

CORROSION BEHAVIOUR OF SUBMARINE POWER CABLES IN SEAWATER ENVIRONMENT

Daniel ISUS, Juan D. MARTÍNEZ, General Cable, Manlleu, Barcelona (Spain), disus@generalcable.es, jdmartinez@generalcable.es

Virginia MADINA, Patricia SANTA COLOMA, Tecnalía, San Sebastián (Spain), virginia.madina@tecnalia.com, patricia.santacoloma@tecnalia.com

ABSTRACT

Submarine cables placed on the seabed are susceptible of suffering corrosion processes. Damages to the different parts of the cable might happen and corrosion could be a life-limiting factor. Accelerated laboratory tests have been carried out on two single cable core designs with different metallic screens: one comprised of aluminum sheet and copper wires, and the other comprised of helicoidal copper tape. The external jacket has been intentionally damaged thus exposing the metallic screen to a synthetic seawater media. Obtained results indicate that the corrosion rate of copper in seawater decreases when coupled with aluminum due to a galvanic effect.

KEYWORDS

Submarine cable, corrosion, metallic screen, accelerated tests

INTRODUCTION

The seabed is an aggressive environment where corrosion mechanisms can take place. Submarine cables are susceptible to these processes if the external jacket is damaged during installation or service life.

This work describes the accelerated corrosion tests carried out on single core cables in order to assess the significance of certain changes in the design of the corrosion behaviour. For these tests the external high density poly-ethylene (HDPE) jacket of the cables has been intentionally damaged, thus exposing the metallic screen to a synthetic seawater media.

Impressed anodic current tests have been conducted aimed at evaluating the corrosion resistance of the metal screen. In real service conditions there is a small current passing through the metallic screens of submarine cables as a consequence of the magnetic field associated to the electrical current through the conductor. If there is an external damage in the electrical cable, a corrosion phenomenon in the exposed metallic screen is not discarded if the current leaves this area.

Corrosion degradation could also increase the electrical resistance of the metallic screen materials. One of the purposes of this screen is to provide a path for the flow of fault current. Thus measurements of the electrical resistance have been conducted on damaged samples exposed to the synthetic seawater.

Finally, leaching tests have been carried out in order to evaluate the amount of copper and aluminum that can migrate from the cable, due to the corrosion of the metal screen in contact with seawater.

EXPERIMENTAL PROCEDURE: MATERIALS AND METHODS

Cable designs

Two single core cables with different metallic screens have been studied. One cable comprised of aluminum sheet and copper wires, and the other comprised of helicoidal copper tape. In the first cable design, the cross linked polyethylene (XLPE) layer between the copper wires and the aluminum tape, is not continuous, with some areas of the aluminum and copper wires in physical contact. Therefore, a risk of galvanic corrosion is not discarded if the aluminum tape (anodic or more electronegative) is shorted to the copper wires (cathodic or more electropositive).

The two cable designs are shown in Fig. 1.

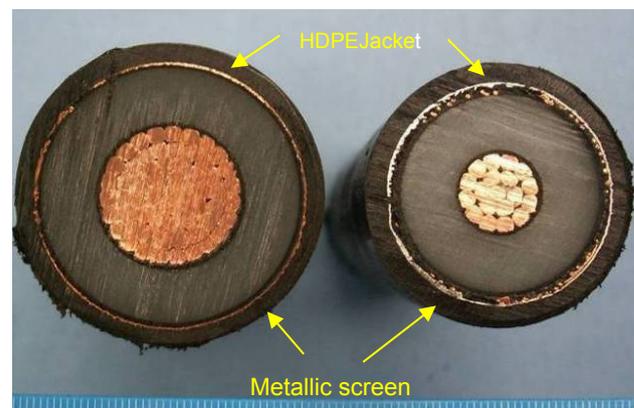


Fig. 1: Cross section of the two single-core cables with aluminum sheet and copper wires (right) and with helicoidal copper tape (left)

Corrosion evaluation under impressed anodic current

Tests under small impressed anodic current have been carried out in damaged jacket samples. The HDPE external layer was punctured in four places leaving the copper helicoidal tape or the copper wires for the aluminum + copper design uncovered. The 4 holes, each with a diameter of 10 mm, were arranged spirally at longitudinal intervals of about 50 mm and circumferential spacing of 90°. This way of producing local damage was similar to that exposed in references [1, 2].

