CHOSEN VIEWS ON CABLE WITH IMPROVED FIRE PERFORMANCE

J. Packa[1], V. Šály[1], J. Sulová[2]

[1]Slovak University of Technology, FEI STU, Ilkovičova 3, 812 19 Bratislava, Slovakia

[2]VUKI a.s., Rybničná 38, 831 07 Bratislava, Slovakia

Abstract

Currently, the fire protection of property and human health are an integral part of buildings security. We cannot neglect the reliability and long-term stability of cable systems which are important for safety, service and economic return on investment, too. For these purposes flame retardant and fire resistant cables are used in cable installation of buildings. Changes of dielectric properties may be related with modifications of insulation in order to limit smoke, fumes and halogens or improve their fire resistance. Manufacturers declare tests in compliance with valid standards. According to our experiences these tests need not verify real life time during operation or unexpected events such as flooding or current overload. The paper deals with application of cables with enhanced fire performance according to standards in Slovakia. The influence of the rated voltage during immersion in the water on insulation resistance and breakdown voltage of insulated cores with different flame barriers in the laboratory conditions are presented, too.

Keywords: *water immersion, dielectric properties, fire performance, cables, testing, flame barriers*

1. INTRODUCTION

Nowadays, there is an increasing emphasis on the fire safety of buildings. Generally, fires cause fatalities, health harm and enormous material damages. For this reason, it is understandable that the efforts of science, research and technical practice are aimed at preventing fires and minimizing their consequences.

The technical standardization is an important tool for increasing fire safety. Slovakia is the EU leader in the field of fire safety of buildings because a relatively extensive national system of fire safety requirements for electrical installations has been established.

It is necessary to combine passive and active fire protection for minimizing fire damages. The passive protection includes solutions for suitable building products and structures that do not contribute to the spread of fire. Active protection is related to activities important for fire detection, alarm announcement, activation of automatic extinguishing systems, etc.

An important part of fire safety of buildings is cable system which is an integral part of buildings. Currently, we could not imagine modern life without electrical equipment and systems which are supplied by cable systems.

Although cables are not always the cause of a fire, they are undoubtedly a potential danger even in cases where the fire occurs for completely different reasons.

The reasons which start a fire is often:

- overheating cables or their parts – the hot materials burns easier
- local overheating, e.g. damaged joints or mechanically damaged insulation(short circuit)
- direct ignition of outdoor spaces, e.g. activity near cable trays (welding)
- failed circuit protection (overload)

Cables and cable systems can contribute to the fire itself in various ways. It depends on their construction, insulation and sheathing materials, ways of installation and their total amount within the area, etc.

Practically, only Mineral Insulated Metal Sheath (MIMS) cables represent a negligible fire hazard. MIMS cables are inorganic and contain no combustible materials. Given cables can withstand very high temperatures, cannot generate halogen and smoke, toxic gasses and propagate flame. In addition, MIMS cables with the copper jacket, mineral insulation (magnesium oxide, beryllium oxide, calcium carbonate, powdered glass, etc.) and copper conductors have a zero fuel-load. Copper MIMS cables can operate continuously at up to 250 °C and short periods of time at temperatures up to 1083 °C, the melting point of copper. This property enables them to continue operating in a fire, supplying power to essential services and, in many cases, afterwards to remain in working condition. Alternatively, the metal sheath can be made of copper or cupro-nickel and stainless which finds increasing application in aggressive environments. Optional protection against some kind of chemical attacks can be provided by outer covering made of a thermoplastic material such as PVC, polyethylene or halogen-free polyolefin, too [1].

Most cable insulations are made from polymers. Polymeric insulated cables have been used in buildings and industries because of their good mechanical, electrical and chemical properties. But these cables, as all organic materials, are more or less flammable. The flammability can be indicated by measures such as the flash ignition temperature, the self-ignition temperature, the limiting oxygen index and temperature index.

