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Resistance evaluation of electrical insulating polymer materials used in flexible cables to operational impact

The article presents the test results of polymer material properties taking into account the possibility of their application for flexible cables insulation. The main types of cable constructions and their operation features are considered. Existing test determination methods of insulation resistance to thermal, mechanical, electrical and environmental conditions are analyzed. Requirements for laboratory equipment and test conditions are given. Evaluation criteria of test results are noted. Experimental evaluation was carried out for change degree in the properties of the main types of electrical insulation materials used currently during the flexible cable production: polyvinyl chloride compound (PVC), rubber, ethylene propylene rubber (EPR), thermoplastic elastomer (TPE), fluoropolymer. Tests were carried out under the influence of high and low temperatures, aggressive environments, ozone, mechanical loads. The main processes that determine the changes in electro-physical, physical and mechanical properties of the studied materials are described. Resistance of EPR, TPE and fluoropolymer insulation to a wide range of temperatures, mechanical loads, diesel fuel and transformer oil are shown. An increased resistance of EPR to ozone was also noted. Rubber and PVC compound did not pass the tests under the influence of low and high temperatures, showed "poor" resistance to aggressive environments, but passed the mechanical stress tests. Recommendations on tests and application of polymer insulation taking into account the specifics of flexible cables working are presented.

Keywords: flexible cables, insulation, sheath, polyvinyl chloride compound, thermoplastic elastomer, fluoropolymer, ethylene propylene rubber, ozone resistance, oil resistance, mechanical strength, tests.

Introduction

Development of power industry, improvement of electrical devices for generation, transmission, distribution and consumption of electrical energy, determines the growing need for cables and wires. Electrical cables improvement is connected with increase of carrying capacity, application of new polymer materials for electric insulation, having considerable technological and operational advantages. At the same time, improving the cable products quality is one of the main tasks due to their mass production, versatility of application and very high material consumption [1].

The flexible cables are one of the main cable types. These cables are used for installation of various electronic units and devices; automation, control and management systems; connection to power grids of mobile mechanisms intended for work in open and underground mines; control of conveyor and lifting equipment, laying of security and fire alarm systems, etc.

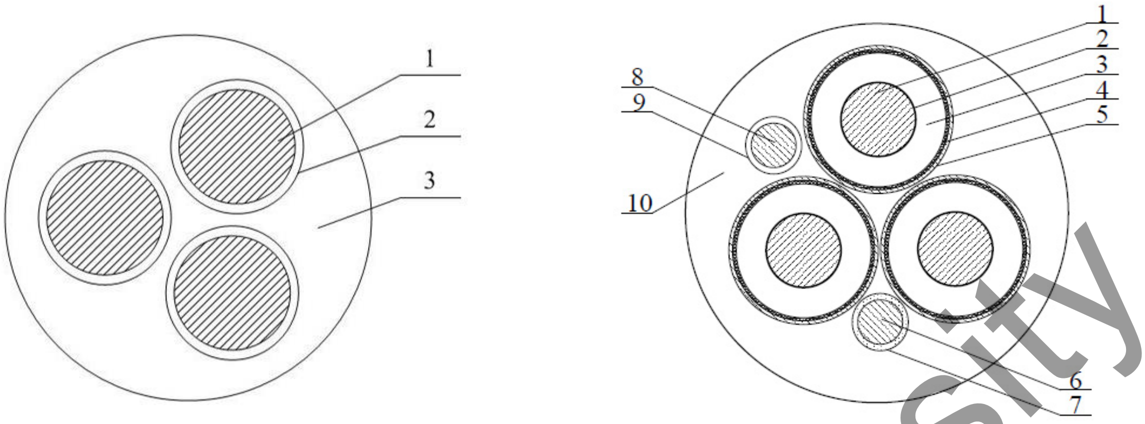
Flexible cables are made with conductors of copper or tinned copper wires. Pure tin or tin-lead alloy is used as tinning material. Depending on the conditions of the cable application, the conductors can be stranded in a core around a central element of rubber or reinforcing aramid fibers. Some cables types are produced with parallel laying conductors. The main typical designs are flexible cables with twisted insulated conductors in the core, with outer jacket (Figure 1 (a)), individual shields over core (Figure 1 (b)), overall shield (Figure 1 (c)), individual shields over core and common shield (Figure 1 (d)) [2].

As can be seen from Figure l, the insulation and sheath are the common element that protects the design of flexible cables from external influences. Reliability and service life are determined by the ability of the polymer material to maintain its integrity and mechanical properties during operation [3].

Rubbers, ethylene propylene rubber, polyvinyl chloride compound (PVC), thermoplastic elastomers (TPE), cross-linked polyethylene (XLPE), and fluoropolymers are used for insulation and sheath of flexible cables [4].

