CONDUCTIVITY AND QUALITY OF SEMI-CONDUCTIVE MATERIALS IN MV CABLE ACCESSORIES

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ABSTRACT

The quality of the external semi-conductive (SC) layer of separable deadbreak connectors designed for MV was assessed with a view to use them in outdoor applications. EPDM and SIR based connectors were exposed during 1000 hours to an artificial accelerated weathering. The external SC layers were characterized and evaluated by means of chemical, material, mechanical and electrical analyses before and after weathering. There is no clear advantage of using SIR rather than EPDM as matrix. However, according to this study, connector 2 (EPDM) showed the best behavior, followed by connector 5 (SIR) and connector 1 (EPDM). Connector 3 (SIR) and 4 (EPDM) are not advised for outdoor application.

INTRODUCTION

The quality of the external semi-conductive (SC) layer of separable deadbreak connectors designed for medium voltage (MV) applications was assessed before and after artificial accelerated weathering with a view to use these accessories in outdoor applications.

The materials and dimensions used in the design of the connectors vary from one manufacturer to another. Therefore a project was launched with the Belgian distribution network operators (DNO's) in the beginning of 2012. The objective was to assess the resistance of the external semi-conductive (SC) layer to weathering (UV light and rain).

Five connectors from several manufacturers were selected as shown in Figure 1 with the corresponding SC layer thicknesses. The polymeric materials composing these accessories are ethylene propylene diene monomer (EPDM), silicone rubber (SIR). The external SC layers were characterized by means of chemical, material, mechanical and electrical analyses.

CHEMICAL AND MATERIAL PROPERTIES OF THE SEMI-CONDUCTIVE LAYERS

All the external SC layers were characterized before

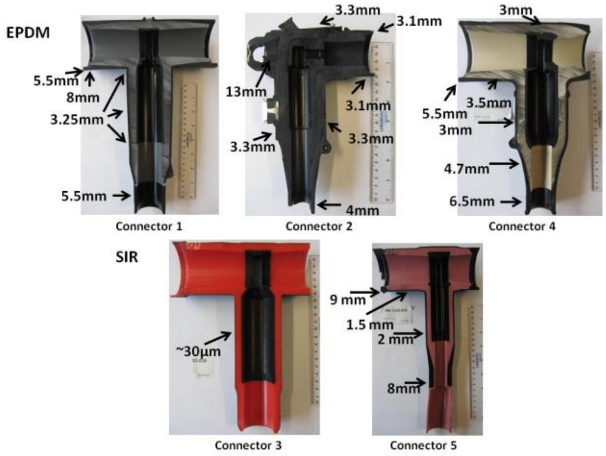

Figure 1: Section of the connectors illustrating their design.

performing the ageing program. The chemical composition was checked using Fourier Transform Infra Red (FTIR) spectroscopy. The carbon black content of the SC layer was determined by thermogravimetric analysis (TGA). Thermal stability was also evaluated using TGA and differential scanning calorimetry (DSC). Additives were detected using X-Ray fluorescence (XRF) and gas chromatography coupled mass spectrometry (GC-MS). The results of these analyses are summarized in Table 1.

Table 1: Characterization of the external SC layers before weathering.

Connector		1	2	3	4	5
SC		EPDM	EPDM	SIR	EPDM*	SIR
ADDITIVES	Vulcanisation materials	S/ZnO	S/ZnO		S/ZnO	
	Processing aid	Stearates, silicone oil	Stearates, silicone oil		Stearates, silicone oil	
	Flame retardant		ATH		ATH + Mg(OH)	
	Reinforcing material					Silicate
CB (wt.%)		30	37	23	11	9
Oxidation resistance (OOT)		275°C	275°C	>300°C	280°C	>330°C

*body of the connector made in EPDM but the cap is made in thermoplastic elastomer.

Three connectors are made in EPDM and the two others in SIR. Most of the additives are related to the processing of the compound (vulcanization materials and processing aids). Silicone oil used as mould release agent was also identified. Flame retardants are found in two of the three EPDM compounds. One SIR layer is filled with silicate. No UV stabilizers were detected excepted carbon black (CB). Carbon black plays also the role of conductive filler. The amount of CB varies considerably from one connector to another.

