (pH between 5 and 6) because of its organic content while the backfill sand has a near neutral pH and higher electrical resistivity. Soil samples taken from the field location were as well used in the lab set-up for the trials under tension, after a dilution 1:5 with water (to facilitate filling up). The corresponding pH and resistivity values are given in Table 2.

Table 2: Soil properties of peat and backfill sand

Soil		**pH**	**Resistivity (ohm * cm)**	**Conductivity (S/m)**
Peat	On field	5,1 – 6	3450 - 5000	0,03 - 0,02
	Diluted 1:5	4,2	780	0,128
Backfill sand	On field	6,0	15670	0,0064
	Diluted 1:5	7,3	8130	0,012

5.5 Results after 6 months and 1-year exposure (field tests)

The samples were extracted after 6 months and 1 year from the test field, cleaned with cold water, weighted and analysed by microscope. An overview is shown in Figure 10. No evidences of corrosion were found on both the cable samples and the reference samples buried in peat. The aluminium surfaces

in contact with soil is unaltered. Only some coloration of the reference plates is observed after 1 year. The weight loss is also negligible (Figure 11).
Similar observations were made on the samples buried in backfill sand. The cable samples are completely not affected by corrosion. However, some pitting was observed on the reference samples. Most likely it is caused by unintentional contact of the plates with peat and sand simultaneously, resulting in corrosion by differential aeration. This explains the little weight loss (0,4%) observed on those samples (Figure 11).
On the samples that were placed in backfill, some pitting was observed on the reference samples. The pitting was localised. Most likely it is caused by unintentional contact of the aluminium sample plates with both with a mixture of peat and sand. This enhances the corrosion rate in respect exposure to the plate with only sand or peat due to the differential aeration effect. The sand enables oxygen in combination with the more acidic peat to the sample, initiating the degradation process. The weight loss after 6 months and one year is negligible, within the experimental error (Figure 11).

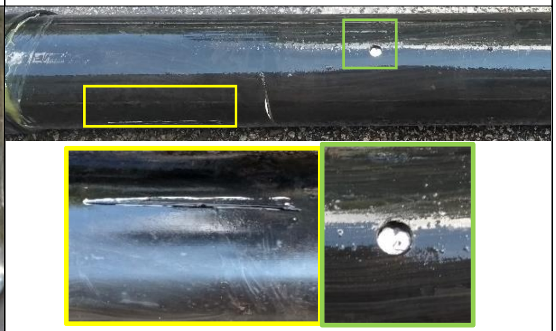
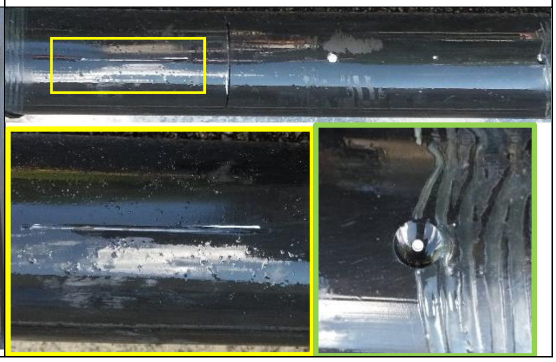
Soil	**Before**	**6 months exposure**	**1-year exposure**	**Cable samples after 1-year exposure**
Peat				
Back-fill sand				

Figure 10: Evolution of cables samples and reference plates buried in peat and backfill sand

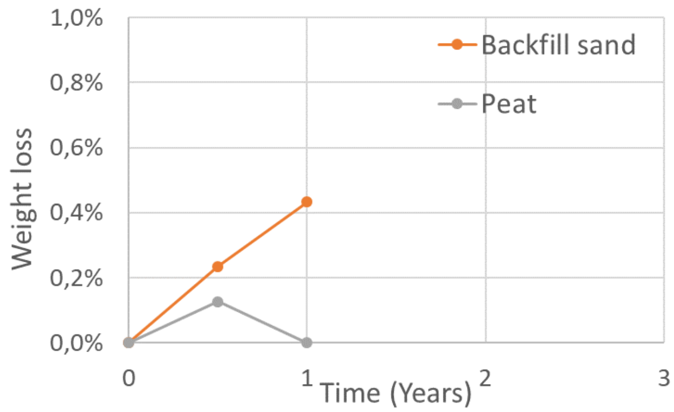


Figure 11: Weight loss of the reference plates buried in peat and backfill sand for different times

5.6 Influence of earth leakage current (AC)

As the influence of AC on the kinetics aluminium can be appreciable, a laboratory set-up was developed in order to assess the impact of AC on degradation of the sheath AluWeld. The experimental set-up provides thus insight on the degradation mechanism, its kinetics and the threshold current value to initiate corrosion.

