The Influence of Thermal Factors on the Protection Characteristics of Electro-Insulating Materials

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Abstract. The use of electrical insulating materials in the manufacture of electrical insulating equipment is the primary prevention and protection measure against electrocution. It must ensure the highest protection of the workers. The study aims to present the results of studies over behaviour of electrical insulating materials under the influence of the thermal risk factors, to verify the functionality and to ensure the safety function throughout their use. Electrical insulating materials and equipment intended for use as protection mean in low and high voltage electrical installations have been tested. The verifications aimed at identifying the technical and safety parameters of the electrical insulating materials and protective equipment, in case of an event generated by one or more thermal factors or in combination with other professional risk factors, to test and guarantee the applicable technical and safety requirements.

1. Introduction
The evolution of electrical power systems, work equipment and protective equipment involves a review of continued electrical research. A particularity of using electrical power in industrial facilities is represented by the electrocution hazard [1].

The role of protective equipment is to protect workers against identified, assessed, verified and certified occupational hazards, which by design and manufacture must not cause any danger to the user and, where appropriate, to persons and animals nearby [2, 3, 5, 6].

Over time, the protective equipment diminishes its technical and protective characteristics, due to wear, aging of materials, non-compliant use. Studies on the behaviour in time of protective equipment in use revealed that during use they lose their characteristic high safety dielectric due to damage nature heat generated by accidental exposure to arc, exposing it to high temperatures combined with mechanical stress and non-compliant use over time.

Analysing statistically the share of factors that influence the safety feature over time, it is found that a fairly large share of thermal factors during use [2, 3].

From the categories of monitored work equipment, it was found that a share of 34% of them show traces of electric arc (the highest share being recorded by electrical insulating tools and fuse handling devices), 7% show material damage due to exposure to fire or heat generated by defects in installations such as hot spots.

Microclimate conditions can decisively influence the safety of insulating working equipment, in terms of insulation degradation, which leads to a high risk for workers [6].
The thermal stresses to which the protective equipment is subjected during use require the choice, from the design, of materials that are resistant both from an electrical point of view, as well as from a thermal and mechanical point of view, and these technical and safety characteristics must to guarantee the observance of the safety and health requirements established by the legislation and in the specific Romanian standards, applicable to the respective product categories [3, 7, 8].

In this sense, when designing and manufacturing, as well as when choosing a protective equipment, the properties of electrical insulating materials from the components and subassemblies of protective equipment must be known, taking into account both safety and ergonomic requirements and technical-economic criteria.

For example fibreglass, a material widely used especially in hot sticks (electrical insulation equipment consisting of one or more electrical insulating tubes provided with coupling systems to each other, and at one end for the purpose of attaching accessories), rigid protectors (shutters, electrical insulating platforms) has high fire resistance, high heat resistance, low thermal conductivity. Fiberglass resists the action of chemicals and biological agents, but mechanically has a weak structural strength with low resistance to compression and torsion. The tests performed in the study on electrical insulating rods made of fiberglass tubes showed the reduced resistance to compression and torsion, for this reason, this type of product was put into use in electrical installations with limited use, being restricted to mounting, with the help of these types of rods of earthing and short-circuiting devices or performing other works involving the mechanical stress of the rod such as removing the victims from the electrical installations by means of an attached accessory, hook type or in case of cleaning works (tree grooming) of the corridors of the high voltage overhead power lines. Another disadvantage of fiberglass is its low moisture permeability, thus limiting the use of fiberglass electrical insulating rods only in dry environmental conditions.

In general, the conductivity of such mixtures increases drastically at a certain concentration of the conductive component, the so-called percolation concentration. Among the parameters influencing the percolation concentration, the filler distribution, filler shape, filler/matrix interactions and the processing technique are the most important ones. On the basis of these parameters, different models have been proposed aimed at the prediction of the conductivity or the percolation concentration. It will be shown here that statistical, geometric or thermodynamic models explain the conductivity behaviour of specific mixtures on the basis of insufficient assumptions. However, the conductivity seems to be predictable with the help of structure-oriented models [9].

The purpose of the analysis of the safety level assessment is to provide the opportunity to know the real situation from the point of view of safety and to take the proper prevention methods for the given situation [10].

