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DISTRIBUTION OF ABSORBED DOSE BY THE PERIMETER AND THE LENGTH OF THE POLYMERIC PROTECTIVE SHEATH AT RADIACINOUS IRRADIATION OF THE SHIP CABLE

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The research of the distribution of the absorbed dose along the perimeter and length of the polymer protective sheath on the basis of a halogen-free composition depending on the technological dose of radiation exposure of shipboard cable samples was performed. It has been established that irregularity of irradiation around the cable perimeter can reach 20…30% with a technological dose in the range of 1.25…0. 5. The irradiation along the cable is more uniform and does not exceed 5% at a technological dose in the range of 1.25…0.567. With a reduction in the technological dose, the irregularity of radiation around the perimeter and length of the cable increases. It is established that with an average absorbed dose of 210 kGy, the protective polymer shell does not meet the requirements of the standard for relative elongation at break. Optimal and physical-mechanical characteristics of the polymer shell made of halogen-free material are provided under irradiation in the range of the absorbed dose of 160 to 170 kGy.

INTRODUCTION

The process of radiation processing of polymer insulation of cable products requires the use of expensive equipment. Due to the high molecular weight of the polymer, even relatively small doses can cause a significant change in its properties [1–3]. For high-quality and effective irradiation, it is necessary to ensure the efficiency of using the energy of electrons and the current of the electron beam, the uniformity of the absorbed dose over the depth of the material and the azimuth of the product [4–7].

The quantitative characteristic of the process of curing polymer insulation is the degree of crosslinking. The degree of crosslinking is characterized by such parameters as the mass fraction of the undissolved substance (index of gel fraction) and the number of segments of the polymer chains between the grid nodes per unit volume [7]. With an increase in the degree of crosslinking of the polymer, there is a natural increase in both the indicator of the gel fraction and the number of chain segments between the grid nodes per unit volume. The degree of crosslinking and, as a result, the quality of the finished product, is determined by the time the cable product is in the irradiation zone, i.e. dose rate.

To determine the optimal mode of radiation modification, irradiation is carried out on a linear electron accelerator when the current strength (I) and cable speed drawing (v) [1]. The absorbed dose of radiation exposure, i. e., the technological dose of radiation, is represented as I/v ratio. The inverse of the technological dose of radiation is the coefficient of radiation K [8, 9].

The efficiency of irradiation of cable polymer insulation is provided by four-sided irradiation systems based on ELV-type accelerators [10]. The control systems of the accelerator and the line of transportation of wires (cables) through the irradiation zone are combined, which allows electron-beam processing of wires and cable blanks in a fully automated mode [11].

Four-sided irradiation provides a much greater uniformity of the gel fraction (degree of crosslinking) by sectors of the insulation section of the cable product in comparison with the two-sided. Depending on the type of irradiated products, this value varies from 20% to 2 times, that is, with a fixed beam current, the processing speed can be increased, or the beam current (accelerator power) can be reduced if the processing speed reaches a maximum value [6].

Currently, preference is given to cable products with improved thermal and fire-resistant characteristics [12, 13]. For ship cables the requirements for electrical and mechanical characteristics, resistance to external aggressive media, reliability and fire safety [14, 15] are being tightened. The protective polymer sheath of such cables should provide the appropriate mechanical characteristics (tensile strength and compression, cracking, flexibility), the ability to resist ignition (non-combustibility), non-propagation of fire; performance at elevated temperatures; non-release of hazardous and corrosive decomposition products when the cable burns; the minimum amount of smoke at ignition; resistance to aggressive media (moisture containing salt, oil and oil products). To provide a set of requirements for the polymer protective sheath of ship cables, radiation-crosslink cable halogen-free compositions are used [8, 9, 13].

The purpose of the article is to investigate of the uniform distribution of the absorbed dose along the perimeter and length of the polymer protective sheath on the basis of a halogen-free flame-retarding composition depending on the technological dose of irradiation of shipboard cable samples.

TEST SAMPLES AND PARAMETERS OF RADIATION IRRADIATION

Samples of the ship's cable with a sheath of non-combustible halogen-free polymer composition with a length of 20 m each. Outer cable diameter is 23.5 mm; cable sheath thickness – 1.8…2.0 mm.