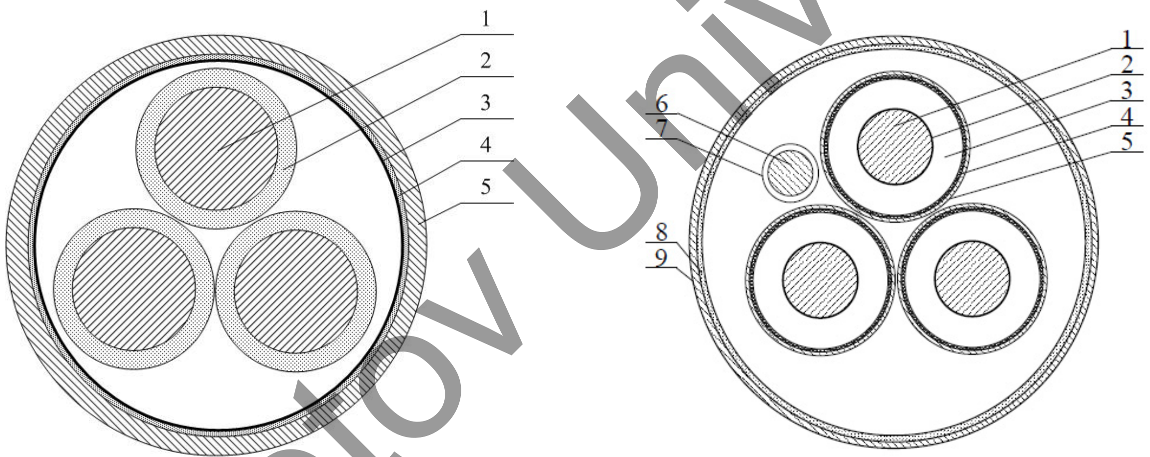
Rubbers have high electrical resistance and moisture resistance. One of the main advantages is elasticity, but most rubbers have low ozone resistance [5].

Ethylene propylene rubber is suitable for use in cables with operating voltages up to 35 kV. The chemical stability of the material, including in relation to ozone and UV radiation, allows to guarantee operation in harsh conditions of industrial plant, subway tunnels, construction site and mining facilities. An important advantage of cables insulated with ethylene propylene rubber is the extended operating temperature range with a lower permissible temperature of — 60 ^{0}C + 90^{0}C [6, 7].



a) 1 — core; 2 — insulation; 3 — cable sheath.

b) 1 — core; 2 — inner conductive shield; 3 — insulation; 4 — outer conductive shield; 5 — metal shield; 6,8 — grounding wire; 7,9 — grounding wire insulation; 10 — cable sheath.



c) 1 — core; 2 — insulation; 3 — inner sheath; 4 — shield; 5 — outer cable sheath.

d) 1 — core; 2 — inner conductive shield; 3 — insulation; 4 — outer conductive shield; 5 — metal shield; 6 — grounding wire; 7 — grounding wire insulation; 8 — overall shield, 9 — cable sheath.

Figure 1. The main designs of flexible cables

PVC is a colorless, transparent plastic, thermoplastic polymer of vinyl chloride. It is characterized by chemical resistance to alkalis, acids and solvents, moisture resistance, sufficient flexibility, relative resistance to solar radiation. However, it should be noted that the aging of cable made of PVC is much faster. Permissible operating temperature of 70 ^{0} C. With further increase in temperature heating begins to release harmful hydrogen halogen chloride, which is dangerous to humans [8].

Thermoplastic elastomers combine the high elastic properties of rubbers and the ability to melt above the yield point and be processed by extrusion. The advantages of TPE in comparison with rubbers are as follows: reduction of material intensity due to lower density, increase in productivity and reduction of labor and energy costs during processing. The disadvantage as compared to rubbers in terms of application in cables and wires is an inherent ability of any thermoplastic material to melt at high temperatures. They have a higher cost: their formulation cannot be "diluted" with more fillers. In addition, TPEs have insufficient chemical resistance and heat resistance [9].

Polyethylene has a high chemical resistance to acids, alkalis and various chemical liquids. However, at high temperatures PE swells or even dissolves in toluene, benzene, carbon tetrachloride. PE at room temperature is resistant to nitric acid, but at +50 ^{0}C is completely destroyed after two days of exposure to this acid. The mechanical characteristics of PE are related to its molecular weight, degree of branching and crystallinity [10, 11].

Fluorine-containing polymers are characterized by high heat resistance, high electrical insulation properties, chemical and corrosion resistance. In addition, they have good weather ability and high frost resistance, low friction coefficient, low water absorption and gas permeability, high electrical strength. They have temperature operation in the range from — 269 ^{0}C to + 260 ^{0}C. Fluoropolymers are insoluble or poorly soluble in many organic solvents, resistant to acids, alkalis, oil products. The disadvantages are high cost, difficulties in processing in the cable industry [12].

Depending on the purpose and operating conditions, flexible cables must be resistant to a wide range of operating temperatures, mineral oils and diesel fuels, electrical voltages, mechanical loads and other factors (Figure 2) [13-15].