The limiting oxygen index (LOI) is proportion of oxygen in the atmosphere for which the combustion of a material can be sustained at room temperature and is determined by standardized tests. Of course, the limiting oxygen index varies and materials with an LOI greater than the atmospheric oxygen concentration are called fire retardant materials. A number of polymers are inherently flame retardant. For instance, there are some LOI of insulation materials: polyethylene 18 %, ethylene-propylene rubber (EPR) 18 %, chlorosulphonated polyethylene (CSP) 27 %, silicone rubber 26-39 %, polyvinyl chloride (PVC) 47 %, polytetrafluoroethylene (PTFE) 95 % [2].

It should also be taken into account that the flammability is not the only important property, but we must consider all aspects of a materials fire behavior. Large quantities of plastic polymers in the cables can represent a significant fire risk. The fire risk is greater when the cables are not hidden or embedded in the construction. They can spread of fire from one part of building to another and their toxic combustion products, smoke density as well as corrosivity can have fatal consequences for the evacuation of people, also.

2. CABLES PROPERTIES REQUIREMENTS IN FIRE CONDITIONS

2.1. General

Currently, the share of cables and cable insulation with enhanced fire properties in the field of cable technology is growing. This trend is directly linked to a number of catastrophic events such as Kitzsteinhorn (underground funicular railway 2000), Düsseldorf (airport 1996), London (underground 1987) where extensive material damage were caused and many people died.

In general, from the point of view of fire safety, the requirements for cable and cable systems can be divided into two basic areas.

The first one is related to the impact of cable installations in a fire. In this context, we can mention the properties such as flammability (spread of fire), smoke evolution, toxicity and corrosivity, etc.

The second area of requirements is maintained the circuit integrity for important systems and equipment in a fire. These systems, such as fire-technical and technological equipment, signaling and control circuits, emergency lighting etc., are related to evacuation of people.

With regard to the application possibilities of cables with enhanced fire properties, it should be emphasized that given cables and cable systems in some cases must cover both mentioned areas of requirements. These requirements are more stringent than they were in the past and this trend will likely continue in the future.

European legislation supports this effort, as well. Specifically, regulation (EU) No 305/2011 of the European Parliament, Construction Product Regulation (CPR) [3] is stated in basic requirements for construction works as a whole that they must be designed and built in such a way that in the event of fire:

- the load-bearing capacity of the construction can be assumed for a specific period of time,
- the generation and spread of fire and smoke within the construction works are limited,
- the spread of fire to neighboring construction works is limited,
- occupant scan leave the construction works or be rescued by other means,
- the safety of rescue teams is taken into consideration.

The cables which are permanently incorporated into a building are also construction products. They are covered by regulation mention above. From the point of view of CPR is fire safety evaluate by two parameters:

- reaction to fire (TRO),
- circuit integrity in fire (fire resistance).

Reaction to fire is the response of a test specimens when it is exposed to fire under specified conditions in a fire test. Fire resistance is regarded as a special case and is not normally considered as a “reaction to fire” property.

2.2. Reaction to fire

Fire classification (EuroClass) using data from reaction to fire tests on electric cables in Slovak republic is given by standard STN EN 13501-6 [4].

The contribution of power, control and communication cables, including optical fibre cables. to the development of a fire is classified on the basis of the heat of combustion, the spread of the flame, the total released heat, maximum heat release rate and fire development rate index (FIGRA) and is supplemented by additional classifications for smoke generation, burning droplets/particles and acidity.

According to STN EN 13501-6:

- **main part of classification** is seven fire reaction cables – Aca, Bca, B2ca, Cca, Dca, Eca, Fca. The Aca class contains non-flammable cables (without effect), while the Fca class contains cables that do not meet the requirements of the Eca class (i.e. with unspecified performance).
- **additional part of classification** is split into three parts:
  - s (smoke) - amount and transparency of smoke released from hot contact, which affects the evacuation time and direct health (value: s1, s1a, s1b, s2, s3, with s3 being the worst),
  - d (droplets) - amount of burning drops that can be used to eliminate the fire (value: d0, d1, d2, with d2 being the worst),
  - a - determination of acid gases release by pH-value and conductivity (value: a1, a2, a3, with a3 being the worst).

The assessment of fire hazard parameters such as heat release, smoke release, or combustion gas corrosivity should be built on performance based test rather than assumed relationships for broad material classifications [5].