For each cable sample, 2–3 standard samples (SS) of the absorbed dose of the electronic radiation are attached to the sheath around the perimeter (Fig. 1). Standard samples are polymer films of single use with phenazine dye size 10x35 mm, packed in paper, laminated with polyethylene. Standard dosimeter samples (*SDS*), without disturbing the tightness of the package, were also attached at a distance of 5, 10, and 15 m from the edge of the cable sample. For each of the three films contained in SS, three measurements of the optical density (*A*) were carried out on a DP-1m densitometer. The reserch were performed at a wavelength of 530 nm. The average of 9 values (3 measurements on each of the 3 films) was determined, and then the absorbed dose of electron radiation was determined $D = 71,46 \cdot A^{1,188}$, *kGy* .

The film in its original state has a yellowish-orange color (Fig. 2,a). With an increase in the irradiation dose to 180 kGy, the film acquires a maroon color (see Fig. 2,c). In Fig. 2,b shows a film irradiated with a dose of 6 kGy (color – red).

Fig. 1. Fragment of the arrangement of standard samples of the absorbed dose of electron radiation on the surface of the protective polymer jacket of the cable

a *b* *c*

Fig. 2. Dynamics of change in the color of the film during irradiation

Radiation irradiation of the cable samples was performed at the ELV-2 electron accelerator. The irradiation was carried out on one side (top), but the cable charging system was made so that the cable scrolls in the process of passing: when passing, the cable turns to the other end of the outlet side. This is, in fact, 4-sided irradiation, but without side magnets on the outlet socket.

The parameters of radiation exposure: the current of the electron beam – I = 10 mA; electron energy – 1.2 MeV; the number of cable passes under the electron beam – 18; the cable pulling speed v varied in the range from 8 to 30 m/min: 8, 10, 15, 20, and 30 m/min. The technological radiation dose at a given pumping current and drawing speed is 1.25; 1,00; 0.67; 0.50, and 0.33 (the radiation coefficient K, respectively, are 0.8; 1.0; 1.5; 2.0; 3.0).

DISTRIBUTION OF ABSORBED DOSE BY THE PERIMETER AND THE CABLE SAMPLES LENGTH

In Figs. 3 and 4 shows the distribution of the absorbed dose around the perimeter of cable samples depending on the distance of installation of standard dosimeter sensors along the cable length at different values of the technological irradiation dose (drawing speed at a constant pump current).

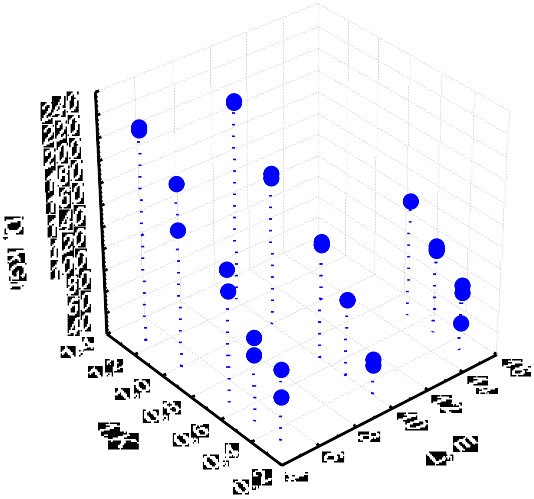

Fig. 3. The distribution of the absorbed dose around the perimeter of cable samples depending on the installation distance of standard dosimeter sensors along the cable length and the technological dose of radiation

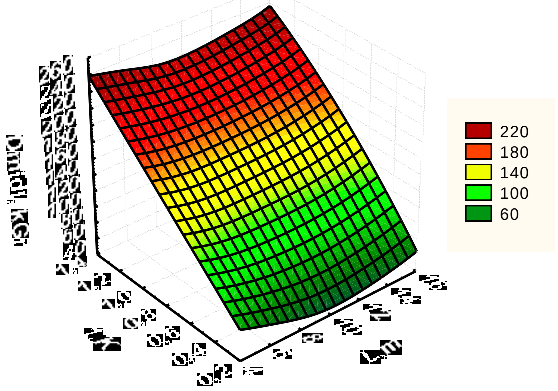

Fig. 4. 3D Diagram of the dependence of the average absorbed dose of cable samples on the installation distance of standard dosimeter sensors along the cable length and the technological dose of radiation

The scatter of the values of the absorbed dose over the cable perimeter is significant: 28% for samples irradiated with a technological dose of 1.0; 0.5, and up to 76% at a technological dose of 0.33 (see Fig. 3). The most uniform irradiation around the cable perimeter is fixed on the central parts of the samples.