The set-up consists of a PVC casing wherein the same cable samples (with artificial defects machined on the outer jacket) used in the field trials were installed (Figure 12b). The ends of casing were closed and completely filled with peat and sand diluted in water. A voltage tension was applied between the aluminium sheath and a cylindrical stainless counter electrode, placed at about 35 mm distance from the cable surface. In practice, a current circulates between the defects on the outer jacket and the counter electrode, simulating the earth leakage current. Three tension levels where investigated: 10 V, 40 V and 80 V. Although these values are lower than the highest induced voltage expected on the sheath, they result in comparable leakage currents.

Since the samples could not be visually checked during the campaign, to follow the evolution of aluminium in presence of AC, reference samples (thickness 1 mm, dimensions 3 cm * 4 cm) were immerged in glass beakers containing the same soil (Figure 12a). The moisture content was carefully monitored and adjusted when needed. The same voltage levels were applied between the samples and a stainless steel counter electrode. In accordance with the objective (minimum time between detecting a failure and repair) the tests (peat and sand) were carried out for 3 months. During the campaign the voltage was kept constant and the current and temperature were monitored. After the 3-month test period was stopped, the samples were carefully removed from the PVC casing and analysed.

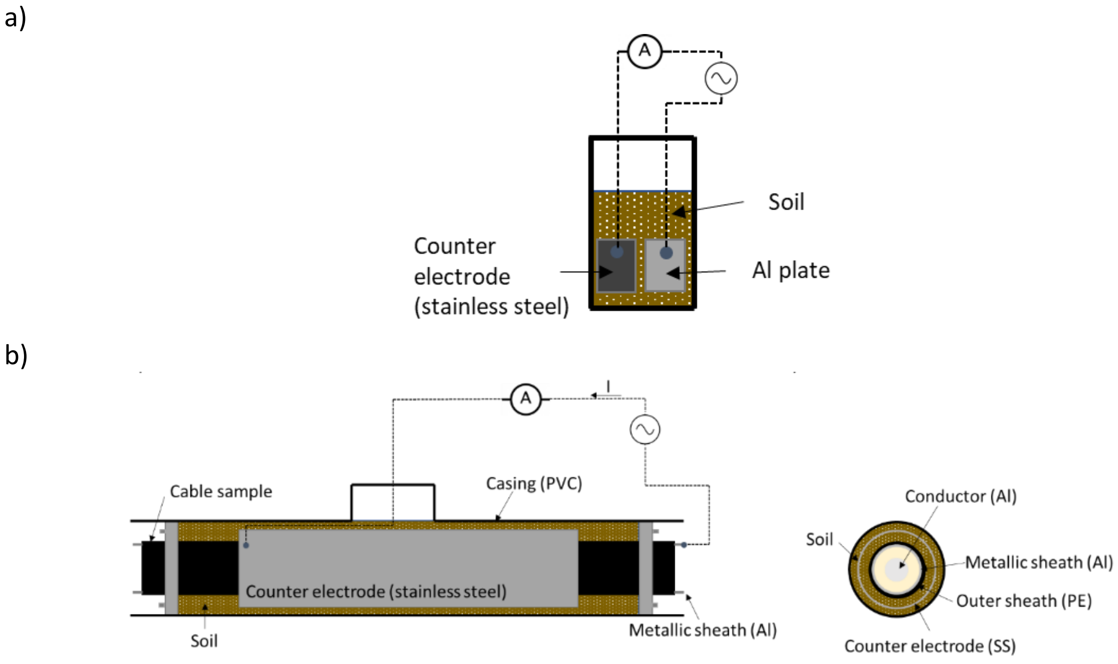


Figure 12: Illustration of the experimental set-up used to a) assess the influence of AC on reference plates b) the influence of AC on cable degradation

5.7 Effect of AC on reference plates

The reference samples show a similar corrosion behaviour in sand and in peat. An example of the evolution is given in Figure 13 for sand. This means that the corrosion degradation is mainly dependent on the current density, rather than the chemical composition of the soil. A current density of about 70 A/m^2 was measured at 10 V in sand (Figure 13). For voltage levels above 40 V, leading to a current density of ~200 A/m^2, the corrosion rate was excessive, within one week the sample has failed. Extrapolating this to 1-3 months, it means that a maximum current density of 30-60 A/m^2 could be admissible.

