CORROSION AND METHODS OF PROTECTING THE ALUMINUM CASING OF COMMUNICATION CABLES

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Aluminum casings of communication cables in comparison with lead casings ensure an appreciably better protection of communication circuits against the effect of external electrical magnetic fields and lightning strikes and greater mechanical strength; they are lighter and cheaper. However, they are less corrosion resistant when in service underground, being subjected to soil corrosion and stray-current corrosion, and do not tolerate repeated bending [1-7]. The wide use of aluminum-encased communication cables underground is possible only if they are reliably protected against corrosion.

The purpose of this work was to elicit the factors promoting corrosion of aluminum underground, to evaluate the protective properties of insulating covers of cables with an aluminum casing, and to investigate the possibility of protecting aluminum against corrosion by the cathodic polarization method.

The experiments to determine the rate of corrosion and to establish the character of destruction of the aluminum casing of communication cables were carried out in solutions of electrolytes and in the soil. Tubular specimens of the cable casing (aluminum brand Al) were cleaned and degreased on the outside, and after weighing were tightly sealed and insulated on the ends. The working surface of the specimen was about 25 cm^2. The total duration of the corrosion test was 30 days. After the test the specimens were cleaned free from the corrosion products and dried.

If we judge by the average losses (Table 1), the corrosion rate of aluminum depends on the composition and concentration of the electrolyte. Among the investigated components the most corrosive proved to be the ions Fe^{2+} and Fe^{3+}; in the presence of these ions corrosion not only was very severe but also uneven (pitting). An increase of pH greatly accelerated dissolution. In the presence of chlorine ions its rate was higher than in the presence of SO_4^{2+}. The corrosion rate increases when dissolved gases, oxygen and carbon dioxide, are in the electrolyte. The weight loss in a 1% solution of NaCl saturated with carbon dioxide was $37 \cdot 10^{-6}$ g/cm^2 per day; when the carbon dioxide and air were removed from the solution by boiling, the corrosion rate at the same pH value of 3.5 dropped to $1 \cdot 10^{-6}$ g/cm^2 per day.

TABLE 1. Average Weight Losses of Aluminum as a Function of Composition and Concentration of Electrolyte

Electrolyte	Concentration of electrolyte		Weight loss (g/cm^2/day)	Test time
	%	g-equiv/liter		
NaCl	3	0.51	7.2	30 Days
	1	0.17	3.7	
	0.3	0.05	3.1	
$MgSO_4$	2.4	0.4	3.8	Same
	0.24	0.04	1.34	
	0.024	0.004	0.28	
$NaNO_3$	0.4	0.05	7.0	»
	0.04	0.05	5.7	
	0.004	0.0005	3.57	
$NaHCO_3$	3.4	0.4	5.42	»
	0.34	0.04	9.6	
	0.034	0.004	8.9	
NaOH	0.004 (pH11)	0.001	41.5	»
	0.00004 (pH9)	0.00001	11.6	
H_2SO_4	0.0049 (pH3)	0.001	33.2	»
	0.000049 (pH5)	0.00001	5.5	
$FeSO_4$	0.76	0.1	93.3	24 h
$Fe_2(SO_4)_3$	0.66	0.1	17.75	»

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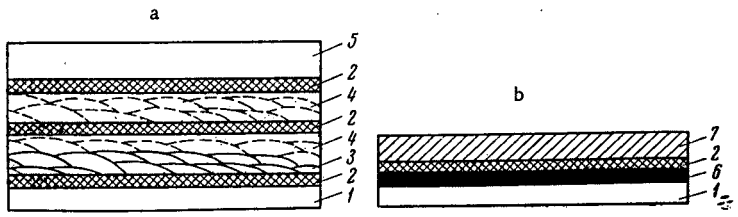

Fig. 1. Design of insulating coating of the wrapping (a) and hose (b) types. 1) Aluminum casing; 2) compound; 3) plastic wrapping; 4) cable paper; 5) armor and protective coatings; 6) layer of inhibitor; 7) continuous layer of plastic.

The rate and character of destruction of the aluminum also depended on the structure of the soil and its water content. In sand soil destruction was more uneven than in clay and peat soils. The corrosion rate increased with water content of the soil, reached a maximum, and then again dropped. For example, in clay moistened with a 0.5% solution of NaCl at a water content of 17 and 25%, the corrosion rate was respectively $5.3 \cdot 10^{-6}$ and $2.3 \cdot 10^{-6}$ g/cm^2 per day. In sand soils the corrosion rate increased from $7.85 \cdot 10^{-6}$ to $12.5 \cdot 10^{-6}$ g/cm^2 per day when the water content increased from 10 to 20%.