For samples irradiated with a technological dose of 1.25 and 0.67, the deviation of the average absorbed dose along the cable perimeter does not exceed 20% (see Fig. 3).

The deviation of the average absorbed dose between CO, placed along the length of the sample, does not exceed 5% for samples with a technological dose of 1.25; 1.0, and 0.67 (Fig. 4). With a decrease in the technological dose of irradiation, the irregularity of irradiation along the length of the sample increases.

With 18 passes of ship cable samples with an outer diameter of 23.5 mm under the electron beam at the ELV-2 accelerator, the average absorbed doses are:

210, 160, 130, 95, and 65 kGy with a technological dose of radiation 1.25; 1.00; 0.67; 0.50, and 0.33, respectively (Fig. 5).

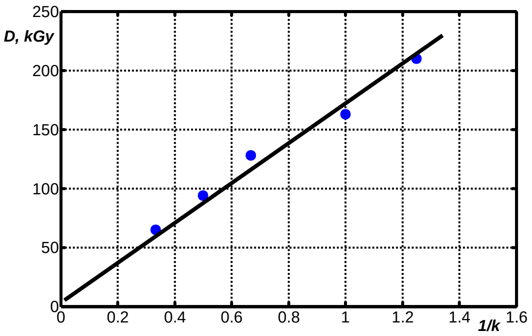

Fig. 5. Correlation between technological and average absorbed dose of cable samples

The Pearson pair-correlation coefficient between the process and absorbed dose is 0, 9945.

INFLUENCE OF ABSORBED DOSE ON PHYSICAL AND MECHANICAL CHARACTERISTICS OF POLYMER PROTECTIVE SHEATH

Research tests have been performed to determine the effect of the absorbed dose of electron radiation on the physical-mechanical characteristics of cable samples with a sheath of halogen-free composition.

For testing, samples of the shell with a length of 1 m were selected from the same section of the cable where the standard samples were attached.

From the sheath of each sample cable lengthwise, along the length, prepared by 4 strips. For each strip are determined: tensile strength, elongation at break and thermal deformation at a temperature of 200 °C and a load of 20 N/cm^2 for 15 min at baseline, after irradiation (Figs. 6, 7) and after heat aging at 120 °C for 168 h; after soaking in industrial oil at 100 °C for 24 h (Fig. 8).

According to the test results, it was established that at a technological dose of 1.25, corresponding to an average absorbed dose of 210 kGy, the protective polymer shell does not meet the requirements for relative elongation at break: the shell is overexposed (see Fig. 6).

With an absorbed dose of 65 kGy, half of the samples do not pass the heat distortion test (see Fig. 7: marked by a larger diameter point on the axis of the average absorbed dose). Requirements for resistance to thermal deformation of the cable sheath is provided with a technological dose in the range of 0.5…1.25.

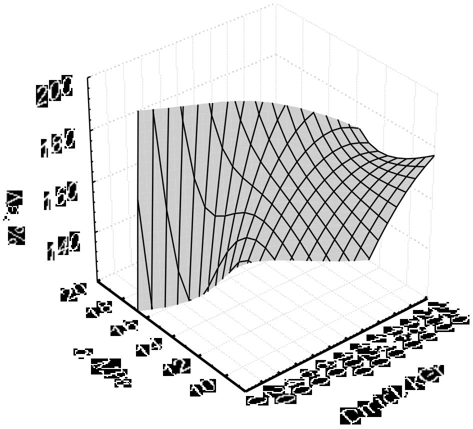

Fig. 6. The effect of the average absorbed dose on the mechanical tensile strength and elongation at break of the polymer protective sheath during radiation exposure of cable samples

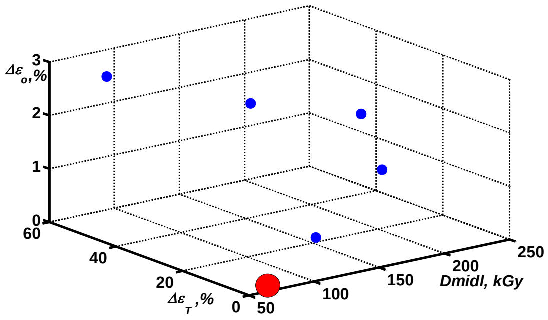

Fig. 7. Resistance to heat distortion ($\Delta\varepsilon_T$) under load and residual strain ($\Delta\varepsilon_o$) after removal of the load of samples depending on the average absorbed dose