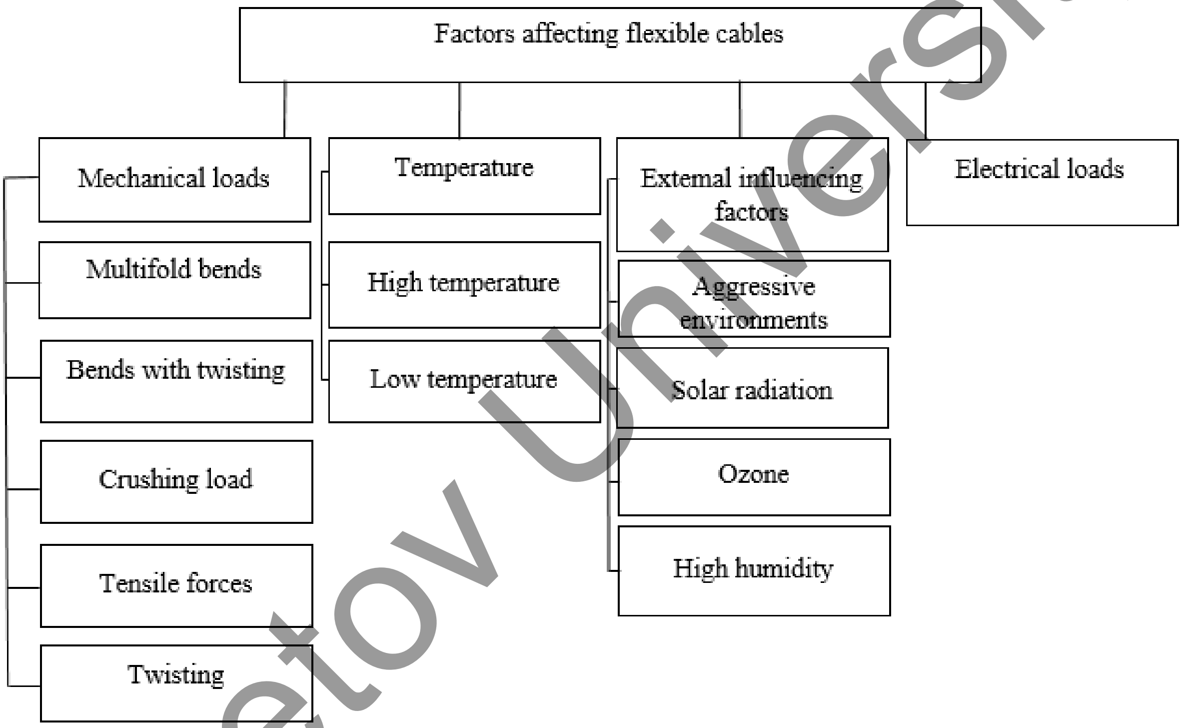


Figure 2. Factors affecting flexible cables

Thus, the reliability of electrical equipment is generally determined by the quality and reliability of cable design. At another point, polymer insulation is an element determining the flexible cables reliability during operation.

There are several methods to assess the performance flexible cables properties according to criteria:

– mechanical loads (multifold bends, bends with axial torsion, crushing loads, tensile force);
– electrical loads;
– external factors (high, low temperatures).

Determining the methods in formativeness, taking into account the significance for each flexible cables types, will simplify the task of selecting electrical insulation materials and reduce the time spent on the stage of preliminary tests.

Overview of flexible cables test methods

A generalized analysis of the test methods for the resistance of flexible cables to the operational effects is given in Table 1.

Table 1

Test methods for flexible cables

Type of test	Test method	Evaluation criterion (result)
Multifold bending resistance [16]	Cable samples are fixed in the clamping device and bent around the cylinder at an angle of $\pm\pi/2$ with a load creating a pressing force. Sample length, load weight, number of bending cycles and rollers diameter should be specified in the technical documentation for cables.	High voltage test, no cracks on the insulation and sheath surface, the number of wire breaks and metal shields should not exceed 30 %.
Multifold bendig resistance trough a roll system [17]	Tests are carried out on samples with a length of at least 3.5 m, with the application of current load to the cable at rated alternating voltage with frequency of 50 Hz specified in the normative document. Cable samples are fixed on a device consisting of a carriage with exchangeable rollers, a mechanism providing end-to-end motion, a tensioning device or a set of weights and clamps limiting the sample movement. Number of bending cycles, rollers diameter shall be specified in the specifications for cables.	No current interruption, no short circuit between conductors, no short circuit between sample and stand rollers.
Bending resistance with twisting [18]	Tests are carried out on samples with a length of at least 3.5 m. Samples of cables are fixed on a device consisting of a clamp with end-to-end motion, a mechanism ensuring rotation of the clamp. The test specimen is clamped at one end of the clamp and a load is hung at the other end. The test cycle consists of the clamp rotating in full turn, the specimen must be bent along a given radius at all points alternately contacting with the clamp as it rotates.	Overvoltage test, visual inspection.
Crushing resistance [19]	The test consists in compressing the sample between the dies. The dies form, the pressure value on the sample, the mutual arrangement of dies and the sample between them must be specified in the regulatory documentation for the cables.	No short circuit between conductors or between conductors and shield.
Resistance to high temperature impact [20]	Tests are carried out on three cable samples coiled in coils with an inner diameter not exceeding three minimum allowable bending radius during operation. Time and temperature of tests should be specified in the normative document on cables.	No cracks on the insulation and sheath surface, insulation resistance must meet the requirements of regulatory and technical documentation.
Resistance to low temperature impact [21]	Depending on the nominal cross section of conductors, the test procedure is different. For cables with an outer diameter of up to 12.5 mm, the samples are kept for at least 4 h and wound on a metal rod. The diameter of the rod, the windings number are chosen depending on the outside cable diameter. For cable products with a diameter of more than 12.5 mm, the samples are kept in a cold chamber for at least 4 h. After exposure, the sample must be subjected to three bending cycles around the rollers in opposite directions at an angle of at least 90^0. The bending cycle shall include right (left) bending, straightening, left (right) bending and straightening. Rollers diameter, test temperature shall be specified in the regulatory documentation for cables.	Over-voltage test, no cracks on the insulation and sheath surface.
Resistance to temperature changes [22]	The tests are carried out by three consecutive cycles on three samples coiled in coils. Coil diameter, cycles number and test temperature shall be specified in the specifications of the cables.	Overvoltage test, no cracks on the insulation and sheath surface.
Resistance to solar radiation [23]	Tests are carried out on three cable samples with a length of at least 1 m. Samples are placed in the chamber, turn on the radiation source, and then set the temperature in the chamber (in the shade) $55\pm2\ ^0$C. Exposure time is 5 days.	No cracks on the insulation and sheath surface.
Ozone resistance [24]	The samples are placed in a test chamber with an ozone concentration of at least 0.0015 % and withstood for at least 180 min. The samples are bent at ambient temperature around	No cracks on the insulation and sheathing surface.