A comparison of the test results showed that corrosion in electrolytes is more uniform, has a slower rate, and is less disastrous than in soils.

It has been established that the aluminum casings of communication cables being in contact with corrosive soil are destroyed within 1-2 years by through-holes.

Owing to design features, and as a result of assembly, the aluminum casing of communication cables can have an electrical contact with steel slating and lead casing. In all cases the aluminum becomes an anode with respect to steel and lead and will be subject to contact corrosion.

When the surface of the aluminum participating in the work of the corrosion element is small, the density of the anode current becomes large and the casing is destroyed within a short time. Especially severe corrosion develops at the boundaries between insulated and noninsulated aluminum surfaces.

Stray currents, both direct and alternating, create a great danger of corrosion [8-10]. On exposure to direct currents aluminum is dissolved regardless of whether it is the cathode or anode. However, cathodic dissolution is not observed in all cases but only when certain cathodic potentials are reached (see below).

The dissolution rate of aluminum exposed to alternating currents depends on the frequency and density of the current and composition and concentration of the electrolyte. According to our data, at a frequency of 50 cps in neutral, alkali, and acid solutions corrosion begins with 2.0 mA/cm^2.

The effect of stray direct currents on the aluminum sheath in the presence of stray currents of industrial frequency leads to a marked increase of the corrosion rate.

The basic method of protecting aluminum cable sheaths against corrosion is to insulate them against the action of the ambient corrosive medium and stray currents by special protective covers.

Protective covers should have high dielectric properties, good adhesion to the aluminum casing, be continuous, water-proof, have weak moisture absorbability, provide the required plasticity in the temperature range from -10 to +50°, and not be subject to appreciable aging. The service life of the cover should be 30-40 years. Protective coverings should not lose their original properties in service. Furthermore, the mechanical properties of coverings should ensure the possibility of transporting the cable over large distances and laying it mechanically.

The reliability of protecting aluminum-encased communication cables against corrosion is determined by a combination of such factors as the construction of the insulating cover, the type of insulating materials used and their characteristics, the care used in applying the coating, its quality control, etc. [12]. Special experimental investigations were carried out to evaluate the protective properties of individual materials and designs of insulating covers.

TABLE 2. Resistance of Insulation of Specimens in Different Electrolytes for 900 Days

Construction of coating	Resistance, * mΩ/km	Medium		
		0.05 N H_2SO_4	0.05 N NaOH	1.5% KCl
Aluminum	R_1	0.034	0.051	0.054
Polyvinyl chloride	R_{900}	0.024	0.225	0.27
Aluminum	R_1	0.207	0.066	0.136
Inhibitor				
Polyvinyl chloride	R_{900}	0.314	0.262	0.21
Aluminum	R_1	26.2	43.5	27.1
Inhibitor				
Bitumen compound				
Polyvinyl chloride	R_{900}	2.62	4.5	2.6

*R_1 is initial resistance, R_{900} is resistance after 900 days.

TABLE 3. Resistance of Insulation of Specimens in Different Electrolytes for 900 Days Exposed to a Direct Current (+6 V)

Construction of coating	Resistance, mΩ/km	Medium		
		0.05 N H_2SO_4	0.05 N NaOH	1.5% KCl
Aluminum	R_1	0.064	0.037	0.12
Polyvinyl chloride	R_{900}	0.165	0.195	0.345
Aluminum	R_1	0.135	0.120	0.172
Inhibitor				
Polyvinyl chloride	R_{900}	0.255	0.360	0.270
Aluminum	R_1	28.5	27.0	41.2
Inhibitor				
Bitumen compound				
Polyvinyl chloride	R_{900}	4.5	3.75	3.75

It was established that coatings of the wrapping type (Fig. 1a) are appreciably inferior in reliability to covers of the hose type (Fig. 1b). This conclusion is confirmed by investigations performed in other countries [11]. It has also been established that multilayered coverings are more resistant to corrosive media and to stray alternating and direct current than single-layered coverings of the same thicknesses. Bitumen and other compounds and corrosion inhibitors are important elements of most presently used constructions.

