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INFLUENCE OF TECHNOLOGICAL DOSE OF IRRADIATION ON MECHANICAL AND ELECTRICAL CHARACTERISTICS OF POLYMERIC INSULATION OF WIRES

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Creation of cables and wires with polymer insulation without halogens based on ethylene vinyl acetate with a high content of fire retardants is impossible without radiation modification properties. On the industrial accelerator of charged particles, the effect of ionizing radiation on wires with a copper conductor cross section of 1.0 mm^2 and an insulation thickness of 0.7 mm is performed. The influence of the electron energy at identical irradiation factors on the increase in the mechanical strength of insulation during stretching is shown. For electron energy of 0.5 MeV, an increase in the mechanical strength of insulation at a tension of 27% was established, the insulation resistance more than doubled, and the breakdown voltage by 35% at the optimum radiation dose relative to the unirradiated state.

INTRODUCTION

Electron-beam technologies are widely used in the cable industry for the radiation cross-linking of polymer insulation and protective shells [1–5]. Sources of ionizing radiation for modifying the polymer insulation of cables and wires with current-conducting veins of 0.5…120 mm^2 cross section are electron accelerators with energies 0.3…5 MeV and power up to hundreds of kilowatt. Physical modification has significant advantages in comparison with chemical cross-linking: the possibility of modifying a wide range of polymers of different chemical structure; reagentless technologies, i.e. no need to use initiators, cross-linking accelerators; solid phase technology at normal temperature, which eliminates the use of solvents and high temperatures. Application of the technology of radiation modification provides a qualitative change in electrical, mechanical, thermal and other properties as a result of irradiation of cables and wires [4–9]. As a result, the service life is prolonged, the heat resistance, the current throughput are improved, and the physical properties of the cables and wires are improved.

The most common way to irradiate cable products around the world at present is bilaterally irradiated. With this method, there is no shadow effect from the conductive core of the cable (wire).

The main parameter determining the degree of radiation modification of the insulation of cables and wires in the technological stage of manufacture is the radiation dose absorbed by the insulating material [2–4]. The determination of the absorbed by the insulation or the shell dose is problematic because of the uneven distribution of it due to the design of the cables (round shape) and the technology of radiation modification. In connection with this, in the physical modification of insulation and cable sheaths, an irradiation factor (K) is used, representing the ratio of the conductor transfer velocity under the electron beam to the electron beam current. The inverse of the irradiation factor is the technological dose of irradiation ($1/K$). Polymers with the same chemical formula are cross-linked differently depending on the process dose and thickness. The justification of the technological dose of irradiation, determined at the stage of investigation of the cable composition and the development of the cable (wire), is the result of a compromise between the various properties and technical requirements imposed on the finished product.

The purpose of the article is to investigate the effect of the technological dose of irradiation on the mechanical and electrical characteristics of a halogen-free composition based on an ethylene-vinyl acetate copolymer with a high filling of wire insulation with flame retardants.

METHODOLOGY OF PHYSICAL MODELING OF RADIATION EXPOSURE OF SAMPLES OF A WIRE

The use of cables that do not spread combustion and do not contain halogens [10, 11] is an actual problem, for the solution of which modern highly flame retardant polymeric insulating compositions containing halogens are used. Aluminium hydroxide $Al(OH)_3$ and magnesium $Mg(OH)_2$ are used as industrial flame retardants of synthetic and natural origin [12]. The mechanism of the fire retardant action of hydroxides consists in the absorption of a large amount of heat due to the release of water as the temperature rises. Compositions based on ethylene vinyl acetate copolymer (EVA) are the most popular in the cable industry, do not contain halogens in their structure and have high elasticity, good adhesion to various materials. Using EVA in cross-linked polymer cable compositions improves processability, improves the ability to absorb mineral filler and resistance to high temperatures.

To ensure uniform cross-linking throughout the volume of insulation, the accelerator must work with stable parameters of the electron beam: energy, beam current, front radiation width. An important factor of irradiation is the dose rate of the installation: low dose rate leads to an increase in the duration of the irradiation process and the need to take measures to prevent oxidation of the polymer upon irradiation (the need to apply vacuum or inert environment). It is possible to “overexpose” the insulation and lose its necessary properties, first of all, elasticity at doses corresponding to the processes of destruction.

Radiation modification of wire samples with copper conductor of 1.0 mm^2 cross section with highly filled flame retardants (up to 70% by weight) halogen-free based on a 0.7 mm thick ethylene vinyl acetate copolymer was carried out by exposure to ionizing radiation at an industrial ELV-1 charged particle accelerator with a foil outlet (Tabl. 1).