Type of test	Test method	Evaluation criterion (result)
	a brass, aluminum or wooden rod. The bent samples together with the rod are kept in the air at ambient temperature without any additional treatment for 30-45 min before starting the tests. The samples are then kept in a desiccator for at least 16 h at (23±5) ^{o}C. Both ends are fixed in the clamping device, stretch it by (33±2) % and leave in this device.	
Oil resistance [25]	Tests are carried out in the environment of industrial oil I-40A or I-50A according to GOST 20799 or diesel fuel. Exposure time and heating temperature of oil (diesel fuel) must be specified in technical conditions for specific cable brands.	The deviation of tensile strength and elongation at break before and after exposure does not exceed 40 %.
Resistance to high air humidity [26]	Tests are carried out on three cable samples with a length of at least 2 m. Cable samples are placed in the moisture chamber. Temperature, humidity and holding time shall be specified in the regulatory document for the cables.	No cracks on the insulation and sheath surface, insulation resistance must meet the requirements of regulatory and technical documentation.
Determination of physical and mechanical characteristics after exposure to high and low temperatures [27], [28]	Measurement of physical and mechanical characteristics is carried out on samples in the form of double-sided blades. The number of samples should be at least 5 for each test point.	The change in relative elongation and tensile strength should be no more / no less (%), must comply with the requirements of regulatory and technical documentation.

Depending on the purpose of the flexible cables, some or other methods are used in various combinations.

Methodical part

The representatives of the main groups of electrical insulating polymer materials currently used for manufacture of flexible cables were selected as the test object: rubber, EPR, PVC, polyolefin and urethane TPE, photopolymer.

The choice of test method is determined by standards recommendations, depending on the type of operational impact (Table l).

Test conditions and equipment requirements are stipulated in the regulatory and technical documentation: rollers, cylinders for cable coiling test and cable bending test through a roll system (error of measurements ± 0.5 %), equipment for testing cables through a roll system (measurement error of ± 10 %), breaking machines (measurement error of ± 0.5 %), climatic chamber of heat/cold (measurement error of ± 3 ^{0}C) micrometer (measurement error of ± 0,01 mm), microscope (measurement error of ± 0,003 mm), high-voltage tester (measurement error of ± 3 %), ozone resistance tester for rubber and cables (measurement error of ±10 %).

Experimental part

Heat resistance tests

Heat resistance is the ability of materials to maintain performance properties at high temperatures.

Temperature is a common factor affecting all cables. Thermal heating of insulation occurs due to dielectric losses when electric current flows through conductors and exposure to external ambient temperature. Long-term exposure to temperature leads to insulation aging and its gradual degradation with deterioration of physical, mechanical and electrical properties of the material, which ultimately reduces the service life.

Samples of cables without mechanical damage, cracks, pollutions and defects according to [27, 28] were selected for testing. Ageing time was 168 h. Test temperature was selected in accordance with the normative documents for flexible cables.

Evaluation criterion is the change in physical and mechanical characteristics not more than ±20 %. Aging temperature and evaluation results are shown in Table 2 and Figure 3.

Table 2

Aging temperature of polymeric materials

Insulation materials	Rubber	EPR	PVC	TPE (polyolefin, urethane)	Flouropolymers
Aging temperature, °C	80	135	100	100	280

Cold resistance tests

Implementation of programs for the Arctic region development determines the increased demand for cable products that are resistant to low temperatures.