2. Technique identification
In order to identify the specific technical and technical safety requirements that the electrical insulating materials must meet, which are part of the electrical insulating work equipment, the following was performed:

- analysis of the types of protective equipment in use, the fields of use, the types and technical characteristics of the electrical installations in which these protective equipment are used, the works for which they are used and the environmental conditions are used.
- analysis of the new types of protective equipment, of the people of use, of the types and technical characteristics of the electrical installations in which these protective equipment will be used, of the works to be used and of the environmental conditions [11].
- the analysis performed was performed corroborating conditions of compliance established in the Law no.245 / 2004 with health and safety provisions in use stipulated in GD no.1146 / 2006 on the minimum safety and health requirements for the use of work equipment by workers work and observance of the technical conditions established in the specific Romanian standards, applicable to the respective product categories [3, 7, 8].
The electrical insulating materials of the protective equipment must be selected in accordance with the electrical, mechanical, thermal and chemical stresses to which they are subjected during use. This material must have adequate resistance to aging and must not propagate the flame.

Electrical insulating coatings consisting of one or more layers of electrical insulating material must be selected in accordance with the same safety requirements and technical criteria. The electrical insulating materials in the protection equipment component must retain their characteristics and technical properties in case of thermal instability, especially in the hand-held protection equipment. For example, electrical hand tools must be used without restrictions in the temperature range of -20 °C and +70 °C. The electrical insulating materials applied on the hand tools used in live electrical installations must maintain their adhesion on the conductive side in the above-mentioned range [11, 12].

It is important that these materials do not have a high heat transfer in the metal components of the protective equipment. Heat can be transferred by conduction, convection or radiation or by a combination of all three.

A defect, pre-existing or created by the in-service stresses, gives rise to an ionization process in a volume bounded by insulating walls. With time the process does not remain identical due to both changes in the material and gas evolution, which makes it difficult to interpret the detected electrical signal. The end of life will occur through microcracks in which new discharges are initiated, activating the propagation of these structural failures [13].

![Diagram](image.png)

**Figure 1.** Technical and thermal safety requirements applicable to component electrical insulating materials of a protective equipment.

Figure 1 identifies technical requirements and safety nature of heat for material insulating components of equipment protection or for protective equipment as a whole.

3. **Experimental procedures**

Studies on the behaviour characteristics of protective thermal insulating materials that goes into protective equipment to made on different categories such as: tools electrical, hot sticks, protective rigid means (plates, insulating platforms) protective flexible means (sheaths and electrical insulating foils), devices for handling fuses with high breaking capacity. Their analysis, diagnosis and evaluation was performed on both new and in-use protective equipment.

The tests were performed on samples of protective equipment and electrical insulation materials taken from the production lines of some manufacturers who have electrical insulation products /
equipment under certification in the ICSPM - CS Certification Body, within INCDPM “Alexandru Darabont” Bucharest.

The tests were performed according to the verification methods specified in the applicable Romanian standards, the procedures of the Certification Body and the testing laboratories "Electrical and Mechanical Risks" and "Individual Means of Protection" within INCDPM.

In order to assess the quality of safety against the risks of thermal nature of the equipment protection must be identified and determined the best method is by testing. Ideally, the test methods should accurately reproduce the conditions that occur in practice, which is not possible and for practical reasons, tests on these risks are performed by accurately simulating the real effects that occur in practice [11, 14].

3.1. Flame propagation

The purpose of the test is to determine the properties of the electrical insulating materials from which the protective equipment is made or their flame-retardant coating. For the electrically insulating hand tools, the method provided in the standard SR EN 60900:2013 was used.

The test must be performed on fully assembled protective equipment (in the case of assembling hand tools); however, if this is not possible, the test must be performed on the relevant parts. The points required for the flame must be the points considered to be the weakest and are the working ends - which could be exposed to thermal stresses during use in electrical installations [15].

The outer parts of the tool head insulation were positioned horizontally above a blue flame 20 mm ± 2 mm high, generated by a methane gas burner. The exposure time of the specimens to the flame was 10 seconds, after which they were removed and for 20 seconds the behaviour of the material or coating was followed.

