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Piotr KACZMARZYK*
Daniel MAŁOZIĘĆ*
Łukasz WARGUŁA**

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RESEARCH ON ELECTRICAL WIRING USED IN THE CONSTRUCTION OF WORKING MACHINES AND VEHICLES IN THE ASPECT OF FIRE PROTECTION

Machines and equipment are characterized by various working conditions, and their parts change temperature depending on the principle of operation or the process being carried out. Wires in such devices should be resistant to high temperatures or insulated from heat sources. Danger of damage to cables due to high temperatures occurs not only in the case of structural faults, but also can occur during testing or diagnostics. Another cause of a fire may be the inflaming of installations during renovation work, for example when gas burners are used. The article presents the results of testing selected cables used in the construction of machines. The resistance to the degree of degradation of non-metallic constituents of conduits as a result of convection of heat was determined and the possibility of ignition of electric wires subjected to direct single flame operation was indicated together with the indication of the burnout section in case of ignition of non-metallic layers of the duct.

Keywords: construction of working machines, electrical wiring, fire protection

1. INTRODUCTION

The Polish National Labor Inspectorate in 2014 revealed that technical reasons accounted for 15.2% of all fires during construction production [Obolewicz 2015], and accidents on sea-related ships related to fires in 2009-2014 accounted for 21%

* Scientific and Research Center for Fire Protection Józefa Tuliszkowskiego – National Research Institute, Laboratory of Combustion Processes and Explosions.
** Poznan University of Technology, Faculty of Machines and Transport.

of all accidents. In maritime transport, the causes of fires were the following: damage to electrical equipment including cabling, damage to mechanical equipment (e.g. fires and explosions in marine power plants), damage to the ship's hull or its equipment, damage caused by external factors force majeure, damage caused during service work, e.g. welding, soldering, grinding, etc.; self-ignition of cargo (in holds, containers, etc.) [Gawdzińska et al. 2015]. In agriculture, in 2014, fires and explosions accounted for 0.6% of all accidents. The main cause was, among others, the worn-out electric installation of buildings and fires of machines and devices resulting from the lack of fuses, sparks or short-circuits [Porębska et al. 2015]. There are also described in the literature conditions of fire hazards of machines and vehicles, e.g. in historic means of transport [Łukasik et al. 2017], conveyor belts in opencast mines [Pustułka and Sokolski 2014], passenger vehicles [Rybiński et al. 2013; Szajewska and Rybiński 2014]. Problems related to the fires of electrical installations are important in almost every branch of industry from mining, agriculture to land, air and sea transport. Fires may also apply to test benches.

Flammability tests of materials used in the construction of machines are required by law and implemented in accordance with the guidelines of standards. Working machines or vehicles are characterized by components whose elements can reach very high temperatures. Scientific articles mainly describe the effects of a fire or how to prevent it. There are also works describing combustion products. There are no studies available in the literature that focus on the effect of temperature on the degradation of non-metallic conduit components due to heat convection. Degradation of the cable insulation material is dangerous due to the possibility of sparking and even shorting. In addition, in case of necessity to carry out machine diagnostics or its repair, additional wiring harnesses, which can be found in the presence of heat convection, are used. In order to determine the influence of temperature on electric wires during convection with steel elements of the machine, the degree of degradation of non-metallic components of wires as a function of time was carried out. Another perceived threat to the electrical installation is the pyrolysis of wires due to an open fire during renovation and repair works. The article presents the results of experimental investigations of electrical wiring in the fire protection aspect used in working machines and vehicles during tests as well as repair and maintenance works. The article is part of a wider research cycle aimed at developing fire protection systems used in working machines.

2. RESEARCH OBJECT

The test objects were cables used in working machines and vehicles. The following wires were selected for the tests:

– coaxial cable in PE foam insulation in screen of tape and braid, in polyvinylite PVC [Technokabel data sheet 2018];

– LiYCY 06 / 1kV signal cable [Technokabel data sheet 2018];

– glass fiber reinforced fiber optic cable with loose tubes 1-12Tx12F LT 2.3 [FIBRAIN data sheet 2018].

3. RESEARCH METHODOLOGY

The tests of the degree of degradation of non-metallic conduits components as a result of heat convection were carried out on a heating plate with a constant temperature acc. PN-EN 50281-2-1 standard. The test stand is shown in Figure 1. The test results were recorded in the ANKO ReqTemp program. During the test, the preservance of the sample was observed in terms of discoloration, melting, distortion of pipes and pyrolysis. The test ends with the occurrence of ignition or after 30 min. According to the procedure, it must be considered that ignition occurred if burning or smoking of the test sample was observed. Other observed parameters are the loss of coating properties or the change of their clustering state.