We investigated different constructions of insulating covers of the hose type in acid (0.05 N H_2SO_4), neutral (1.5% KCl), and alkali (0.05 N NaOH) electrolytes. The tests were carried out without polarization and with the effect of direct and alternating currents. The change in the condition of the cover in time was evaluated on the basis of the resistance of the insulation between the aluminum casing and the electrolyte. The measured resistances were calculated for a temperature of +20°. The results of the measurements are shown in Tables 2, 3, and 4. They show that a) the resistance of the insulation depends not only on the starting materials but also on the construction of the covering; b) the elimination of the bitumen compound from the construction of the insulating covering markedly lowers its dielectric properties; c) the character of the medium (acid, neutral, alkali) under the investigated conditions does not have a substantial effect on the resistance of the insulation; d) during the test period (900 days) the direct and alternating currents had no effect on the resistance of the insulation.

The results of control measurements performed on cables with the wrapping type insulation showed that protection against corrosion in this case is inadequate. The potentials of the aluminum casing measured at the control sections and the current in the casing-plate circuit indicated the presence of defects in the insulation and the penetration of the electrolyte to the metal surface. The resistances of the insulation at individual sections had very low values, within 100 Ω/km and lower. Corrosion is possible at such sections if additional protection is not used.

TABLE 4. Resistance of Insulation of Specimens in Different Electrolytes for 900 Days Exposed to an Alternating Current (127 V)

Construction of coating	Resistance, mΩ/km	Medium		
		0.05 N H_2SO_4	0.05 N NaOH	1.5% KCl
Aluminum Polyvinyl chloride	R_1	0.067	0.052	0.030
	R_{900}	0.021	0.033	0.036
Aluminum Inhibitor Polyvinyl chloride	R_1	0.045	0.071	0.043
	R_{900}	0.33	0.345	0.345
Aluminum Inhibitor Bitumen compound Polyvinyl chloride	R_1	4.5	5.25	4.05
	R_{900}	4.5	3.75	4.87

Underground metal structures are often protected against corrosion by the combined protection method in which the insulated surface of the metal is additionally protected by the electrochemical method [13] – by cathodic polarization of the structure by means of protectors, external current sources, and drainage. There are extremely contradictory opinions in the literature concerning the applicability of such protection for an aluminum casing [2, 3, 14-19].

Our experiments showed that corrosion of aluminum, just as of iron and lead, can be stopped or inhibited by cathodic polarization. Figures 2 and 3 show, respectively, the cathodic and anodic polarization curves of aluminum* in a 0.5% solution of NaCl + Na_2SO_4 in a ratio of 3 : 1. Similar curves were obtained in other solutions and in clay and sand soils.

A comparison of the anodic and cathodic polarization curves shows that corrosion of aluminum in an electrolyte and soil is controlled by the cathodic process, primarily with oxygen depolarization. This fact indicates the possibility of using cathodic protection. A determination of the corrosion rate of cathode-polarizable specimens at different potentials which were maintained constant during the experiment showed the practicability of protecting aluminum against corrosion in soils and electrolytes, including against corrosion caused by stray direct currents. It was established that cathodic polarization can protect an aluminum casing that is in contact with armor against corrosion. Protection of the aluminum casing was achieved even in such a corrosive solution as 0.1 N $Fe_2(SO_4)_3$ (see Table 1) at a potential of -1.1 V.

Determination of the range of potentials within which cathode-polarizable aluminum is protected against corrosion was carried out in a 0.5% solution of NaCl + Na_2SO_4 on specimens subjected to anodic dissolution. An aluminum specimen with a surface area of 25 cm^2 from which an anode current of 20 mA flowed, was subjected to cathodic polarization from an external current source (the basic diagram of the electrical circuit

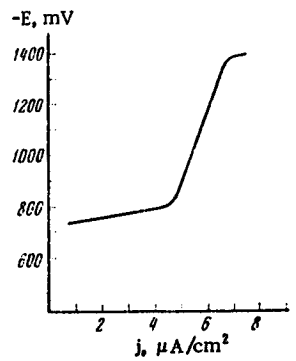

Fig. 2. Cathodic polarization curve of aluminum casing in 0.5% solution of NaCl + Na_2SO_4 (3 : 1).

* The values of the potentials here and below are given with respect to a copper sulfate comparison electrode.