Of course, there are different levels of fire performance of cable in the context of their application and installation. In some cases, where there is an acceptable risk of endangering life, health and property, the cables with PVC insulation can also be used. On the other hand, some areas directly require strict requirements forhalogen-freee missions, low smoke and flammability, etc.

The CPR does not make recommendations for the application of cables according to EuroClass, but on the other hand suppliers, customers, consultants and installers should know where cables of a given EuroClass can be used.

The current legislation in Slovakia significantly helps to apply cables with reaction to fire (TRO) in operation. The standard STN 92 0203 [6] requires EuroClass **B2ca - s1, d1, a1** for cables in selected areas of the building such as nursery school, inpatient departments of hospitals, anesthesiology and resuscitation department, surgical department, assembly space, communication spaces, rooms in hotels with accessories, common areas e.g. hall, reception, dining room, restaurant, protected escape routes, etc.

Specifically, B2ca means that a cable burning test was performed in a bundle where the total amount of heat released from the cables in 1 200 s is ≤ 15 MJ, with the highest value of heat release rate ≤ 30 kW, flame spread ≤ 1.5 m and fire development rate ≤ 50 Ws $^{-1}$.

The additional classification s1 expresses the total amount of smoke development TSP 1 200 ≤ 50 m^2 and the instantaneous amount of smoke released SPR ≤ 0.25 m^2/s. The letter d1 indicates that there are no burning droplets / particles lasting longer than 10 s for 1 200 s. All listed parameters are verified by the standard STN EN 50399 [7]. The additional classification a1 is tested in accordance with the standard STN EN 60754-2 [8] determining the conductivity <2.5 S/mm and pH > 4.3.

2.3. Circuit integrity in fire (fire resistance)

In general, cables with improved properties in fire can be divided into two basic groups: flame retardant (mention above) and fire resistant cables (fire rated). The main difference is that flame retardant cables should not propagate fire and fire resistant cables maintain circuit integrity and continue to work in the presence of fire.

The temperature in fire can reach 1000 °C or more. Many polymers will ignite and burn readily while others will resist ignition more, but sooner or later they will decompose and burn. That is why the insulation layer of fire resistant cables should be able to withstand high degree of heat and of course, maintain circuit integrity for required time.

In order to address this problem, a wide range of cables with different fire barriers has been developed. There are several means by which this can be achieve. A tape composed of mica impregnated glass fibre is often wound around conductors as a means of imparting limited circuit integrity characteristics. Armored cables can also give fire performance benefits. Another common way of providing a fire survival capability is to use silicone elastomers in combination with fire resistant tapes.

In recent years, special polymeric fire resistant compositions have been developed to provide a limited fire survival capability. These compositions are able to form a self-supporting porous ceramic when exposed to fire rating temperatures. Of course, there are other fire resistant system, but these are not as widely used in a cable applications.

The standards for fire rating of cables vary depending on the country or standards, but are generally based on heating the cables to temperatures such as 650 °C, 750 °C, 950 °C, 1050 °C in a prescribed manner for specified time such as 15 minutes, 30 minutes, 60 minutes, 90 minutes, 120 minutes or 3 hours. The aim is to ensure better fire safety and fire rescue capability.

The most widely used tests to investigate the fire resistance properties of cables are based on IEC 331. Fig 1. shows cable testing according to STN IEC 60331-21 at constant temperature 750 °C with nominal voltage 230 V and fuse 2 A.

Fig. 1. Test of circuit integrity of cable according to STN IEC 60331-21 [9]

The fire resistant cables in Slovakia are used in real operation according to standard STN 92 0203 which determined the minimum time of circuit integrity in the event of a fire. For example, minimum time for the electrical fire alarm system is at least 30 minutes, the visual fire alarm device should be set at twice the evacuation time, but not less than 30 minutes, emergency lighting is at least 60 minutes, the device for heat and combustion products removal is at least 60 minutes, socket up to 1 kV at the intensive care unit, anesthesiology and resuscitation department, operating department for at least 90 minutes, etc.