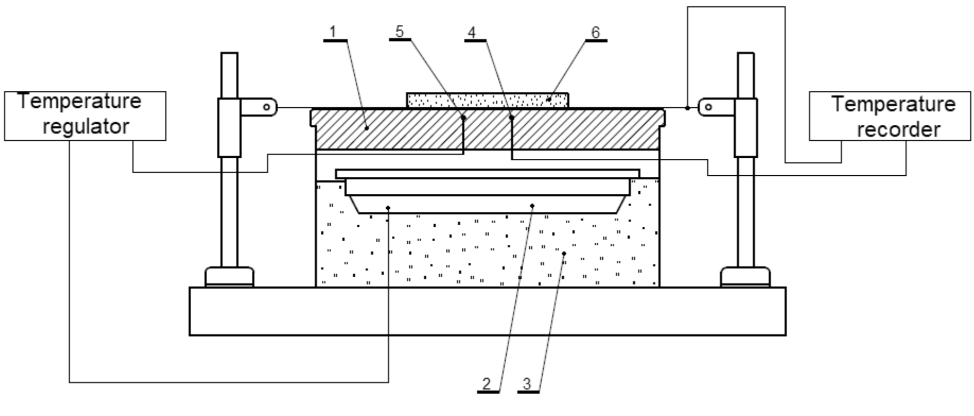


Fig. 1. Stand for testing the degree of degradation of non-metallic components of wires as a result of convection of the wire and steel plate, 1 – heating plate, 2 – heater, 3 – thermal insulation, 4, 5 – thermocouple for measuring the temperature of the plate, 6 – tested cable

The second type of test is the determination of the possibility of ignition of electric wires subjected to direct action of a single flame together with the indication of the burnout section in case of ignition of non-metallic layers of the duct. The test consists in subjecting the vertically placed sample to the direct interaction with the flame without the presence of thermal radiation. This method is used to determine the ignitability of electric wires exposed to a single flame. The test was carried out on a test bench for testing the flammability of electrical and fiber optic cables, which is used to determine their fire classification according to PN-EN 13501-6: 2014-04 standard. The test stand was made in accordance with the requirements of the

PN- EN 60332-1-2 standard. The burner control system allows to set the flame height and control its operation precisely. The flame produced had a total height of about 148 mm to 208 mm, and the internal blue cone ranged from 46 mm to 78 mm in accordance with the standard PN-EN 60695-11-2. The burner was applied to the sample at an angle of 45°. The metal cover and the source of the fire (burner) were in the chamber, equipped with devices for discharging toxic combustion products. The temperature in the chamber was 23°C±10°C. Preparation of the test stand required mounting the sample in the holders so that the lower end of the sample was 50 mm from the bottom of the metal sheath. The course of the measurement test begins with the flame height control, which was checked before each application of the test sample. Then the burner was inclined at an angle of 45° and it was moved horizontally until the flame reached the established contact position of the blue flame cone with the sample (Fig. 2) at a defined distance of 475 mm ± 5 mm from the lower edge of the upper holder. Getting the desired position started the time of measurement. If, after the test is finished, the burner has been shut down, the test sample does not go out and there are flames, it is being extinguished.

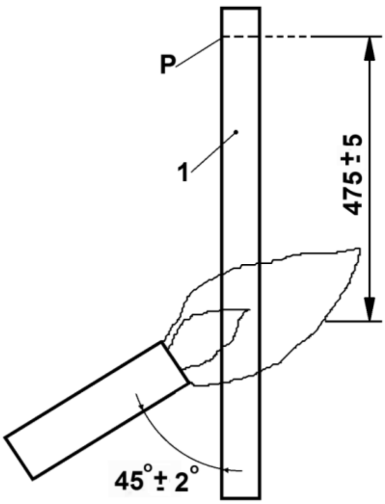


Fig. 2. Geometry of the test stand during the test of ignition of electric wires subjected to direct action of a single flame, P – lower edge of the upper holder, 1 – sample

4. RESEARCH RESULTS

The results of tests on the degree of degradation of non-metallic components of selected ducts as a result of heat convection are presented in tables 1–6.