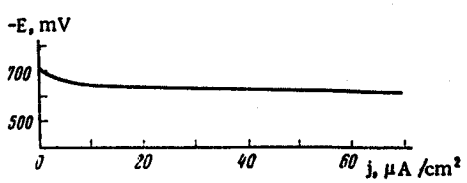

Fig. 3. Anodic polarization curve of aluminum casing in 0.5% solution of NaCl + Na_2SO_4 (3 : 1).

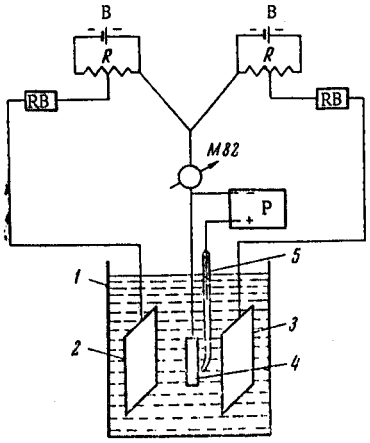

Fig. 4. Basic circuit for measurements in cathodic protection of an aluminum casing subjected to anodic attack. 1) Glass vessel; 2) auxiliary electrode in circuit of cathodic protection; 3) auxiliary electrode in circuit of anodic attack of specimen; 4) investigated specimen; 5) copper sulfate electrode; 6) batteries; R) rheostat; M-82) millivolt-milliammeter; RB) resistance box; P) potentiometer.

TABLE 5. Corrosion Losses of Cathode-Protected Aluminum Casing in Clay

Potential, V	Moisture content of clay, %	Corrosion losses
−1.0	30	Practically complete protection
	25	Same
−1.2	30	"
	25	"
−1.6	25	$82.65 \cdot 10^{-4}$ g/cm^2/day

is shown in Fig. 4). The experiments were carried out at constant values of the potentials -0.85 V, -1.0, -1.2, -1.4, and -1.6 V. The experiments lasted 8 h.

Without cathodic protection the weight loss of the specimen was $148.35 \cdot 10^{-4}$ g/cm^2/day. Dissolution of the cathode-polarizable aluminum markedly dropped at a potential of -0.85 V, and virtually complete protection was achieved in the range −1.0-1.4 V. A further shift of the potential toward negative values accelerated corrosion, which can be explained by the increase in the concentration of hydroxyl ions in the layer adjacent to the electrode. Actually, with a drop of potential from -1.4 to -1.6 V, the current density markedly increased, namely, from 4 to 35 μA/cm^2.

Similar results were obtained on cathode-polarizable specimens in clay moistened with 0.5% solution of NaCl + Na_2SO_4 (Table 5). When the aluminum casing is under an insulating cover the migration of hydroxyl ions formed upon cathodic polarization is hampered and favorable conditions are created for their accumulation in the layer adjacent to the electrode. An increase of alkalinity can evidently change the found range of protective potentials.

To elucidate this question we carried out long (three months) experiments with cathodic polarization of specimens insulated by a polyvinyl chloride film at potentials -1.0, -1.2, -1.4, and -1.6 V.

In the range of potentials from -1.0 to -1.4 V cathodic protection of the aluminum casing of the communication cables had a favorable effect. At a potential of -1.6 V pitting of the aluminum was observed.

The obtained results indicate a real possibility of protecting aluminum casings against corrosion caused by environmental conditions and stray direct currents with periodic control and observance of the indicated values of the protective potentials.

A test with magnesium protectors connected to the aluminum casing of an in-service cable showed that when the resistance of the insulation is 1500-3000 Ω/km a protective potential up to -1.1 V over a section 10-20 km long is provided.

CONCLUSIONS

1. Communication cables in an aluminum casing are subject to corrosion by soil, stray direct and alternating currents, and by contact with other more noble metals (iron, lead, copper).

2. The basic type of protecting the aluminum casing of communication cables against corrosion is its insulation. Insulating covers of the hose type made of high polymer materials are most effective. The hose should be applied to the aluminum casing over a layer of bitumen.

3. An especially effective method of protecting the aluminum casing against corrosion is combined protection – the application of insulating covers in combination with cathodic polarization.

4. Electrochemical protection of the aluminum casing of cables against corrosion caused by the environment and stray direct currents can be accomplished by means of protectors, external direct current sources, and drainage. In this case it is recommended to maintain the potential within -0.85 and -1.4 V with respect to a copper sulfate comparison electrode.

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