The fire resistance of mention cables must be tested in accordance with the standard STN 92 0205 [10]. The test specimen mounted horizontally at least 3 meters length shall be treated using a standard temperature-time curve (STN EN 1363-1). The test will be passed if during the course of the test no fuse fails (3A) and the lamp (60W, 240 V) is not extinguished.

3. LONG-TERM STABILITY OF OPERATING CABLE PROPERTIES

Although, the fire performance of cables with enhanced fire properties is a priority, we cannot ignore the other important properties of these cables. Some changes of insulation properties may be related with their modifications in order to increase their fire performance. Early compounds of this type suffered from a deterioration in physical properties and processibility because of the high level of filler, in comparison to halogen based systems. Typically, addition levels of over 60 % by weight of these mineral fillers are required to give acceptable flame retardance. Considerable effort has been expended in recent years to modify and improve the fire behavior of polymeric cable materials [2].

Unfortunately, most flame retardant systems have some problems such as weak water resistance, poor compatibility with polymer matrix, toxicity, causticity, poor thermal degradation, etc. The disadvantages lead to a decrease in the properties of the polymer composites, not only flame retardancy, but also some other properties [11].

Generally, cables can be required to perform in a very wide range of climatic and operating conditions such as temperature, humidity, radiation, etc. Cables with enhanced fire performance are widely used in nuclear power plants, subways, tunnels, high-rise building, hotels, etc. Different environments can start various degradation processes in cable insulations. Therefore, it is important to take into account the stability of physical, electrical and mechanical properties of cable insulations.

Considering the fact that insulating compounds and construction of cables with enhanced fire performance is relatively new technology, a complex and demanding testing of other operational properties, is very important, too. Manufacturers declare tests in compliance with valid standards. According to our experiences these tests are not adequate to verify real life time during operation.

Our laboratory has been testing cables and cable insulations, which are more demanding than standards tests for decades. The purpose of these tests is to reveal weaknesses in insulation materials during their long-term operation and verified their resistance to unexpected events at the same time.

4. RESULTS AND DISCUSSION

The intention of our experiment was to simulate unexpected events during operation such as flooding of cable systems, water ingress through the open ends of the cables or damaging of the sheath. The fire resistant core insulation with different type of flame barrier was compared. All examined core of commercially produced cables of rated voltage 0,6/1 kV were halogen free, fire retardant, low smoke generation and fire resistant.

The construction details of examined samples are in the Table I.

Construction element	**Construction of fire resistant cores**		
	sample 1	***sample 2***	***sample 3***
Core	Cu, round shape	Cu, round shape	Cu, round shape
Flame barrier	Glass-mica tape (muskovit)	Glass-mica tape (flogopit)	Ceramic forming mixture
Insulation	Low Smoke Zero Halogen (LSZH)	Low Smoke Zero Halogen (LSZH)	

Table 1. The construction details of examined samples

The effect of water immersion was achieved in laboratory conditions. The samples of insulated cores with three different flame barriers (blue and brown color) with length of 5,1 m were placed in water tank. Consequently, insulation resistance, capacitance and dissipation factor at ambient temperature from 21 °C to 25 °C were measured during 114 days. Measurements of insulation resistance were performed at 100 V dc and capacitance as well as dissipation factor at 100 V, 50 Hz. All measurements, also breakdown voltage were arranged core-water because samples did not have any metal screen. The breakdown voltage (50 Hz) values were determined using a voltage rise ramp of 2 kV/min. The average values of breakdown voltage were calculated from six measured values at ambient temperature 22 °C. Conductivity of water was 1.1 mS.

Some results of our tests mention above were published in [12]. According to [12] all examined samples have demonstrated very good water resistance. The measured values of capacitance, dissipation factor and insulation resistance were more or less stable during long-term experiment. Relatively large changes during the first days of immersion can be attributed to poor wettability of the insulation surface that caused resistance of water-insulation interface. Sample 3 depicted increasing of insulation resistance for the first 50 days after immersion. It could be possibly due to releasing of the conductive compounds from the ceramic forming mixture surface layers and thereby reducing its conductivity. Both, blue and brown cores have very similar results of measured characteristics. But, on the other hand, some differences of measured characteristics depending on flame barrier was shown. The sample 3 has better performance compared to sample 1 and 2.