Table 1. Degree of degradation of non-metallic components of conductors as a result of convection of a coaxial conductor in PE foam insulation in a screen with a tape and a braid, in a polyvinyl-acetate coating and a steel plate

The temperature of the plate [^oC]	Time of impact [min]	Surface anomaly
100	30	no changes
125	30	slight melting of the PVC coating
150	1	no changes
	3	no changes
	5	spillage of polyethylene foam PE insulation and plastic deformation of PVC coating
	10	spillage of polyethylene foam PE insulation and plastic deformation of PVC coating (at the same level as after 5 min)
	30	spillage of polyethylene foam PE insulation and plastic deformation of PVC coating (at the same level as 5 and 10min)
175	1	no changes
	3	spillage of polyethylene foam PE insulation and plastic deformation of PVC coating
	5	increased intensity of spillage of polyethylene foam insulation and plastic deformation of PVC coating
	7	thermal degradation of the PVC coating, delamination of the composite structure, separation of coatings
200	1	intensive spillage of polyethylene foam insulation, thermal distribution of polyvinyl PVC coating, stratification of composite structure, separation of coatings

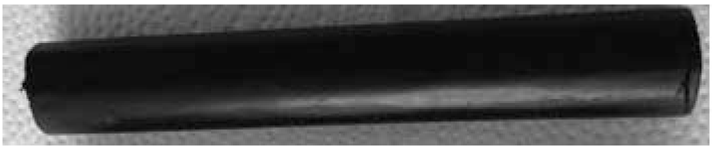
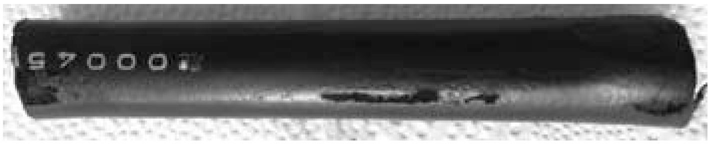
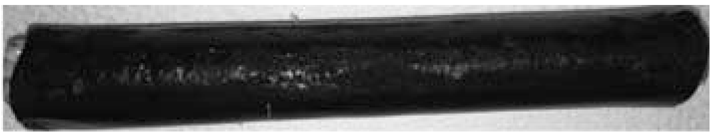
Table 2. Degree of degradation of non-metallic components of wires as a result of thermal convection of glass fiber reinforced fiber optic cable with loose tubes 1-12Tx12F LT 2.3 and steel plate

The temperature of the plate [^oC]	Time of impact [min]	Surface anomaly
100	30	no changes
150	30	slight melting of the LSOH coating
200	3	slight melting of the LSOH coating
	15	increased melting of the LSOH coating, no observation of coating separation
	30	no observation of increased degradation intensity than 15 minutes earlier
250	3	slight melting of the LSOH coating
	5	beginning of pyrolysis of the LSOH coating, production of gaseous combustion products, delamination of coatings

Table 3. Degree of degradation of non-metallic components of wires due to the convection of LiYCY 06 / 1kV signal cable with a steel plate

The temperature of the plate [°C]	Time of impact [min]	Surface anomaly
100	30	no changes
150	30	slight melting of PVC tire
200	3	slight melting of PVC tire
	15	beginning of pyrolysis of the PVC tire coating, which results in intensification of its melting and creation of gaseous decomposition products
	30	pyrolysis without increased intensification than in earlier 15 min
225	3	starting to melt the PVC tire coating
	4	start pyrolysis
	15	separation of coatings and wires as a result of progressive pyrolysis

Table 4. Photos of the degree of degradation of non-metallic components of wires as a result of thermal convection of fiber optic cable reinforced with glass fiber with loose tubes 1-12Tx12F LT 2.3

Temperature [°C] and time [min]	The appearance of the sample after the process
100 and 30	
150 and 30	
200 and 3	

Test results of the possibility of ignition of electric wires subjected to direct single-flame operation together with the indication of the burnout section in case of ignition of non-metallic layers of selected wires are presented in tables 7 and 8.