Applied voltage	before	3 h	2 days	7 days	14 days	21 days	42 days	Time to failure	Current density (A/m²)
10 V								42 days	70
40 V					X	X	X	7 days	200
80 V					X	X	X	7 days	>2000

Figure 13: Evolution of the reference plates under different applied voltages in sand

5.8 Influence of AC on degradation of AluWelds cable samples with damages on the outer PE jacket

The impact of corrosion shown for the cable samples subjected to a voltage tension is consistent with the observations made on the reference plates. In Figure 14, the degradation at the level of the longitudinal and radial defect are presented. The longitudinal defect was observed to be the most critical one, compared to the hole defects. The following observations were done on the cable samples in peat and sand:

- At 10 V, only a very slight swelling of the cable was noted in peat. The gap is filled with a white, non-adherent, corrosion product (most likely aluminium oxide). Almost no degradation is observed in sand.
- At 40 V, in peat the corrosion of the sheath leads to significant swelling close to the defect. The fissure widened and the aluminium sheath is no longer visible at the bottom of the defect. Only little degradation is observed in sand.
- At 80 V, in peat the swelling of the cable is even larger, the gap of the gap even wider and filled with corrosion products. The aluminium jacket is completely consumed. Significant degradation is observed also in sand.

Voltage	Peat	Sand
10 V	 30 A/m²	 50 A/m²

40 V	 340 A/m²	 30 A/m²
80 V	 >750 A/m²	 200 A/m²

Figure 14: Degradation on the longitudinal defects after 3 months days, in function of the voltage applied on the aluminium sheath

Some cross sections were cut at the level of the longitudinal defect to get more insight on the mechanism of cable degradation. In Figure 15 two examples are provided for the samples at 40 V in sand and in peat, respectively. In sand, where the leakage current was 30 A/m², a decrease in thickness is observed but the aluminium sheath kept its integrity. More exacerbate is the degradation observed in peat, due to the much higher current flowing through the defects (340 A/m²). Corrosion started on the bare surface of aluminium and leads quickly to perforation. Then, corrosion propagates under the PE outer sheath. Under the pressure of the corrosion products, the aluminium sheath is pushed up and the gap widened further. The Al sheath is finally completely detached from the insulator (delamination) and water can penetrate into the cable. Cross sections cut at the height of the hole defects, reveal significant degradation in the sample exposed to peat: the aluminium sheath is almost completely consumed, and the holes are entirely filled by corrosion products, leading to a pronounced bulging of the outer sheath.

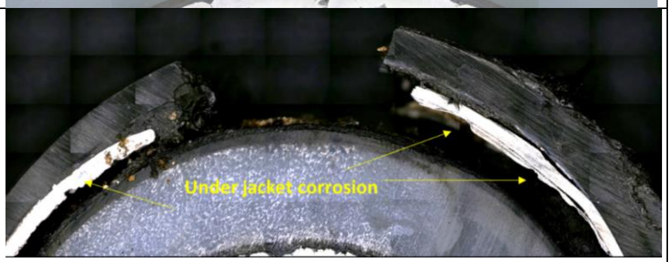
Sand (30 A/m²)	
Peat (340 A/m²)	

Figure 15: Cross sections of the cable cut through the longitudinal defect

5.9 Maintenance and repair

For the moment it is unlikely that the cable aluminium sheath is directly exposed to soil. Hence it is not expected that severe corrosion takes place. However, if such an event should occur, the cable fault could be detected by a sheath current measurement. Sheath current testing should be selective enough to detect it, as corrosion of the aluminium is anticipated by damage of the outer sheath and the adhesive layer. In this case the outer sheath and the metallic sheath can be repaired.

At the same time, sheath current measurement experiments are running to verify if any abnormalities in the cable protection layers can be identified. A first practical pilot experiment was performed [8]. Sheath current measurements are expected to be a reliable indicator of damage to the cable's outer sheath, as faults on the outer sheath will cause an imbalance in the cable system, altering the flow of the sheet currents. Using this hypothesis, continuous sheath current measurements are under investigation in order to determine the feasibility of implementing algorithms to predict failures in the early stages and to monitor the cable in the event of third-party damage.
Measurement sensors (Rogowski coils) are installed at the start and end of each major section, and the main cable currents are monitored as well. This allows synchronized measurement capabilities for data processing. The lifetime of the system is 3 to 5 years limited by the battery lifetime. The intent is to collect sheath current data over time in order to correlate it and pinpoint existing faults in the system, as well as to have monitoring capabilities for faults caused by third parties.