In this paper, we would like to present the influence of the rated voltage (50 Hz, 230 V) during immersion in the water. The influence of water immersion with and without connection of rated voltage on insulation resistance, dissipation factor and breakdown voltage of measured samples is shown in Fig. 2, Fig. 3 and Fig. 4.

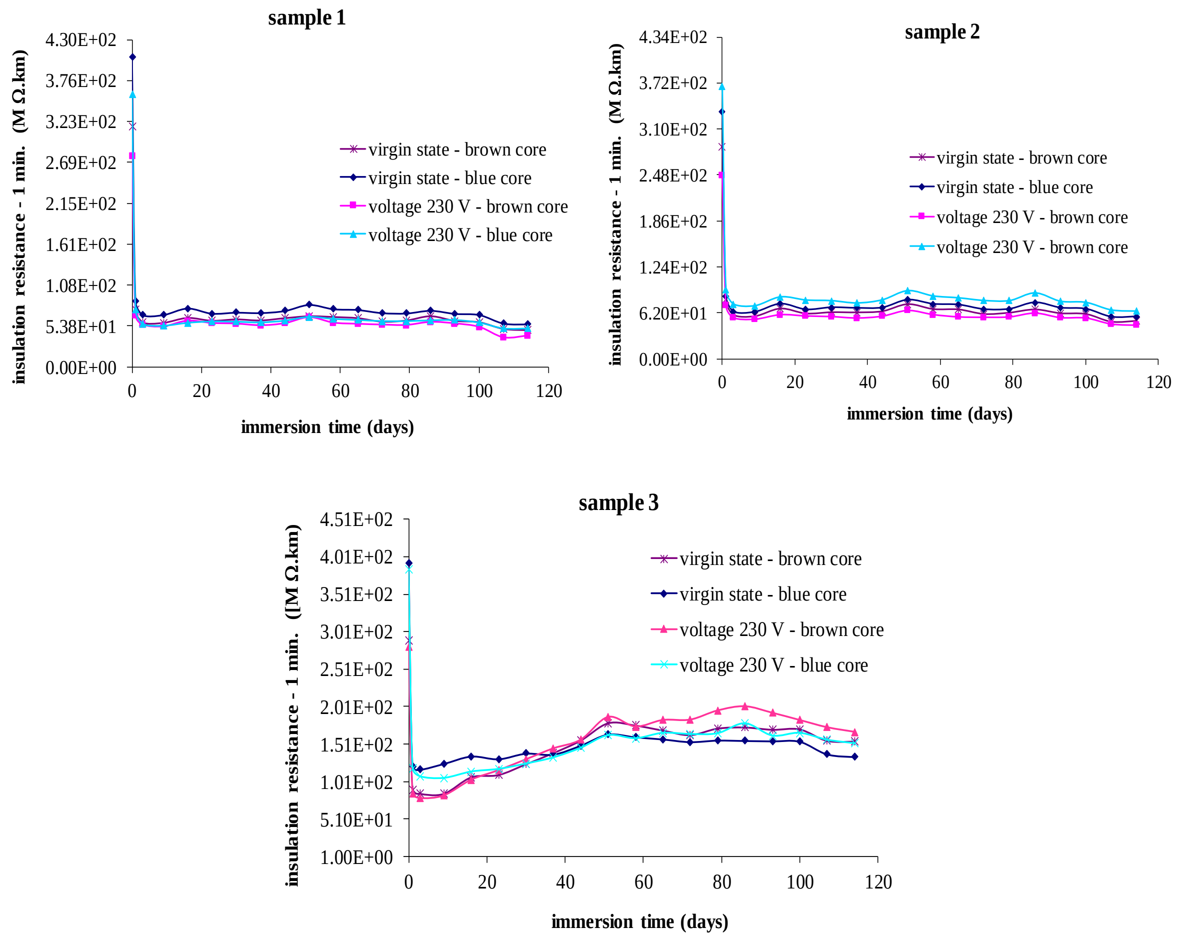
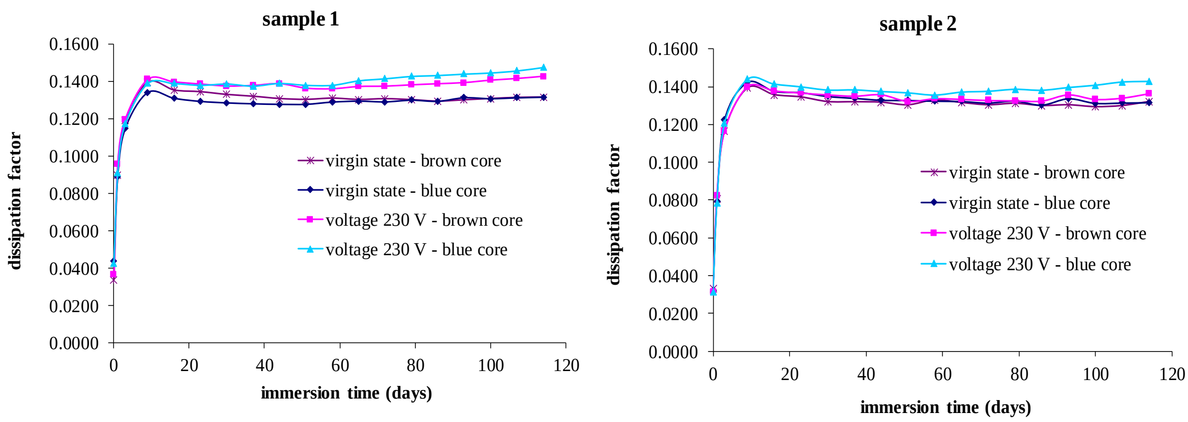