Each cable sample was introduced in a plastic container filled with synthetic marine water Type 1, according to the ASTM D 1141 standard [3]. A small anodic current of 10mA was applied, by means of a potentiostat, between the metallic screen and a graphite counter.

The exposed copper was the anode; this is, the location where the current leaves, or what is the same, the zone that corrodes. The graphite electrode was the cathode, the place towards the electrons go. The impressed current was maintained till the exposed section of the damaged cable was totally corroded (or dissolved). Potential measurements were carried out during the test. Tests were conducted at 60°C and at atmospheric pressure.

A design of the experimental set-up is given in Fig. 2.

At the conclusion of the tests the cable samples were examined in order to evaluate corrosion progression. The chemical nature of the corrosion products generated during the tests was also determined.

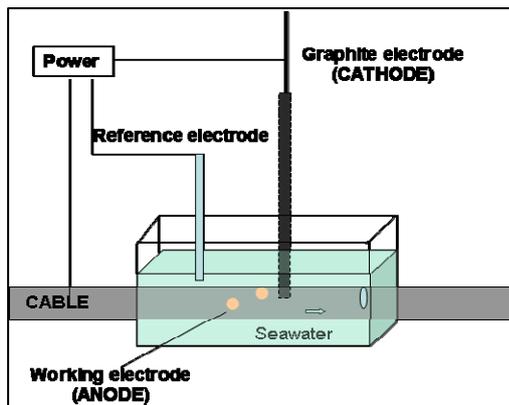


Fig. 2: Experimental setup design for impressed anodic current tests of screen material with damaged outer jacket

Measurement of the electrical resistance

Measurements of the electrical resistance have been performed on samples from the two cable designs. In these samples the HDPE external layer was punctured as described previously.

Cables were introduced in a plastic container filled with synthetic marine water. An electrochemical interface (Solartron 1287) was used to provide accurate controlled voltage or current. Connections were made to the copper screen at the wire or copper tape ends. The Solartron device applies an intensity of 2 amps for 20 seconds and measures the potential difference between the two extremes. Electrical resistance was estimated by Ohm's law. Tests were carried out at 60°C and at atmospheric pressure. At the conclusion of the tests the cable samples were examined for signs of corrosion progression.

Leaching tests

The leaching tests were carried out based on NEN 7375:2004 standard [4] for monolithic materials (test tank), replacing the leaching liquid (demineralised water in the standard) by synthetic seawater.

For both cable designs the exposed metal screen area was approximately 20 cm². Each cable sample was placed in a plastic container filled with seawater. After an initial period of time, all the eluate volume was collected and replaced with the same volume of fresh leaching fluid (seawater). The process was repeated several times. Values of copper and aluminum were measured according to standardized methods of analysis.

RESULTS

Anodic current tests

Aluminum + copper wire screen cable

White voluminous corrosion products from the aluminum tape were observed right from the beginning of the test. However, greenish corrosion products due to copper corrosion were only detected after approximately 750 hours testing. After 1200 hours almost all of the exposed copper was dissolved (Fig. 3).

At the end of the test, the cable sample was examined for corrosion progression under the HDPE jacket (Fig. 4). No swelling was observed on the tested cable. The examination of the tested cable indicated a total dissolution of the copper wires in the area exposed to seawater, this corrosion being mainly circumscribed to this punctured area. For the aluminum tape, significant corrosion damage was observed even under the HDPE jacket.