Three groups were tested man tools complicated to work in electrical installations, consisting of five tools / screwdrivers and pliers. Group A is made up of five tools man signed for work in electrical installations. They have electrical insulation consisting of two layers of electrical insulation material, different colours (red-orange), and the working tip has a single red coating. The internal electrical insulating coating is a rigid coating with very high insulating characteristics, and the outer one is supple and protects the inner coating for shock absorption, improving comfort in use. Hand tools in group B have an electrical insulation coating consisting of two layers of electrical insulation material, different colours (red-yellow), both layers of material are rigid. The working tip has a single red coating. Hand tools from group C have an electrically insulating coating made of a single layer of electrical insulating material, the second layer of material being applied only on the side of the tool. The working tip has a single red coating.

All specimens passed the test, during the 20 seconds of observation, the flame did not exceed 120 mm in height, according to the method from the above mentioned standard.

During the test, in addition to the height of the flame emitted by the test piece, the duration until ignition, flame propagation, heat release and drops or incandescent particles were monitored (dropping of burning particles). Rapid flame propagation was found on the rods of small diameter screwdrivers and on the working ends of tools covered with PVC electrical insulation material and also incandescent particles were found during combustion. In two of the specimens (screwdrivers) tested, the flame reached near (between 45 and 50 mm) the handles / handling area. Also, during the tests performed on the handles of the specimens with two coats of material, it was observed in the specimens from group A, that on the outer casing of electrical insulating material the flame spread more slowly, while on the base coating the flame spread faster. It has been assumed that the rapid spread of the flame on the coating of the basic electrical insulating material is due to the increase in temperature at its surface. For clarification, the tests were performed on specimens that had only the base material coating. It was found that the flame spreads faster than the flame spreads on the outer shell, but this is also influenced by the high temperature on the surface of the electrical insulating material, the manufacturer choosing, for technical and economic reasons, a material that has a lower
flame propagation speed for outer coating and a higher flame propagation speed material for inner coating.

The second set of tests was performed on electrical insulating shutters. In order to test the properties of the electrical insulating materials, from which the electrical insulating plates are made, related to the flame propagation, the test method was assimilated, also used for testing the electrical insulated foils.

Electrical insulated shutters are protective equipment that apply between the disconnector contacts (the disconnector in the open position) and the fixed part of the disconnector. Nine different model samples and different materials were taken from the production lines. Three specimens (specimen code RE 0434) are made of electrical insulating material obtained by an extrusion process from non-plasticized mixtures based on polypropylene (PP), three other specimens (specimen code RE 0435) are made of material obtained by extrusion from a mixture non-plasticized PVC and three (test code RE 0436) are obtained from polyester resin coated with fiberglass (FGRPR) [2, 3, 11].

The specimens were positioned horizontally above a blue flame 20 mm ± 2 mm high. The exposure time of the specimens to the flame was 10 seconds, after which they were removed. The propagation (action) of the flame on the test sample must be observed for 60 seconds after the flame has been extinguished. The test is considered successful if during the observation period the flame does not propagate to any point at a distance of 50 mm from the centre of the specimen (the place where the flame acted). All specimens passed the test, during the 60 seconds of observation no drops or incandescent particles were recorded.

Traces of carbonization are present in the area of contact with the flame. Table 1 shows the results of flame propagation tests for polypropylene (PP) specimens.

| Test sample | Flame exposure time [sec] | Observation time after flame exposure [sec] | Maximum diameter of damaged area [mm] |
|-------------|---------------------------|-------------------------------------------|-------------------------------------|
| RE 0434-1   | 10                        | 60                                        | 44                                  |
| RE 0434-2   | 10                        | 60                                        | 45                                  |
| RE 0434-3   | 10                        | 60                                        | 50                                  |

Figure 2a. Leakage current values – before thermal tests.  
Figure 2b. Leakage current values – after thermal tests.

Result tests on specimens of PVC and FGRPR are inferior to those registered in the PP specimens, the maximum values of the damaged area being included in the limit of safety requirement.

After the flame propagation test, samples were tested at baseline and after dielectric application of heat. The dielectric test consisted of the application of a 50 kV in three points, progressively raised
and maintained for 3 minutes. The electrodes were in the form of cylinders with a diameter of 25 mm and a height of 25 mm, respectively a diameter of 75 mm and a height of 25 mm [2, 3, 11].

During the tests, the leakage current, the flashovers and the local heating were monitored. It has been found that specimens that have lost the dielectric characteristic also show visible local [16].