Fig. 2. Time dependence of insulation resistance of measured samples (blue and brown cores) during water immersion at ambient temperature with and without connection of rated voltage



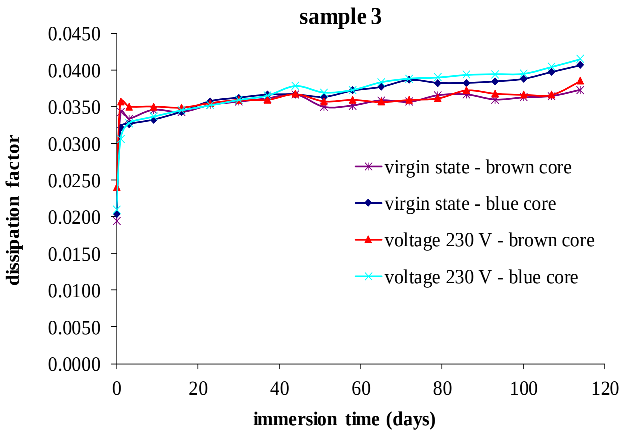


Fig. 3. Time dependence of dissipation factor of measured samples (blue and brown cores) during water immersion at ambient temperature with and without connection of rated voltage

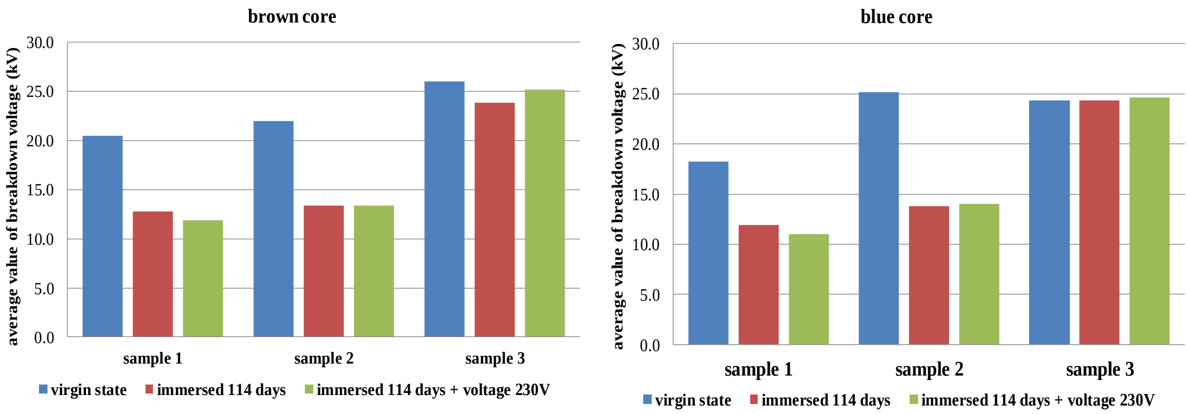


Fig. 4. Breakdown voltage of measured samples (blue and brown cores) after water immersion at ambient temperature with and without connection of rated voltage

Insulation resistance a dissipation factor measurements do not show any significant influence of the rated voltage (50 Hz, 230 V) in comparison with and without connected voltage for blue and brown cores of all measured samples. The similar behavior was also substantiated with results of capacitance measurement which are not published in this article.

The samples with glass-mica tape and LSZO insulation (sample 1 and 2) exhibit lower remnant breakdown voltage after 114 days immersing for both, brown and blue core color. On the other hand, the connected rated voltage (50 Hz, 230 V) did not significantly affect the breakdown voltage of all examined samples.

5. CONCLUSIONS

The purpose of cables with improved properties in fire is to ensure the protection of human health and property. The construction and new composition of insulation materials can significantly affect their physical and chemical properties. For this reason, it is necessary to test stability of their operating properties. The influence of the rated voltage on chosen properties on insulated cores with different flame barriers during immersion in the water were investigate in this paper.

All examined samples have demonstrated very good water resistance with and without connection of rated voltage. Practically, the connected rated voltage (50 Hz, 230 V) had no significant influence on the insulation resistance and the breakdown voltage. On the other hand, sample 1 and 2 with glass-micatape and LSZH insulation exhibit lower remnant breakdown voltage after 114 days immersing for both, brown and blue core color. The better performance of sample 3 with ceramic mixture has been proven.