The cables cold resistance is determined by the choice of electrical insulating polymer materials. It is the cable insulation fault that determines its breakdown at critically low temperatures. Compound frost resistance is the ability to maintain its performance properties at specified negative temperatures. Frost resistance criteria may be different depending on the requirements related to the conditions of its application. There are limited reductions of deformability or limited increase of frost resistance, absence of brittleness for insulation and sheath of cable products. The choice of polymer materials mainly has a significant impact on the operation efficiency and cable line reliability.

Three samples with a cable length of 1.5 m without mechanical damage, cracks, pollutions and defects were selected for testing according to [21]. Each sample was wound on a metal rod after 4 hours of staying in a cold chamber. The test temperature was from -10 to -60 ^{0}C. The coils number was selected based on the cable product diameter.

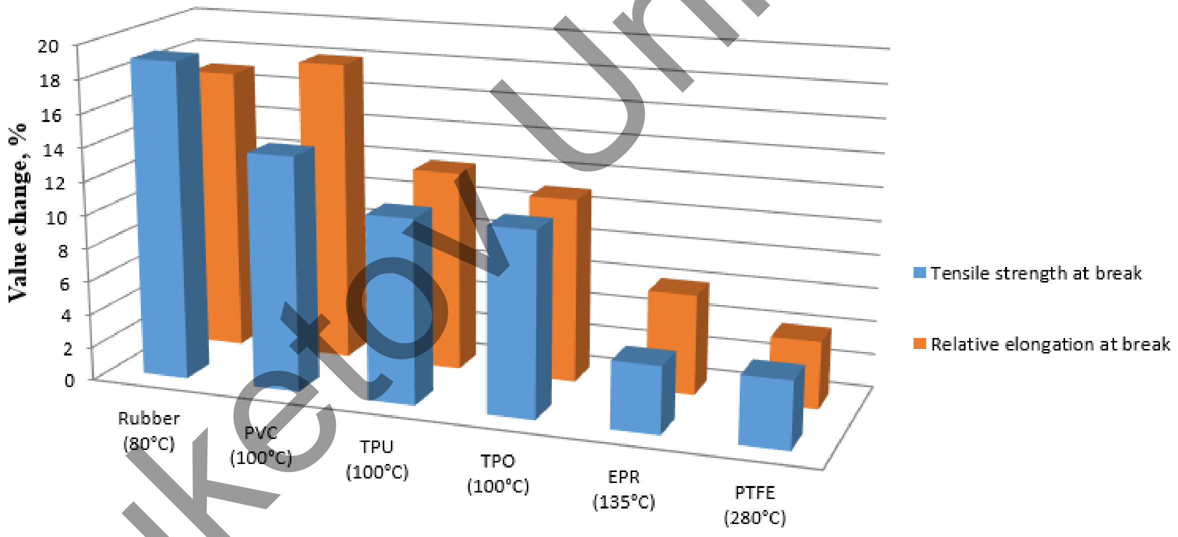


Figure 3. Physical and mechanical properties after thermal aging (test temperature indicated)

The evaluation criterion is the absence of cracks on the samples surface (Table 3).

Table 3

Installation bend resistance test results

Temperature, ºC	Material					
	EPR	PVC	Polyolefin TPE	Urethane TPE	Rubber	Fluoropolymer
-10	+	+	+	+	+	+
-15	+	+	+	+	+	+
-30	+	+	+	+	+	+
-40	+	-	+	+	+	+
-50	+	-	+	+	-	+
-60	+	-	+	+	-	+

Determination of cable resistance to the low temperature impact was also determined indirectly [27, 28] by determining the change in physical and mechanical characteristics (Table 4). The exposure time of the samples in the cold chamber was 4 h. Test temperature was chosen in accordance with the technical guide for flexible cables. Samples in the form of a double-sided blades were fixed in the tensile machine within the cold chamber. After the set exposure time, the relative elongation at break *Δl/l* was determined.

Evaluation criterion — the relative elongation must be at least 20 %.

Table 4

Elongation value after low temperature impact

Temperature, °C	Material					
	EPR	PVC	Polyolefin TPE	Urethane TPE	Rubber	Fluoropolymer
-10	345 %	150 %	230 %	304 %	240 %	295 %
-15	334 %	102 %	210 %	295 %	180 %	289 %
-30	320 %	60 %	198 %	288 %	90 %	270 %
-40	307 %	-	156 %	270 %	40 %	268 %
-50	306 %	-	121 %	260 %	-	268 %
-60	302 %	-	120 %	251 %	-	267 %

Oil resistance test

Low-voltage cables are operated in conditions where the sheath and insulation are exposed to many factors simultaneously, including the aggressive environment impact. In production and transportation, liquid hydrocarbons exposure (diesel fuel (DF) and transformer oil (TO)) is one of the most important aging factors for low-voltage cables. To a greater extent, the cable service life depends on the sheath ability to withstand these fluids action.

The polymer materials oil resistance evaluation was carried out according to the results of change in tensile strength (σ_p) and change in relative elongation (*Δl/l*) after soaking samples in diesel fuel and transformer oil. The methodology recommended by [25, 27] was taken as the basis. Ageing time was 1000 hours, every 50 hours a batch of samples was taken out, and σ_p и *Δl/l* were determined. Aging time and evaluation results are shown in Figure 4 and Figure 5.