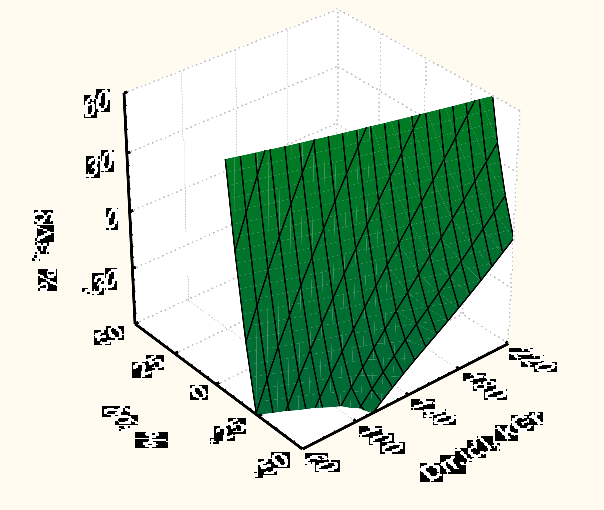

Fig. 8. The effect of the average value of the absorbed dose on the deviation of tensile strength ($\delta\Delta\varepsilon$) and relative elongation ($\delta\sigma$) after holding the samples in oil

The effect of the average value of the absorbed dose for 4 strips of each cable sample on the physical-mechanical characteristics after exposure to oil at a temperature of 100 °C for 24 h is shown in Fig. 8. Optimal oil resistance characteristics are achieved after irradiation with an absorbed dose of 160…170 kGy. With such an absorbed dose, the deviation of the tensile strength, elongation and thermal deformation relative to the initial values are within acceptable limits.

CONCLUSIONS

Performed studies of the distribution of the absorbed dose using standard samples of electron radiation indicate irregularity of radiation around the cable perimeter, which is up to 20…30% with a technological dose in the range of 1.25…0.5.

The irradiation along the cable is more uniform: the deviation of the average absorbed dose between standard specimens placed along the length of the sample does not exceed 5% at a technological dose in the range of 1.25…0.567.

With a decrease in the technological dose (irradiation coefficient), the irregularity of irradiation around the perimeter and length of the cable increases.

The stability of oil resistance results directly depends on the uniform irradiation of the sheath. With uniform irradiation with a dose of 157…160 kGy, consistently high oil resistance results were obtained. With the heterogeneity of the absorbed dose along the cable perimeter, there is a variation in oil resistance.

Optimal and physical-mechanical characteristics of the polymer shell made of halogen-free material are provided under irradiation in a fairly narrow range of the absorbed dose: from 160 to 170 kGy.