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REFERENCES

1. Moore, G F (editor) 1997, "Mineral insulated cables", *Electric cables handbook*, third edition, ISBN -13- 978-0-632-04075-9, pp. 271-279.
2. Moore, G F (editor) 1997, "Cables in fires – Material and design consideration", *Electric cables handbook*, third edition, ISBN -13- 978-0-632-04075-9, pp.92-107.
3. Regulation (EU) No 305/2011 of the European Parliament, Construction Product Regulation (CPR), 2011.
4. STN EN 13501-6: Fire classification of construction products and building elements. Part 6: Classification using data from reaction to fire tests on power, control and communication cables, 2019.
5. Dickinson P.R, 1992, "Evolving fire retardant material issue: a cable manufacturer's perspective", *Fire technology*, pp. 345-368.
6. STN 92 0203:Fire protection of buildings. Continuous power supply responding for fire, 2013.
7. STN EN 50399:Common test methods for cables under fire conditions. Heat release and smoke production measurement on cables during flame spread test.Test apparatus, procedures, results, 2012.
8. STN EN 60754-2:Fire Test on gases evolved during combustion of materials from cables. Part 2: Determination of acidity (by pH measurement) and conductivity, 2015.
9. STN IEC 60331-21: Tests for electric cables under fire conditions. Circuit integrity. Part 21: Procedures and requirements. Cables of rated voltage up to and including 0,6/1,0 kV, 2001.
10. STN 92 0205: Fire behavior of construction products and building constructions. Circuit integrity maintenance of cable systems. Requirements, testing, classification and aplication of test results, 2014.
11. Wang, B, Sheng, H, Shi, Y, Hu, W, Hong, N, Zeng, W, Ge, H, Yu, X, Song,L, Hu,Y2015 "Recent advances for microencapsulation of flame retardant,"*Polymer Degradation and Stability, 113*, pp. 96-109.
12. Packa, J, Ďurman, V, Sulová, J 2019, "Behavior of fire resistant cable insulation with different flame barriers during water immersion", *20th International ScientificConference on Electric PowerEngineering (EPE)*, Czech Republic, ISBN 978-1-7281-1333-3, pp. 265-268.