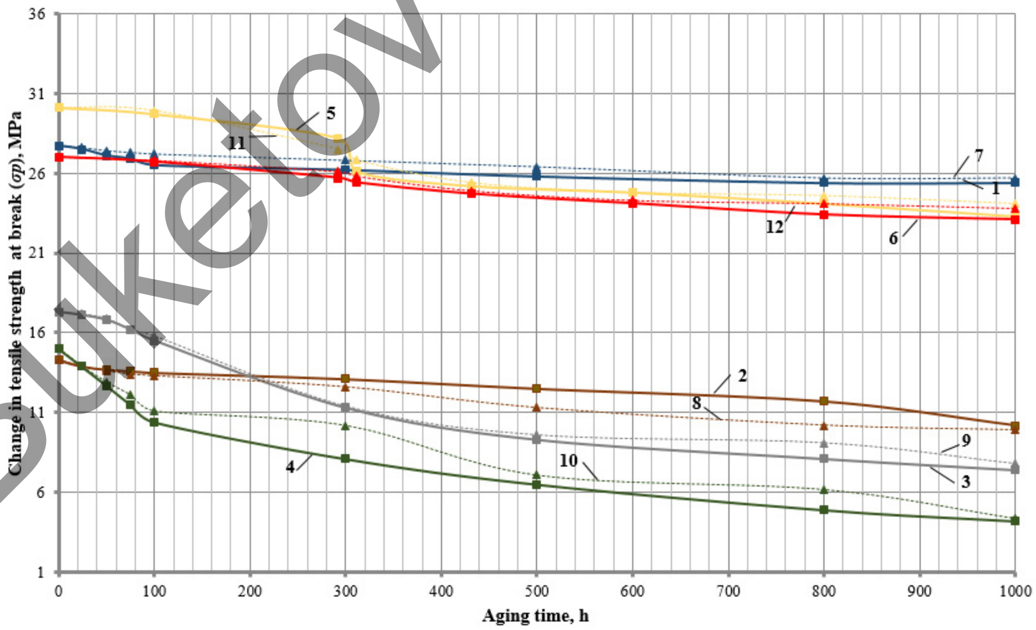


Figure 4. The tensile strength at break (σ_p) as a function of ageing time in diesel fuel and transformer oi, where 1 is PTFE in DF; 2 is PVC in DF; 3 is EPR in DF; 4 is rubber in DF; 5 is TPU in DF; 6 is TPO in DF; 7 is PTFE in TO; 8 is PVC in TO; 9 is EPR in TO; 10 rubber in TO; 11 is TPU in TO; 12 is TPO in TO.

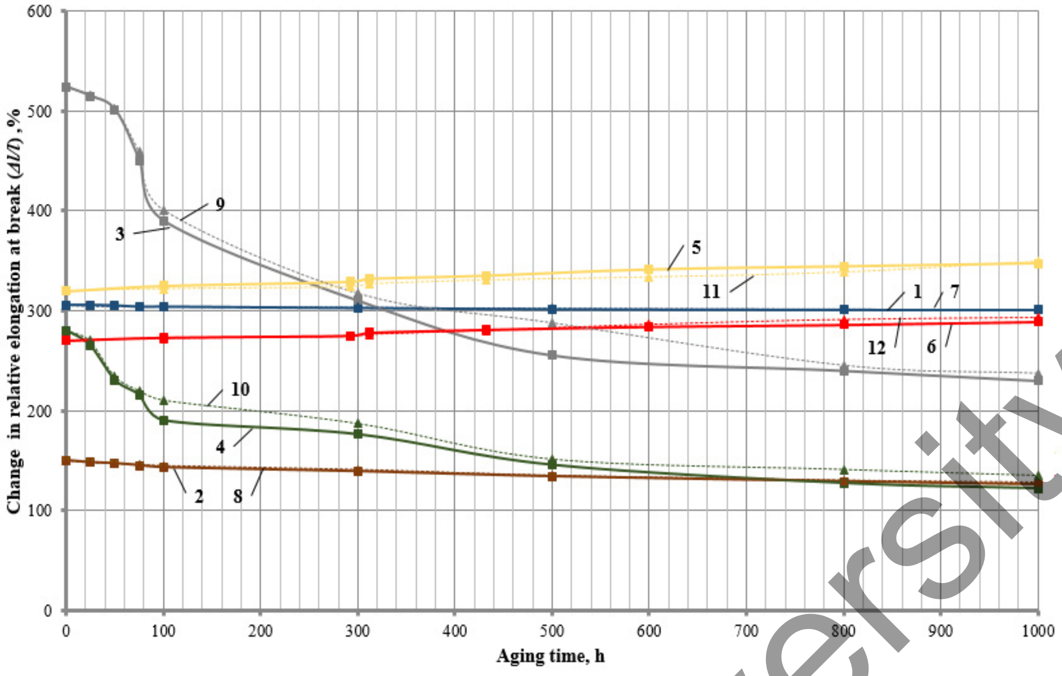


Figure 5. The relative elongation at break (*Δl/l)* as a function of aging time in diesel fuel and transformer oil, where 1 is PTFE in DF; 2 is PVC in DF; 3 is EPR in DF; 4 is rubber in DF; 5 is TPU in DF; 6 is TPO in DF; 7 is PTFE in TO; 8 is PVC in TO; 9 is EPR in TO; 10 is rubber in TO; 11 is TPU in TO; 12 is TPO in TO.