EPDM and SIR are stable materials in an oxidative environment. They start to decompose above 275°C. SIR has a better stability than EPDM.

ARTIFICIAL ACCELERATED WEATHERING OF THE CONNECTORS

All the connectors were subjected to an artificial accelerated weathering program using a xenon arc lamp. They were exposed to simulated day light and water spraying as described in standard ISO 4892-2. The applied method includes the following cycle:

Table 2: Artificial accelerated weathering program.

Step 1	Step 2
• 102' dry cycle with light • Chamber T°: 38°C • Relative humidity of 50%	• 18' water spray with light • Chamber T°: 38°C

This cycle was repeated for 1000 hours corresponding approximately to an ageing period of 18 months.

Artificial weathering is a 2D test and is only effective on one side of the connectors. The exposed surface was visually inspected after the test as shown in Figure 2 for connector 3.

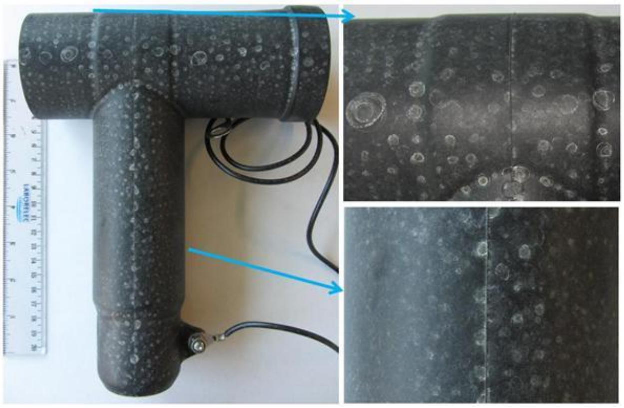

Figure 2: Aspect of connector 3 after artificial accelerated weathering.

The inspections did not reveal any surface defects (cracks or blisters) or change in coloration of the semi-conductive layers. The surface was marked with dried water droplets in each case. The waxy aspect caused by the mould release agent was markedly decreased for connectors 1 and 2 after weathering.

The external SC layers were then characterized and compared to the references.

CHARACTERIZATION OF THE SEMI-CONDUCTIVE LAYERS AFTER WEATHERING

Chemical and material properties

The chemical composition and material properties of the aged SC layers were assessed and compared to the references.

No oxidation was observed for SIR layers as displayed in the infrared spectrum of connector 5 (Figure 3). The absorption peaks are identical for the aged and unaged compounds confirming the resistance of SIR towards UV light [1].

The behavior of EPDM based layers is more complex as shown for connector 1 (Figure 3). A slight increase of the absorption band of hydroxyl groups (-OH) is observed 3100 – 3600 cm^{-1}. No characteristic oxidation peak at 1715 cm^{-1} is detected [2]. The formation of zinc carboxylate (oxidation product) is not observed at 1580 cm^{-1} [3]. Oxidation of the EPDM seems in this case very limited. It has to be noted that the mould release agent is also detected for connector 1 after weathering.

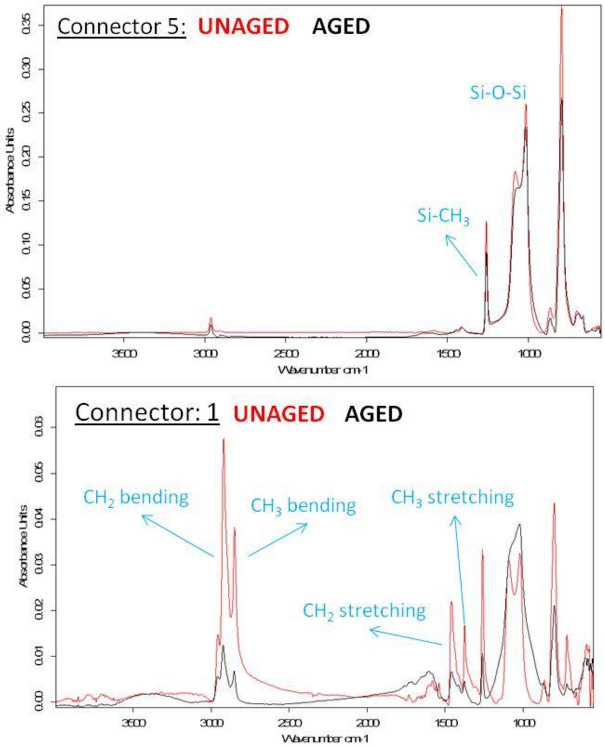

Figure 3: Infrared spectra of SC layers of connectors 5 and 1, before and after weathering.