In case of future sheath failures identified, repair methods for the sheath are available without the necessity of usage of a joint. Firstly, the cable core is exposed by cutting out the affected sheath (both metallic and polymeric) and removing any swollen water blocking tapes. The core is then protected by conductive tapes. A copper gauze tape is applied on top of it and is connected to both sides of the open metallic sheath. Copper braids of suitable cross-sections are then connected, to restore the electrical continuity of the metallic sheath. Radial watertightness is achieved by applying an aluminium tube foil on the copper braids with water blocking tapes in-between. Finally, the outer water barrier is made by polymeric tapes and ultimately heath shrinkable tubes. This outermost polymeric barrier acts also as electrical insulation between screen and ground. In order to qualify the repair a sheath test shall be performed.

6. DISCUSSION

About a decade ago the TSO changed towards an aluminium metallic sheath, due to amongst others, the environmental aspect, weight and quality perspective. Since then, there is a continuous growth of new cable systems in the TSO's power network in the Netherlands. The soil composition is diverse, and most areas have high water tables. In order to act in time and to enhance comfort in operation, the corrosive behaviour of the AluWeld was investigated. The main question for the TSO was, "is the frequency of the sheath integrity tests according to the existing maintenance program sufficient?".

Experiences around the world show the risk of corrosion degradation in AC power cables but its extent depends on a multitude of parameters. All the experiments performed in the present work confirmed that aluminium sheath degradation does not occur when the integrity of the outer jacket is not compromised. It can be stated that the protection coverings are key to protect aluminium against corrosion. If the outer jacket is partially damaged, the adhesive layer with the remaining outer jacket still guarantees considerable protection.
Degradation of the AluWeld sheath was observed only after removal of the outer jacket. Comparison of both tests carried out with and without an applied voltage shows that the aluminium corrosion is mostly driven by AC leaking current rather than soil composition. Even in slightly acid peat, which was selected as a worst-case starting point for the studies, the first field test results show no or very mild corrosion. As the study will continue for several years (corresponding to the maintenance interval, namely 3 years), more insight of the evolution of corrosion will be gathered. In other potentially dangerous soils, such as clay (with gypsum), cinder embankment and polluted soils containing heavy metals, the use of backfill sand in the cable trench is recommended to avoid the contact of acid compounds or heavy salt metals with the cables.

Leakage current is shown to act as the main driver for the degradation. Its actual intensity depends on many factors, which are difficult to reproduce on a lab set-up. The current measured should be considered as an indication and not as absolute values.
Results show that for a leakage current of 40-60A/m^2, cable failure occurs within 1-3 months. This is consistent with results presented in literature. Lower leakage currents are below the threshold for initiation of corrosion (<10 A/m^2), which was traceable in the experiments. To avoid too excessive earth

leakage currents, it is of importance to ensure the integrity of the outer jacket. The sensitivity analyses for the leakage current enables the classification of the severity and thus risk for the degradation. Besides that, it shows the evolution of the degradation, whereon preventive or repair actions should be undertaken. For instance, earth leakage currents below ~<40A/m^2 are not likely to affect the sheath properties, whereas leakage currents above >100A/m^2 to a detached sheath and does require an immediate maintenance action.
It should be noted that both FEM simulations and the laboratory experiment are worst-case scenarios. In the practical situation in case of a rupture in the outer jacket, a larger contact resistance at the cable-soil interface is expected, which will reduce earth leakage currents. Moreover, the actual induced voltages depend on loading profiles (not always full capacity), which reduces in turn the rate of the degradation.
To define clear rules for maintenance, it is proposed to investigate further how outer jacked failures can occur in the field and verify its impact on the sheath integrity practical cases by simulations. Next to that, current densities should be also verified in the field, as it is the main driver for degradation. Sheath current monitoring is a promising method to identify early sheath faults. All these data will allow to establish maintenance guidelines, which take all input parameters into account to determine the degradation risk. Building up a data base with reported sheath faults will help to make the maintenance guidance more accurate.

7. CONCLUSIONS

Although there is a good understanding about aluminium corrosion worldwide, understanding of the actual corrosion behaviour on a HVAC power cables AluWeld sheath is missing. In this paper the corrosion kinetics are visualised, supported by available experience throughout the world and with the support of results obtained from practical experiments (using samples with artificial machined defects). The risk on degradation of the AluWeld sheath of an AC power cable is very unlikely when the coverings are not compromised and with a good inert aluminium property.
Experimental results show that metal sheath degradation in case of outer jacket rupture is strongly dependent on the leakage current. Practical cases are yet missing to verify the realistic leakage currents obtained, which argues for keeping the current maintenance interval for now. To gain practical experience, it is advised is to directly plan a repair when a sheath fault is detected.

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