Ozone resistance tests

Ozone resistance is the ability of insulating material or insulation to remain in an atmosphere with high ozone content without damage or significant deterioration of properties [29]. Ozone exposure leads to accelerated aging and degradation of rubbers, and to a much lesser extent plastics. Ozone is especially dangerous for rubber-insulated/sheathed cables used outdoors, as even small ozone concentrations (e.g. after a thunderstorm) will cause the crack insulation. Because rubber-insulated/sheathed cables are flexible and designed to be connected to moving electrical equipment (walking excavators, industrial robots, etc.), they are often subjected to bending. Ozone exposure causes the crack insulation at the point of bending, causing the insulation to break and exposing the conductors.

Rubber and EPR aging were carried out for 8 hours with sample removal at 3, 5, and 8 hours, with an ozone concentration of 0.015 % according to [24]. At the end of the aging time, physical and mechanical characteristics were measured and visual inspection was performed. Results of ozone resistance tests of EPR and rubber are shown in Table 5.

Table 5

Results of ozone resistance tests of EPR and rubber

Aging time (hours)	EPR		Rubber	
Physical and mechanical characteristics	*σp*, MPa	*Δl*, %	*σp*, MPa	*Δl*, %
Aging temperature (150 ºC)				
0	5,5	348	Sample break (after 45 minutes the samples are completely destroyed)	
3	5,9	280		
5	5,9	280		
8	5,9	280		

Mechanical load tests

As a rule, flexible cables break down not as a result of electrical loads, but because of dynamic effects. Therefore, it is important to ensure equal strength of all design elements: core, insulation, shields and protective sheath under mechanical influences.

Tests are regulated by [17]. Tests are carried out on samples with a length of 5 m under current loading applied to the cable. Number of bending cycles is 30000. Evaluation criterion: there should be no short circuit between the conductors, short circuit between the sample and the stand rollers. Tests results for mechanical loads are shown in Table 6.

Table 6

Tests results for mechanical loads

Number of cycles	Material					
	EPR	PVC	Polyolefin TPE	Urethane TPE	Rubber	Fluoropolymer
30000	+	+	+	+	+	+

Results and Discussion

1. The existing approach makes it possible to effectively assess the polymer insulation heat resistance both at the stage of cable products manufacturing and during the incoming inspection of materials. After thermal aging all materials showed satisfactory resistance. Change of physical and mechanical characteristics was not more than 18 %. It is quite admissible, as according to normative and technical guide of cables with similar electric insulating materials the change of properties by more than ± 20 % is critical.

2. After low temperature exposing to materials (as PVC -30ºC, rubber -40ºC, thermoplastic elastomers, EPR and fluoropolymer -60ºC) relative elongation change $\Delta l/l$ of samples from EPR, TPE and fluoropolymer is insignificant. At the same time insulation materials from rubber and PVC also have not passed tests at temperatures from -40 to -60ºC in connection with "embrittlement" of materials.

3. Physical and mechanical properties changing after exposing to aggressive environments fully enough indicates the ability of the material and the design as a whole, to resist the action of hydrocarbon liquids. Among the polymers considered, fluoropolymer is the most resistant. Fluoropolymer samples showed "good" resistance to the action of both diesel fuel and transformer oil. The tensile strength changing at break σ_p and relative elongation $\Delta l/l$ does not exceed 10 %. Resistance of fluoroplastic to hydrocarbon liquids is explained by high value of bonding energy "carbon-fluorine", by specific structure of polymer macromolecules expressed in the fact that fluorine atoms completely "screen" the carbon skeleton of macromolecules [30-31]. Samples made by rubber and ethylene propylene rubber, thermoplastic elastomers showed "poor" resistance to aggressive media. The change of physical and mechanical characteristics was about 37 %. However, such values are admissible due to the fact that in normative and technical documentation the evaluation criterion is the change of physical and mechanical characteristics by not more than 40 %. Samples from PVC were not passed, as the change in relative elongation was more than 50 %. These materials are weakly polar. The polymers chemical nature affects the diffusion rate of physically aggressive environment into them. Weak resistance of samples to penetration of hydrocarbon liquids means that there is a high affinity between the polymer molecules and the aggressive environment (diesel fuel, transformer oil), the measure of which is the change in free energy. The greater the decrease in free energy during mixing, the more hydrocarbon liquid penetrates into the polymer. The dissolution intensity of polar liquids in polar materials significantly exceeds the dissolution intensity in non-polar materials [32].

4. The ozone effect on rubber in its destructive power is one of the most aggressive. Ozone aging of rubber is expressed in the appearance of characteristic cracks on the surface and loss of the original physical and mechanical characteristics and other properties. The resistance of ethylene propylene rubber is due to the insignificant content of double bonds.