Table 5. Photos of degradation level of non-metallic components of wires due to thermal convection of the LiYCY 06 / 1kV signal cable

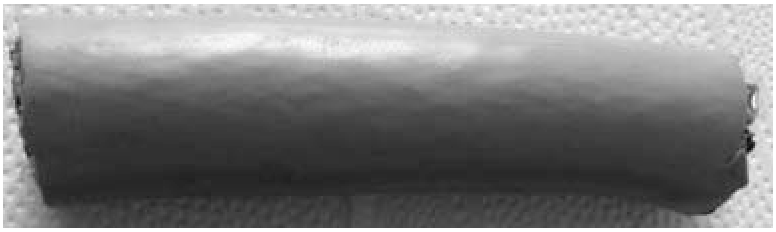
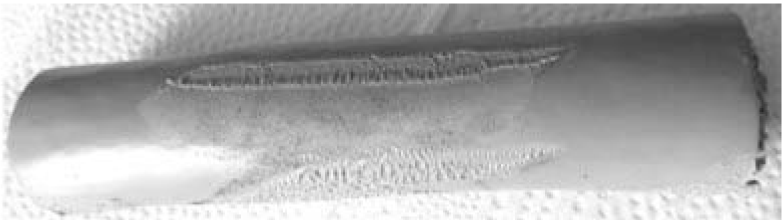
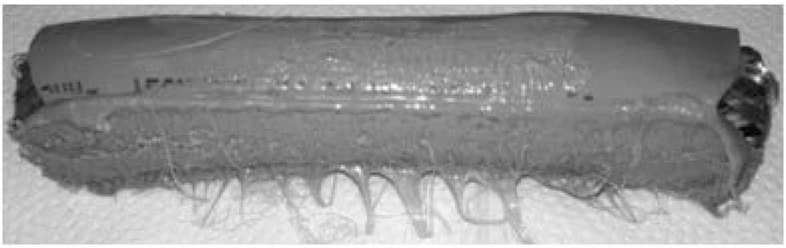
Temperature [°C] and time [min]	The appearance of the sample after the process
100 and 30	
150 and 30	
200 and 3	
225 and 3	

Table 6. Photos of the degree of degradation of non-metallic components of conductors as a result of convection of a steel plate with a coaxial conductor in PE foam insulation in a screen of a tape and a braid, in a polyvinyl-acetate coating

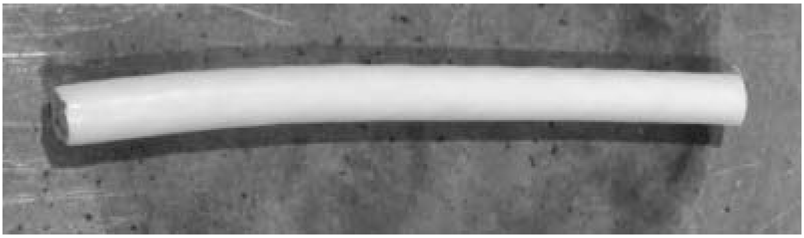
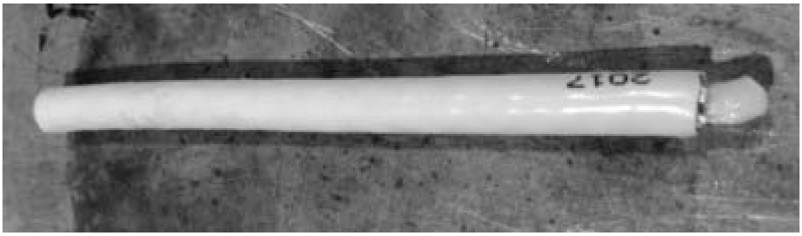
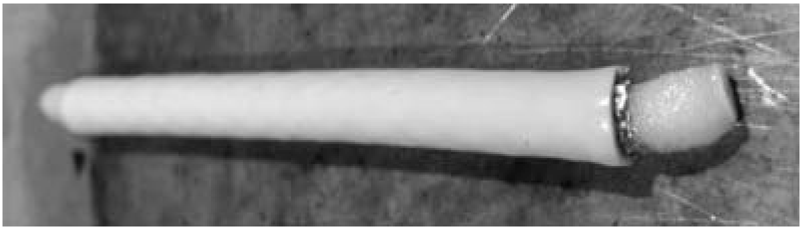
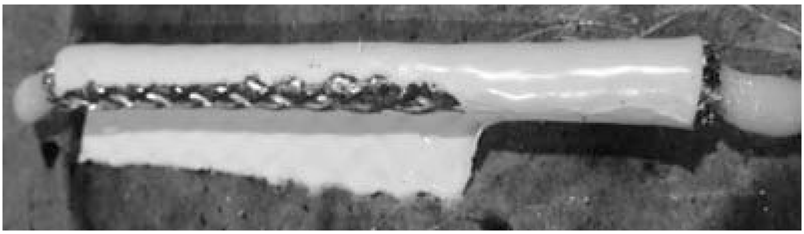
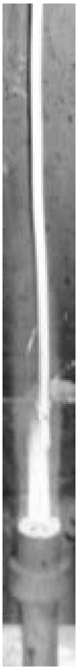
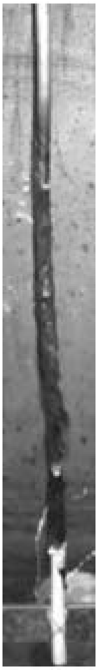
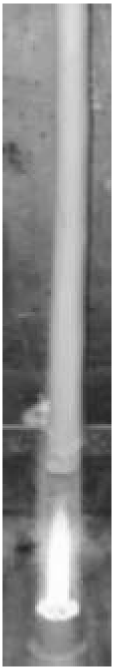
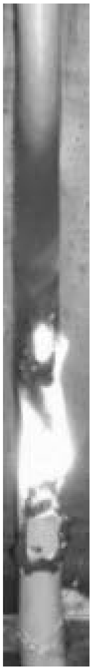
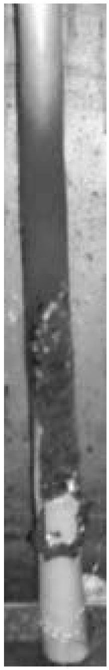
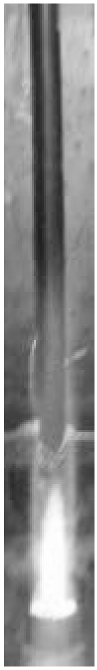
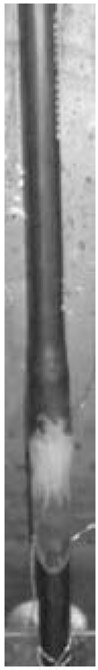
Temperature [°C] and time [min]	The appearance of the sample after the process
100 and 30	
125 and 10	
175 and 5	
200 and 1	