Stabilization of the SC layers was assessed by measuring their resistance against oxidation. This was performed by measuring the oxidation induction time (OIT) using DSC as shown in Figure 4.

Weathering has no influence on the SIR stabilization (connectors 3 and 5). The behavior of the EPDM based layers is different from one connector to another. For connector 1, the aged SC layer seems to be less stabilized (small exothermic peak at the beginning of the test) than the unaged. Connector 2 is also less stabilized after weathering. Connector 4 is a little bit more stabilized after weathering.

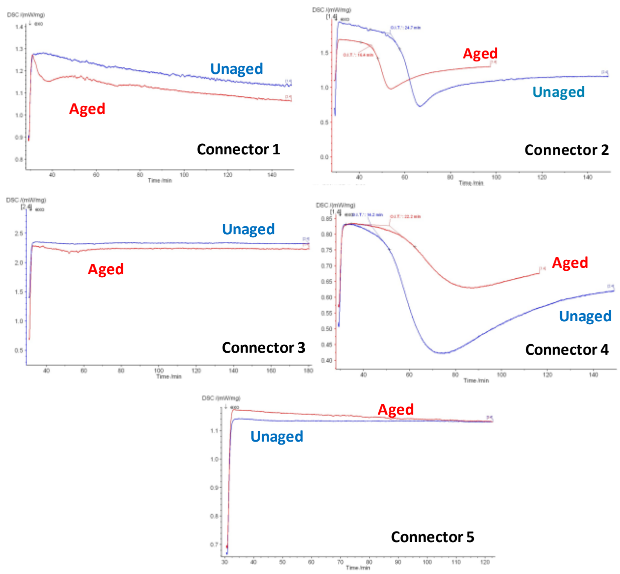

Figure 4: Oxidation induction time (OIT) measurements on the external SC layers before and after weathering.

Mechanical properties

Hardness measurements were made with a durometer (Shore A) on the external SC layers on different spots (identified as position 1 to 4) for each connector before and after weathering. Change in hardness was then calculated. Results are presented in Figure 5.

The ageing of a rubber is translated by an increase in hardness. A change of 5 points in Shore A is not considered as significant. Four of the five connectors are aged due to the weathering but only one is significant: connector 4. Connector 2 has the best behavior.

A decrease in hardness is the consequence of the absorption of a liquid by the rubber. This phenomenon is often measured during compatibility tests between a rubber and a solvent. The connector 5 has probably absorbed water during weathering. This could be attributed to the silica filler but not to the silicone matrix.

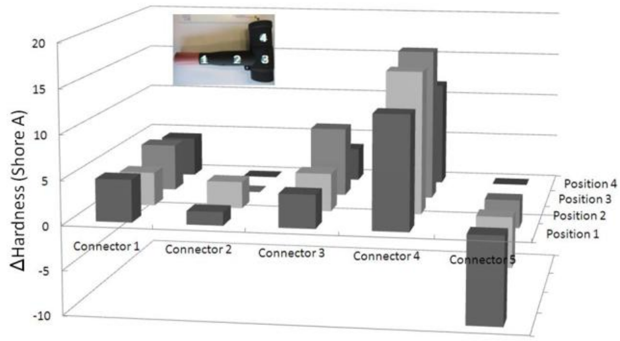

Figure 5: Change in hardness due to the weathering.

Tensile tests

The intrinsic mechanical properties of the external SC layers were measured in tensile tests. For each sample, five dumbbells were prepared and tested. The measured elongation at break is presented in Figure 6.