Table 1

Technical characteristics of electron accelerators

Accelerator type	Energy range, MeV	Power in the beam, kW	Maximum beam current, mA
ELV-0.5	0.4…0.7	25	40
ELV-1	0.4…0.8	25	40
ELV-2	0.8…1.5	20	25
ELV-3	0.5…0.7	50	100

Inside the boiler filled with SF_6 gas, is the primary winding, a high-voltage rectifier with an in-built accelerator tube, a high-voltage electrode and an injector control unit. It is the location of the accelerating tube inside the column of the high-voltage rectifier that makes the ELV accelerators the most compact among the machines of their class. The elements of the vacuum system with the outlet device are attached to the bottom of the boiler. Electrons emitted by the cathode located at the upper end of the accelerator tube pass through the elements of the vacuum system and enter the outlet device where, with the help of electromagnets, the sweeps are uniformly distributed along the foil and discharged to the atmosphere. The irradiated material is transported under the frame of the discharge window.

Samples of wires 5 m long are irradiated with different irradiation factors *K* in a fairly wide range: 17; 15; 13; eleven; 10; 9; 8; 7; 6; 5, and 4 at an accelerated electron energy of 0.5 MeV, and 11; 9, and 7 at an accelerated electron energy of 0.4 MeV. One sample is control (not exposed to radiation).

The coefficient of irradiation of the insulation was regulated by a change in the speed of passage of an isolated vein under an electron beam with an unchanged electron beam current equal to 10 mA. The number of wire passes under the electron beam, which depends on the thickness of the irradiated insulation, is 80.

In the initial state (before irradiation) and after exposure, mechanical and electrical tests of wire samples were carried out.

RESULTS OF THE RESEARCH

The physical and mechanical properties of the insulation of wire samples irradiated by electrons with an energy of 0.4 and 0.5 MeV are significantly different: with decreasing electron energy, the tensile strength decreases (Fig. 1), and the elongation increases (Fig. 2). When the electron energy is changed by 25% (from 0.4 to 0.5 MeV), the tensile strength increases practically by 20% over the entire irradiation dose range (see Fig. 1). The insulation irradiated with electrons with energy of 0.4 MeV has a lower degree of cross-linking compared to samples irradiated with electrons with an energy of 0.5 MeV, with identical irradiation factors *K*.

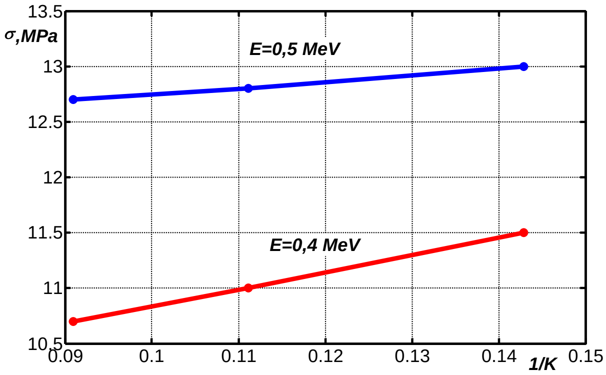

Fig. 1. Effect of electron energy on the tensile strength of halogen-free filled insulation of wire samples

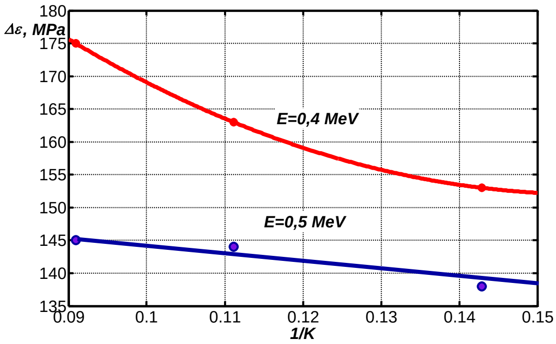

Fig. 2. Effect of electron energy on the elongation at break of halogen-free filled insulation of wire samples

The results of measurements of mechanical (average values for 5 measurements) and electrical (single measurement values) of the characteristics of wires with high fireproof insulation for different irradiation factors for electrons with an energy of 0.5 MeV are given in Tabl. 2. The mechanical characteristics vary in different ways with a decrease in the irradiation coefficient *K*, i. e. with increasing technological radiation dose (1/*K*). In comparison with the unirradiated condition, the tensile strength increases by 27% to an irradiation dose value of 0.2, after which it begins to decrease insignificantly (Fig. 3). The relative elongation throughout the entire range of the irradiation coefficient decreases monotonically (Fig. 4). For an irradiation dose value of 0.2, the elongation is reduced by 67% relative to the original, unirradiated condition.