5. All polymer materials have successfully passed the test for mechanical tests. This approach makes it possible to evaluate not only the properties of the materials, but also the reliability of the design as a whole.

Conclusions

According to the test results, promising materials for insulation and sheath of flexible cables can be identified:

- EPR, TPE and fluoropolymer for use in flexible cables operating at low and high temperatures, as well as when exposed to hydrocarbon liquids;
- EPR as insulation and sheath of flexible cables operating under ozone exposure.

The success of the passed tests with all samples confirms the correctness of the preliminary selection.

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Икемді кабельдерге қолданылатын полимерлі электр оқшаулағыш материалдардың эксплуатациялық әсерлерге төзімділігін бағалау

Мақалада оқшаулау ретінде икемді кабельдерді пайдалану мүмкіндігін ескере отырып, полимерлі материалдардың қасиеттерін зерттеу нәтижелері берілген. Кабельдік бұйымдардың құрылымдарының негізгі түрлері және олардың жұмыс істеу ерекшеліктері қарастырылған. Оқшаулаудың жылу, механикалық, электрлік және сыртқы әсер етуші факторларға төзімділігін тәжірибелік анықтаудың қолданыстағы әдістеріне талдау жүргізілген. Зертханалық жабдыққа қойылатын талаптар және сынақ жағдайлары сипатталған. Сынақ нәтижелерін бағалау критерийлері атап өтілген. Қазіргі уақытта икемді кабельдер өндірісінде қолданылатын электр оқшаулағыш материалдардың негізгі түрлерінің қасиеттерінің өзгеру дәрежесін эксперименталды түрде анықтау жүргізілді: поливинилхлоридті пластикат (ПВХ-пластикат), резеңке, этиленпропиленді резеңке (ЭПР), термопластик (ТЭП), фторполимер. Сынақтар жоғары және төмен температуралардың, агрессивті орталардың, озонның және механикалық жүктемелердің әсерінен жүргізілді. Зерттелетін материалдардың электрофизикалық және физика-механикалық қасиеттерінің өзгеруін анықтайтын негізгі процестер сипатталған. ЭПР, ТЭП және фторполимерлі оқшаулау температураның кең диапазонына, механикалық жүктемелерге, дизельдік отынға және трансформатор майына төзімді екені көрсетілген. Сондай-ақ ЭПР озонға төзімділігінің жоғарылауы байқалды. Резеңке және ПВХ-пластикат төмен және жоғары температура әсерінен сынақтардан өтпеді, сонымен қатар агрессивті орталарға «нашар» қарсылық көрсетті, бірақ, өз кезегінде, механикалық әсер кезінде сынақтардан өтті. Икемді кабельдердің ерекшеліктерін ескере отырып, полимерлі оқшаулауды сынау және қолдану бойынша ұсыныстар жасалған.

Кілт сөздер: икемді кабель, оқшаулау, қабық, ПВХ пластикат, термоэластопласт, фторполимер, этиленпропиленді резеңке, озонға төзімділік, майға төзімділік, механикалық беріктік, сынақтар.

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Оценка стойкости полимерных электроизоляционных материалов, применяемых в гибких кабелях, к эксплуатационным воздействиям

В статье приведены результаты исследования свойств полимерных материалов с учетом возможности применения в качестве изоляции гибких кабелей. Рассмотрены основные типы конструкций кабельных изделий и особенности их эксплуатации. Проведен анализ существующих методов экспериментального определения стойкости изоляции к тепловым, механическим, электрическим и внешним воздействующим факторам. Описаны требования к лабораторному оборудованию и условиям проведения испытаний. Отмечены критерии оценки результатов испытаний. Проведено экспериментальное определение степени изменения свойств основных типов электроизоляционных материалов, применяемых в настоящее время при производстве гибких кабелей: поливинилхлоридный пластикат (ПВХ–пластикат), резина, этиленпропиленовая резина (ЭПР), термоэластопласт (ТЭП), фторполимер. Испытания были проведены при воздействии повышенных и пониженных температур, агрессивных сред, озона, механических нагрузок. Описаны основные процессы, определяющие изменение электрофизических и физико-механических свойств исследованных материалов. Показано, что ЭПР, ТЭП и фторполимерная изоляция обладают стойкостью к воздействию широкого диапазона температур, механических нагрузок, устойчивы к воздействию дизельного топлива и трансформаторного масла. Также отмечена повышенная устойчивость ЭПР к воздействию озона. Резина и ПВХ–пластикат не прошли испытания при воздействии пониженных и повышенных температур, а также показали «плохую» устойчивость к воздействию агрессивных сред, но, в свою очередь, прошли испытания при механических воздействиях. Сделаны рекомендации по испытаниям и применению полимерной изоляции с учетом специфики работы гибких кабелей.

Ключевые слова: гибкие кабели, изоляция, оболочка, поливинилхлоридный пластикат, термоэластопласт, фторполимер, этиленпропиленовая резина, озоностойкость, маслостойкость, механическая прочность, испытания.

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