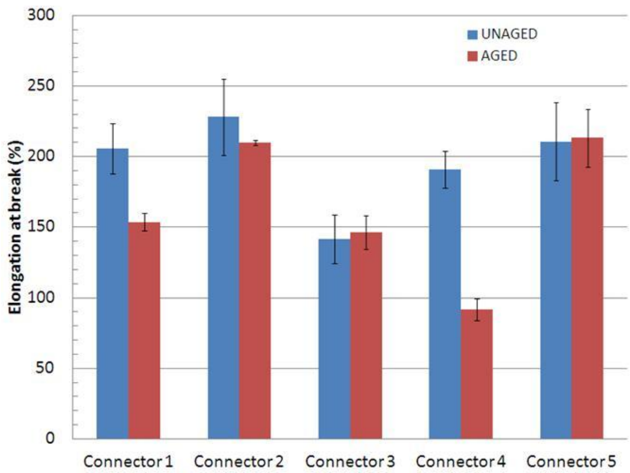

Figure 6: Elongation at break measured during tensile tests.

The elongation of the SC from connectors 4 and 1 is significantly decreased by 50 and 25% respectively. The SC of connector 2 does not lose too much of its properties and the one of connector 5 remains unchanged. Measurements performed on connector 3 are not representative of the behavior of the SC layer. The SC layer thickness was too small in order to cut properly a thin slice. The consequence is that the tensile tests were done on the SC + part of the insulation. It has been observed that the SC layer (aged and unaged) was starting to tear before the end of the test.

SCREEN RESISTANCE

Electrical tests were performed in order to check if the connectors have still their functionality after weathering. The resistance of the external SC layer was thus measured. The purpose of this test is to ensure that if a separable connector is touched by hand when it is in service, no electrical shock is experienced.

The screen resistance was measured following the method described in IEC 61442 Screen resistance. Results are presented in Figure 7.

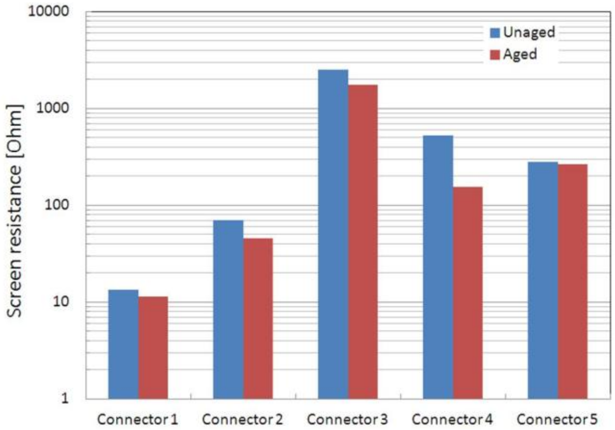

Figure 7: Resistance of the external semi-conductive layer.

The resistance of connector 3 is the highest despite the relatively large amount of carbon black (see Table 1). The high value of the resistance is in this case dominated by the design, i.e. the SC thickness.

The upper limit given in the standard IEC 60502-4 is that the screen resistance must not exceed 5kΩ. All the measurements were below this limit. Moreover weathering seems to decrease the screen resistance of the connectors. A significant drop is observed for connector 4 (logarithmic scale).

CONCLUSION

The resistance against weathering (UV light and rain) of EPDM and SIR based SC layers of MV connectors was assessed by chemical, material, mechanical and electrical tests. According to the results presented in this paper, an evaluation was made and is presented in Table 3.

Table 3: Evaluation of the external SC layers performances.

Connector	1	2	3	4	5
SC layer thickness					
Visual aspect after ageing					
Chemical and material analyses					
Mechanical properties			N.A.		
Electrical properties					

The SIR based connectors did not show any degradation or ageing caused by weathering. However the SC layer thickness of connector 3 could be a risk factor in case of external damage (e.g. scoring). Connector 5 seemed to absorb water during weathering. This could become a problem in industrial environments where acid vapors are present.

The behavior of EDPM based connectors was different from one connector to another. Connector 4 showed an important loss of elongation which could be caused by cross-linking due to weathering. Connector 1 showed a slight oxidation and a loss in elongation. A slight decrease of stabilization was observed for connector 2.

There is no clear advantage of using SIR of EPDM as matrix of the external SC layer of the connector. According to this study, connector 2 showed the best behavior, followed by connector 5 and connector 1. Connector 3 and 4 are not advised for outdoor application.

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