REFERENCES

1. E.E. Finkel, S.S. Leschenko, R.P. Braginsky *Radiation chemistry and cable technology*. M.: “Atomizdat”, 1968, p. 313.
2. A.J. Berejka Radiation response of industrial materials: Dose-rate and morphology implications // *Nuclear Instruments and Methods in Physics Research*. 2007, v. B 261, p. 86-89.
3. G.V. Bezprozvannych, B.G. Naboka, E.V. Morozova. Radiation resistance of cables for general industrial use // *Electrical engineering and electromechanics*. 2006, N 3, p. 82-86.
4. M.R. Cleland. *Power Electron Accelerators for Industrial Radiation Processing. of Polymers*. New York: Hanser Publishers, Munich and Oxford University Press, 1992, 23 p.
5. N. Studer. Electron beam crosslinking of insulated wire and cable: Process economics and comparison with other technologies // *Radiation Physical Chemistry*. 1990, N 35, p. 680-686.
6. A.V. Bubley, N.K. Kuksanov, V.E. Dolgopolov. Launching the system of quadrilateral irradiation with electrons for cable and tubular products // *Elektrotehnika*. 2004, N 3, p. 24-29.
7. I.B. Peshkov. *Materials of cable production*. M.: “Engineering”, 2013, 456 p.
8. G.V. Bezprozvannych, I.A. Mirchuk, Correlation between the electrical and mechanical characteristics of cables with radiation-modified insulation based on a halogen-free polymer composition // *Electrical engineering and electromechanics*. 2018, N 4, p. 54-57.
9. G.V. Bezprozvannych, I.A. Mirchuk. Influence of technological dose of radiation on mechanical and electrical characteristics of polymeric insulation of // *Problems of atomic science and technology*. 2018, N 5, p. 40-44.
10. R.A. Salimov, V.G. Cherepkov, J.I. Colubenko, G.S. Krainov, N.K. Kuksanov. D.C. hiqh power electon accelerators of ELV-series: status, development, applications // *Radiation Physics and Chemistry*. 2000, N 57, p. 661-665.
11. Yu.I. Golubenko, D.A. Kogut, N.K. Kuksanov, PI Nemytov, I.V. Chakin. Information measuring support of electron accelerators ELV and related technological equipment // *Problems of Atomic Science and Technology*. 2012, N 3(79), p. 211-214.
12. M.K. Kamensky, G.I. Meshchanov, A.A. Freak. Fireproof cables and wires. The current state and development trends // *Cables and wires*. 2017, p. 30-35.
13. I.A. Mirchuk. Halogen-free compositions for cable products. Advantages, disadvantages and features of the application // *The Scientific Heritage*. 2018, N 30, p. 32-41.
14. IEC 60092–360:2014 Electrical installations in ships – Part 360: Insulating and sheathing materials for shipboard and offshore units, power, control, instrumentation and telecommunication cables. Edition 1.0, 2014, 54 p.
15. IEC 60092-350:2014 Electrical installations in ships - Part 350: General construction and test methods of power, control and instrumentation cables for shipboard and offshore applications. Edition 4.0, 2014, 114 p.

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РАСПРЕДЕЛЕНИЕ ПОГЛОЩЕННОЙ ДОЗЫ ПО ПЕРИМЕТРУ И ДЛИНЕ ПОЛИМЕРНОЙ ЗАЩИТНОЙ ОБОЛОЧКИ ПРИ РАДИАЦИОННОМ ОБЛУЧЕНИИ СУДОВОГО КАБЕЛЯ

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Выполнено исследование распределения поглощенной дозы по периметру и длине полимерной защитной оболочки на основе безгалогенной композиции в зависимости от технологической дозы радиационного облучения образцов судового кабеля. Установлено, что неравномерность облучения по периметру кабеля может достигать 20…30% при технологической дозе в диапазоне 1,25…0,5. Облучение кабеля по длине более равномерное и не превышает 5% при технологической дозе в интервале значений 1,25…0,567. При меньших значениях технологической дозы неравномерность облучения по периметру и длине кабеля увеличивается. Установлено, что при средней поглощенной дозе 210 кГр защитная полимерная оболочка не соответствует требованиям по относительному удлинению при разрыве. Оптимальные физикомеханические характеристики полимерной оболочки из безгалогенного материала обеспечиваются при облучении в диапазоне поглощенной дозы 160…170 кГр.

РОЗПОДІЛ ПОГЛИНЕНОЇ ДОЗИ ПО ПЕРИМЕТРУ І ДОВЖИНІ ПОЛІМЕРНОЇ ЗАХИСНОЇ ОБОЛОНКИ ПРИ РАДІАЦІЙНОМУ ОПРОМІНЕННІ СУДНОВОГО КАБЕЛЮ

Г.В. Безпрозванних, І.А. Мірчук

Проведено дослідження розподілу поглиненої дози по периметру і довжині полімерної захисної оболонки на основі безгалогенного матеріалу в залежності від технологічної дози опромінення зразків суднових кабелів. Встановлено, що нерівномірність опромінення по периметру кабелю може досягати 20…30% при технологічній дозі в діапазоні 1,25…0,5. Опромінення вздовж кабелю є більш рівномірним і не перевищує 5% при технологічній дозі в інтервалі значень 1,25…0,567. При менших значеннях технологічної дози збільшується нерівномірність випромінювання по периметру і довжині кабелю. Встановлено, що при середній поглиненій дозі 210 кГр захисна полімерна оболонка не відповідає вимогам щодо відносного подовження при розриві. Оптимальні фізико-механічні характеристики полімерної оболонки з безгалогенного матеріалу забезпечуються при опроміненні в діапазоні поглиненої дози 160…170 кГр.