Table 7. Burnout section in case of ignition of non-metallic conductor layers

Type of cable	Length of burnout
Coaxial cable in polyethylene foam PE insulation in a screen with a tape and a braid, in a PVC polyvinyl coating	214 mm
Signal cable LiYCY 06 / 1kV	142 mm
Glass fiber optic fiber optic cable with loose tubes 1-12Tx12F LT 2.3	91 mm

Table 8. Stages of the burn-out process

<table>
<tr><td colspan="2">Coaxial cable in PE foam insulation in screen of tape and braid, in polyvinylite PVC</td><td colspan="3">LiYCY 06 / 1kV signal cable</td><td colspan="2">Glass fiber reinforced fiber optic cable with loose tubes 1-12Tx12F LT 2.3</td></tr>
<tr><td colspan="7">Stages of the process</td></tr>
<tr><td>C</td><td>E</td><td>C</td><td>S</td><td>E</td><td>C</td><td>E</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="7">C – Commencement, E – end, S – self- pyrolysis of the wire</td></tr>
</table>

4. ANALYSIS OF RESULTS

The resistance level of the tested wires to high temperature is presented until the condition of the coating changes in Figure 3, and until the changes allow for shorting the metal elements of the wire in Figure 4.

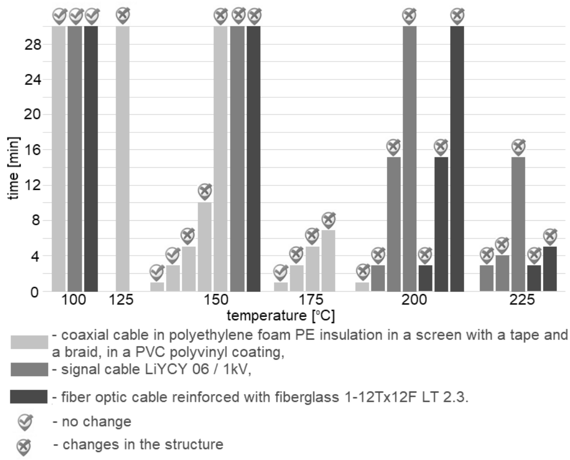


Fig. 3. The resistance level of the tested wires to high temperature until the condition of the coating changes