Figure 2 shows the values of the leakage current before and after the flame propagation test. The decrease of the dielectric characteristics is found.

3.2. Thermal stability
Thermal stability tests were performed on hand tools for work in new electrical installations of different categories (pliers, screwdrivers, wrenches). Three batches of hand tools were tested for work in electrical installations. Lot A consists of 10 hand tools for working in electrical installations. They have electrical insulation consisting of two layers of electrical insulation material, different colours (red-orange).

Polymer insulating materials, are expected to be used under a variety of ambient conditions. Under severe ambient conditions, surface ageing of polymeric materials is closely related to environmental stresses. These environmental stresses affect tracking resistance in two ways. One is a direct effect on the change in the chemical structure of the surface. The other is an indirect effect on physical behaviour, such as variations of surface wetting by contamination and changes of discharge behaviour because of it [17].

The internal electrical insulating coating is a rigid coating with very high insulating characteristics, and the outer one is soft and protects the inner coating for shock absorption, improving comfort in use. Hand tools from group B have electrical insulation coating consisting of two layers of electrical insulation material, different colours (red-yellow), both layers of material are rigid.

Hand tools from group C have an electrical insulating coating made of a single layer of electrically insulating material, the second layer of material being applied only on the side of the tool.

Figure 3 shows the values of the electric leakage current for the 3 batches of electrical insulating tools from different manufacturers, before the thermal stresses are performed.

![Figure 3. Leakage current values, in normal condition, before verification.](image)

The specimens were subjected to climatic conditions at a temperature of -20 °C for 168 hours and +70 °C for 168 hours. Immediately, after each conditioning, a visual inspection of the test specimens and verification of the adhesion of the layers of electrical insulating material was performed both between them and against the metal parts. The adhesion test of the electro-insulating coating was performed according to the methods established by the standard SR EN 60900: 2013. It was found that 1% of the test specimens did not pass the test.
After checking the adhesion, the dielectric strength of the specimens was checked. Figure 4 shows the values of the electric leakage current for the three batches of electrical insulating tools, checking the thermal stability combined with the shock given by the free fall.

![Figure 4. Leakage current values.](image)

From the performed tests it resulted that the parameters of the dielectric characteristic of the equipment are influenced both by the thermal stability of the electro-insulating material coating, and by the way of realizing in the manufacturing procedure of their coating.

4. Results and discussions
The results of the study show that the parameters of the dielectric characteristics of protective materials are influenced by the thermal characteristics of electrical insulating materials in the protection equipment, this information allowing efficient selection and acquisition of component materials, better management of occupational hazards and ensuring a proper maintenance of the protective equipment in use, in order to establish the most appropriate measures for technical diagnosis and inspection / control of the safety level of a protective equipment [3, 11, 18].

In this regard, the appropriate choice of protective materials, which are part of a protective equipment, must take into account the behaviour of electrical insulating materials under the influence of thermal risk factors, including mechanical, in order to ensure functionality and ensure the safety function on the entire duration of their use.

This is ensured by an adequate risk management within the companies that allows an efficient management of the professional risks and guarantee of the placing on the market of some safe and efficient protective equipment.

Awareness and involvement of top management is essential in the development of organizational risk management and to increase risk awareness at different levels of the organization [20].

5. Conclusion and perspectives
The safety checks performed in the research study aimed to identify the technical and safety parameters of electrical insulation materials and protective equipment, in case of an event generated by one or more thematic factors or in combination with other occupational risk factors, in order to test and guarantee the technical and safety requirements applicable to them.

The research study is the basis for the development of a methodology for verifying electrical insulation materials that are part of electrical equipment and protective equipment, given that during use protective equipment is subject to various risk factors generated by the use, maintenance, storage and working environment, which can change both the protection characteristics against electric shock...
and the protection characteristics against other risk factors, such as thermal, mechanical, which can cause a low reliability of these products.

The electrical insulating characteristics of a protection material are determined by the influence of thermal and mechanical risk factors, the environment in which the electrical insulation equipment is used, safety checks, assessment and attestation of conformity following a certification process. Ensuring the introduction on the market of compliant and safe products for users and guaranteeing a safe and healthy work environment at the workplaces in the industrial activity sectors.

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