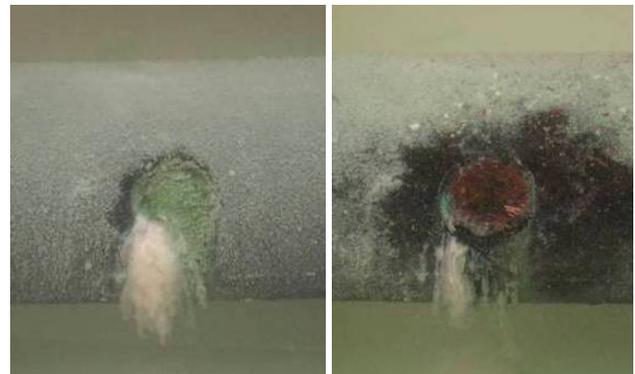


Fig. 3: Corrosion products on damaged jacket after 1128 hours of impressed anodic current test (left); same area after removal of corrosion products (right)



Fig. 4: Dissection of aluminum + copper wire screen cable after impressed anodic current test

The galvanic couple potential or mixed potential of copper wires coupled with the aluminum tape is given in Table 1. This potential shows a certain shift in the noble direction while increasing the duration of the test. This is mainly attributed to the aluminum dissolution.

The corrosion potential of the copper wire and aluminum in seawater at 60°C is also given in Table 1. Aluminum has a more significant electronegative potential than copper (more noble). Thus copper will be galvanically protected (cathodic), and aluminum (anodic) will have a

tendency to suffer accelerated corrosion when electrically connected. The bigger the difference in corrosion potentials, the larger the corrosion current will be.

Test duration (hours)	Mixed corrosion potential (mV) (Seawater, T=60°C)	Uncoupled corrosion potential (mV) (Seawater, T=60°C)
0	-725	-226 Cu wire -935 Al tape
168	-684	
336	-645	
456	-618	
888	-512	
1296	-497	

Table 1: Coupled and uncoupled corrosion potentials of the aluminium + copper wire screen cable in seawater at 60°C.

Finally, the chemical and stoichiometric nature of the corrosion products generated during the tests was determined by energy dispersive spectroscopy (EDS) and micro-RAMAN spectroscopy analysis. Raman analyses identified copper corrosion products as CuCl_2 whereas aluminum corrosion products were mainly constituted of Al_2O_3 .

Helicoidal copper screen cable

Greenish copper corrosion products were detected just after 30 hours testing. After testing during 336 hours a significant corrosion of the copper tape was observed in the area exposed to the seawater (Fig. 5).

At the conclusion of the test, the cable sample was examined for corrosion progression under the HDPE jacket (Fig. 6). Although a total dissolution of the copper tape was observed in the area exposed to seawater, the corrosion progression under the HDPE jacket was not detected. No swelling was observed on the outer HDPE jacket of the damaged cable.

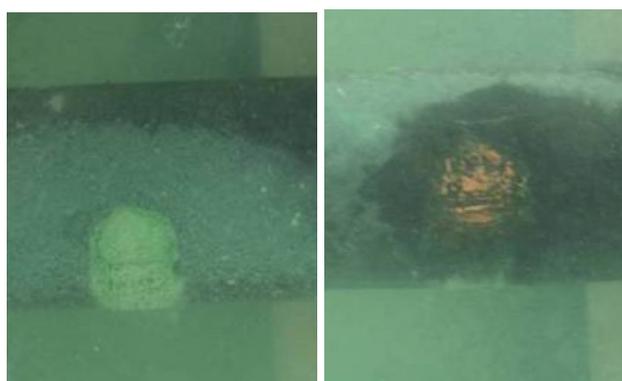


Fig. 5: Corrosion products on damaged jacket after 336 hours of impressed anodic current test (left); same area after removal of corrosion products (right)



Fig. 6: Dissection of helicoidal copper screen cable after impressed anodic current test

Electrical resistance measurements

Aluminum + copper wire screen cable

No significant differences were observed in the electrical resistance values during the test development with values comprised between 6 and 7×10^{-4} ($\text{m}\Omega$). These small differences are mainly due to the variability of the test method.

Voluminous white corrosion products from aluminum were observed just 20 hours after test initiation, whereas copper wires remained practically uncorroded, even after 2200 hours of testing. The absence of corrosion in the exposed copper wires could explain the almost invariable values for the electrical resistance of the copper screen.

At the end of the test the cable was cut up for corrosion evaluation (Fig. 7). No swelling of the outer HDPE jacket was observed.