The nature of the change in electrical characteristics is identical to the dynamics of the change in tensile strength (see Tabl. 2, Figs. 5, 6): with respect to the unirradiated state, the insulation resistance increases by more than two times, the breakdown voltage by 35% at an irradiation dose of 0.15, respectively.

The results of tests of insulation specimens on thermal deformation at a temperature of 200 °C for 15 min show that the relative elongation Δ*l* under a load of 20 N/cm^2 decreases with increasing radiation dose (Fig. 7). For unirradiated samples, testing is not possible. For irradiated with small doses (irradiation coefficient K = 17 and 15), the samples are broken in 2…3 min and 11 min, respectively.

Table 2

Influence of the irradiation coefficient on the mechanical and electrical characteristics of radiation-irradiated insulation of wire samples (energy of accelerated electrons is 0.5 MeV)

Coefficient of radiation K	The average tensile strength σ, MPa	The average value of the relative elongation at break Δε, %	Insulation resistance R_{ins}, MΩ·km	Breakdown voltage at direct current U_{br}, kV
0 (not irradiated)	10.6	241	97.1	20.5
17	11.6	179	208	23.5
15	12.2	170	208	–
13	11.6	165	177	24
11	12.7	144	238	–
10	13.4	144	203	–
9	12.8	144	214	27
8	12.7	150	217	23
7	13.0	138	252	–
6	13.3	144	197	25
5	13.2	138	217	26
4	13.3	119	173	21

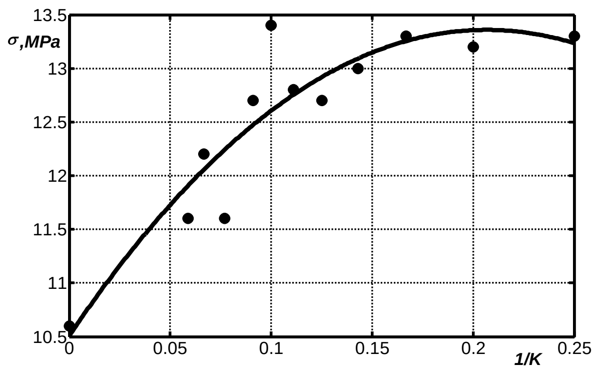

Fig. 3. Dynamics of changes depending on the dose of irradiation of the tensile strength of halogen-free filled insulation of wire samples

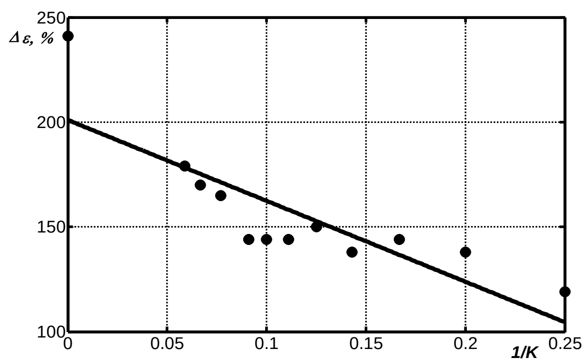

Fig. 4. Dynamics of changes depending on the dose of irradiation of the relative elongation of halogen-free filled insulation of wire samples

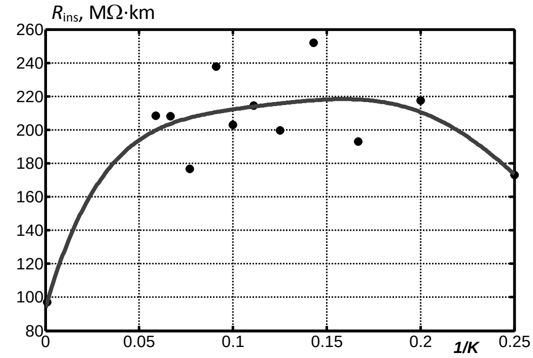

Fig. 5. Dynamics of changes depending on the irradiation dose of insulation resistance of wire samples with halogen-free filled insulation

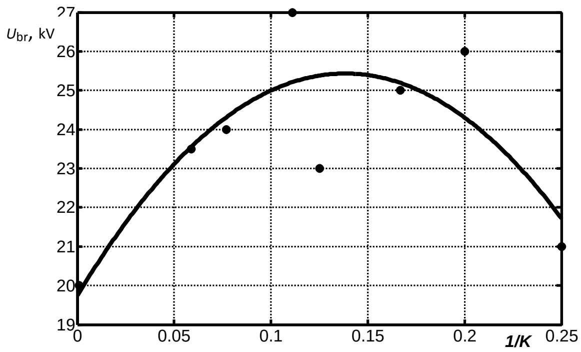

Fig. 6. Dynamics of changes in the dose of irradiation of breakdown voltage of wire samples with halogen-free filled insulation