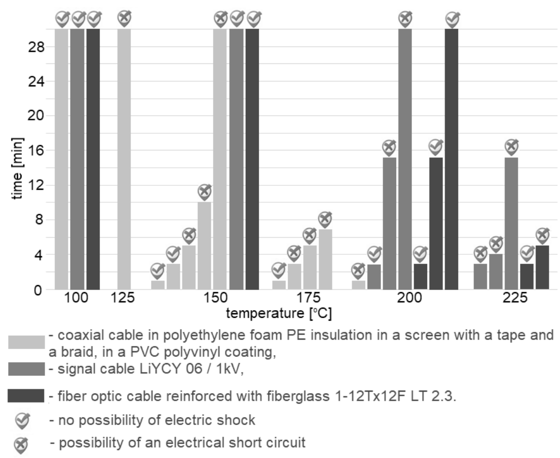


Fig. 4. The level of resistance of the tested wires to high temperature up to the moment of change enabling shorting of metal elements

All tested wires are resistant to temperatures up to 100°C during convection with a steel plate in less than 30 minutes. Increasing the temperature causes plasticization of the non-metallic layers of the wire. The temperature, and in particular the time of its impact on the test sample is the reason for the occurrence of plasticizing the insulation of the ducts or their pyrolysis. The signs of significant damage to the cable, apart from damage to the external matrix, are: plasticizing of the inner layers leading to the lack of insulation of the metallic parts of the conductor that could lead to short-circuits. The fiberglass reinforced fiber optic cable is the most resistant to short-term exposure to high temperatures. This cable is also characterized by the shortest burn-out level after the flame has been applied to it. Cables characterized by a relatively high degree of burnout and burning without a source of flames can cause the spread of fire and, consequently, lead to fire.

5. CONCLUSION

The safety of users depends on the cables used, the reliability of the workmanship, the exploitation conditions and the design of the deployment of the installation. The signal cables both during the machine's operation and during the tests may be exposed to damage. Wires can also contribute to the spread of fire if ignited. The obtained results indicated that among the tested groups optical fiber cables have the highest resistance to convective exchange with the elements of high temperature and flame resistance. When designing machines and during their tests, it is essential to apply fire protection systems to limit the effect of high temperatures on the wires. Further work in the aspect of fire protection, and identifying the causes of fire testing may allow the research on the gaseous products of burning electrical wiring. The obtained results can be used to develop mechatronic systems for the detection of harmful substances that can be used in the chambers of working machines. These systems would record the results of the composition of the gaseous products of combustion and based on control algorithms may indicate the occurrence of fires in the working chamber and also identify the source of a fire risk.

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PN-EN 60332-1-2:2010; PN-EN 60332-1-2/A1:2016-02; PN-EN 60332-1-2/A11:2017-02; Badanie palności kabli i przewodów elektrycznych oraz światłowodowych. Część 1-1: Sprawdzenie odporności pojedynczego izolowanego przewodu lub kabla na pionowe rozprzestrzenianie się płomienia. Aparatura.
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BADANIA PRZEWODÓW INSTALACJI ELEKTRYCZNYCH STOSOWANYCH W BUDOWIE MASZYN ROBOCZYCH I POJAZDÓW W ASPEKCIE PRZECIWPOŻAROWYM

Streszczenie

Maszyny i urządzenia charakteryzują się różnorodnymi warunkami pracy, a ich elementy zmieniają temperaturę w zależności od zasady działania lub realizowanego procesu. Przewody w takich urządzeniach powinny być odporne na wysokie temperatury lub odpowiednio izolowane od źródeł ciepła. Niebezpieczeństwo uszkodzenia przewodów wskutek wysokich temperatur występuje nie tylko w przypadku błędów konstrukcyjnych, ale również może do niego dojść podczas badań lub diagnostyki. Inną przyczyną wystąpienia pożaru może być zapalenie instalacji podczas prac remontowych, np. gdy stosuje się palniki gazowe. W artykule przedstawiono wyniki badań wybranych przewodów stosowanych w budowie maszyn. Wskazano odporność na stopień degradacji niemetalicznych składników przewodów w skutek konwekcji ciepła oraz określono możliwość zapłonu przewodów elektrycznych poddawanych bezpośredniemu działaniu pojedynczego płomienia wraz ze wskazaniem odcinka wypalenia w przypadku zapłonu warstw niemetalicznych przewodu.

Słowa kluczowe: budowa maszyn roboczych, przewody elektryczne, ochrona przeciwpożarowa