Fig. 7: Dissection of damaged jacket after impressed anodic current test

Helicoidal copper screen cable

Potential measurements and electrical resistance values are given in Table 2. An increase in the electrical resistance values was observed when increasing the duration of the test. This was mainly attributed to copper corrosion.

Test duration (hours)	Resistance (mΩ) (Seawater, T=60°C)
0	3.7×10^{-3}
336	4.2×10^{-3}
1128	4.6×10^{-3}
1584	5.0×10^{-3}
1968	5.6×10^{-3}

Table 2: Potential difference and electrical resistance values for helicoidal copper during the test

First signs of greenish copper corrosion products were detected after approximately 300 hours of seawater exposure. At the conclusion of the test, non corroded copper fragments were observed in the punctured holes (Fig. 8).



Fig. 8: Helicoidal copper screen cable after 1968 hours of immersion in synthetic seawater. Corrosion products have been partially removed

Leaching tests

The changes in the concentration of copper and aluminum in the two eluates are given in Figs. 9-10.

Whereas the cable with the copper tape had an increasing trend in copper concentration, the cable with aluminum foil + copper wires gave significant quantities of aluminum but no sign of copper. Again, this behaviour is attributed to a galvanic effect.

In both cases, the migration rate was significantly fast. The aluminum concentration was stabilized around 719 mg/m². On the other hand, the copper concentration in the case of single-core cable with copper tape showed a rapid increase without stabilization, and a continuous migration of copper to the seawater could be expected.

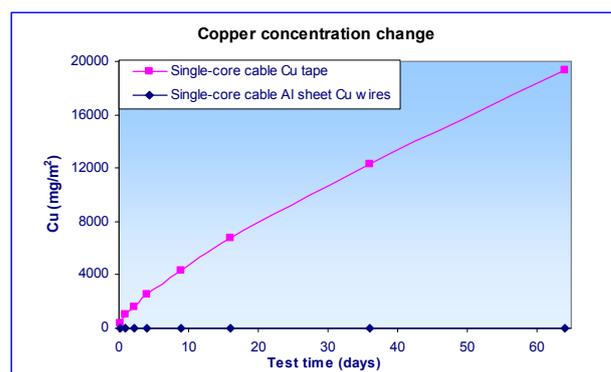


Fig. 9: Copper concentration changes

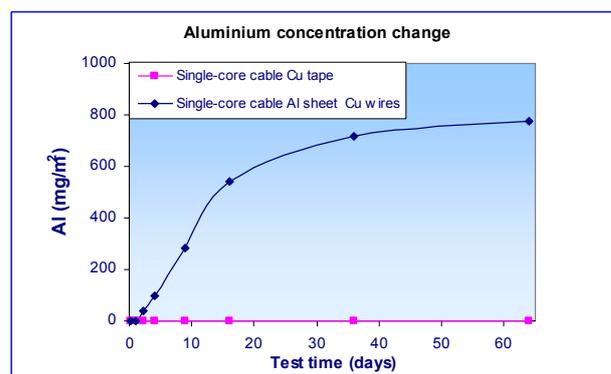


Fig. 10: Aluminum concentration changes

CONCLUSIONS

The significant differences in the corrosion behaviour observed in the two single core cables are mainly attributed to a galvanic effect. Aluminum is more electronegative, thus, it is the anode when coupled with copper. Therefore, copper is protected, whereas the corrosion rate of aluminum is promoted.

Acknowledgments

Authors acknowledge the Spanish Centre for the Development of Industrial Technologies (CDTI) for the financial support to carry out this work under the CENIT Project "EOLIA".

REFERENCES

- [1] CEI 229 (DRAFT), 2006, "Tests on cable oversheaths which have a special protective function and are applied by extrusion".
- [2] EN 10288, 2002, "Steel tubes and fittings for onshore and offshore pipelines. External two layer extruded polyethylene based coatings".
- [3] ASTM D 1141, "Standard practice for the preparation of substitute ocean water".
- [4] The tank test, NEN 7375:2004 "Leaching Characteristics of Moulded or Monolithic building and Waste materials. Determination of leaching of inorganic components with the diffusion test".