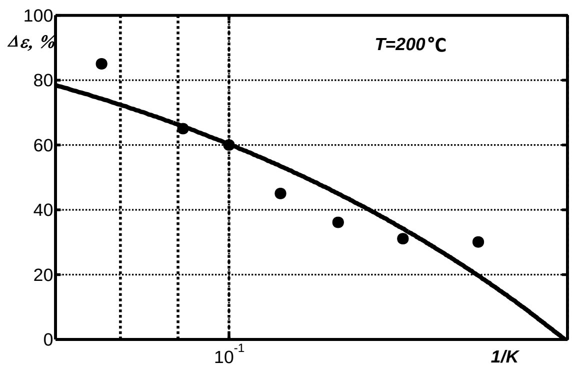

Fig. 7. Effect of radiation dose on thermal deformation of halogen-free filled insulation of wire samples

In Figs. 1–7 points show the experimental data, solid lines – the experimental values of the parameters processed using approximating splines.

CONCLUSIONS

For the first time, the effect of the technological dose of irradiation on the mechanical and electrical characteristics of composite halogen-free based on ethylene vinyl acetate copolymer with a high filling of flame retardant insulation wires was investigated.

Based on the results of mechanical tests, it is shown that the electron energy at the level of 0.5 MeV provides a higher degree of cross-linking of the polymer insulation in comparison with the energy of 0.4 MeV at the same values of the technological dose of irradiation, the beam current and the number of passes of the wire samples under the beam.

An increase in mechanical tensile strength, insulation resistance and breakdown voltage at a constant current with an increase in the irradiation dose up to values of 0.15…0.2 has been established, which is due to the cross-linking of a polymer matrix based on an ethylene-vinyl acetate copolymer. At higher irradiation dose values, destruction of the polymer matrix is observed, which leads to a decrease in these characteristics. The values of technological dose of irradiation in the range 0.15…0.2 can be considered optimal from the point of view of the process of cross-linking of composite insulation with high insulation of wires with an insulation thickness of 0.7 mm. At such values of the radiation dose, the relative elongation of the insulation remains at a level of not less than 120%, which provides a compromise between the elasticity and the and the rigidity of the wire.

These researches are of practical interest in the field of creating cables for nuclear and thermal stations, wind farms and solar power plants, ship cables, wires for on-board systems. These are all products of increased reliability and bear an increased load under extreme operating conditions.

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ВЛИЯНИЕ ТЕХНОЛОГИЧЕСКОЙ ДОЗЫ ОБЛУЧЕНИЯ НА МЕХАНИЧЕСКИЕ И ЭЛЕКТРИЧЕСКИЕ ХАРАКТЕРИСТИКИ ПОЛИМЕРНОЙ ИЗОЛЯЦИИ ПРОВОДОВ

А.В. Беспрозванных, И.А. Мирчук

Создание кабелей и проводов с полимерной изоляцией без содержания галогенов на основе сополимера этиленвинилацетата с высоким содержанием антипиренов невозможно без радиационного модифицирования свойств. На промышленном ускорителе заряженных частиц выполнено воздействие ионизирующего излучения на образцы провода с медной жилой сечением 1,0 мм^2 и толщиной изоляции 0,7 мм. Показано влияние энергии электронов при одинаковых коэффициентах облучения на повышение механической прочности изоляции при растяжении. Для энергии электронов 0,5 МэВ установлено повышение механической прочности изоляции при растяжении – на 27%, сопротивления изоляции – более чем в два раза и пробивного напряжения – на 35% при оптимальной дозе облучения относительно необлученного состояния.

ВПЛИВ ТЕХНОЛОГІЧНОЇ ДОЗИ ОПРОМІНЕННЯ НА МЕХАНІЧНІ І ЕЛЕКТРИЧНІ ХАРАКТЕРИСТИКИ ПОЛІМЕРНОЇ ІЗОЛЯЦІЇ ПРОВОДІВ

Г.В. Безпрозваннних, І.А. Мірчук

Створення кабелів і проводів з полімерною ізоляцією без вмісту галогенів на основі сополімеру етиленвінілацетату з високим вмістом антипіренів неможливо без радіаційного модифікування властивостей. На промисловому прискорювачі заряджених частинок виконано вплив іонізуючого випромінювання на зразки проводу з мідною жилою перетином 1,0 $мм^2$ і товщиною ізоляції 0,7 мм. Показано вплив енергії електронів при однакових коефіцієнтах опромінення на підвищення механічної міцності ізоляції при розтягуванні. Для енергії електронів 0,5 МеВ встановлено підвищення механічної міцності ізоляції при розтягуванні – на 27%, опору ізоляції – більш ніж в два рази і пробивної напруги – на 35% при оптимальній дозі опромінення щодо неопроміненого стану.