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Review of electrostatic hazards in hard coal mining

Electrostatic hazards are considered a category of technical hazards occurring in hard coal mining. These hazards are related to the generation of excess electric charges forming as a result of most technological processes. Products manufactured from plastics that are classified as non-antistatic materials pose the greatest hazard.
The article discusses the Polish and European legal regulations concerning the requirements for materials regarding their antistatic properties. It also presents the results of studies conducted at GIG concerning the systematization of the antistatic processing of plastics. Furthermore, the article proves that the procedure of applying antistatic properties to plastics is neither easy nor homogeneous. The introduced antistatic processing systematics (i.e., the identification of various antistatic processing realization methods) is meant to make both the manufacturers and customers aware of the various (often undesired) properties of modified plastics.

Key words: *static electricity, mining, explosion, plastics*

1. INTRODUCTION

The products utilized in hard coal mining must meet the requirements concerning their antistatic, slow-burning, and non-toxic properties. This is defined by the Ordinance of the Minister of Economy [1] – constituting an implementing act to Mining Law [2]. An electrostatic discharge can be a source of methane ignition. The antistatic character of these products is neither understood unambiguously nor identically realized.

Most plastics do not meet legal requirements regarding their antistatic properties. Products manufactured from plastics tend to electrify, accumulating excess electric charges; this results in electrostatic discharge hazards that may initiate an ignition in an explosive atmosphere.

Plastics classified as electric insulators [3] are becoming increasingly more common in hard coal mining compared to antistatic materials due to their lower cost of production. In order to meet the legal requirements and lower the electrification ability of plastics, they are subjected to antistatic processing; i.e., improvement of their antistatic properties. Antistatic processing is a procedure based on changing the electrostatic properties of a product in order to increase its charge dissipation (offtake) speed and decrease its electrification ability.

Most commonly, the antistatic processing of materials is performed in order to change their resistivity (which is the basic material electrostatic property evaluation parameter) as well as to change the material classification – from dissipative to conductive or from insulative to dissipative. Based on their surface and volume resistivities, materials are classified as conductive, dissipative, or insulative. The first two kinds are antistatic; i.e., they do not undergo permanent electrification and do not accumulate charges on their surfaces.

There are various antistatic-processing realization methods. Many antistatically processed materials change their electrostatic properties over time or undergo changes as a result of external factor influence. Some of them also influence their surroundings. When subjected to the various antistatic processing methods, these materials are characterized by various properties that are not always desirable from the point of view of safety or their functional characteristics. An inadequate undurable product may influence the safety of explosion hazard zones.

2. HAZARDS IN HARD COAL MINES

The division presented below is the author's own division based on a literature analysis (particularly of European and Polish legislation) as well as the current standards.

Hazards related to static electricity can be discussed within the context of the following areas:

- human safety and comfort,
- electronics industry and industry manufacturing elements susceptible to ESDS-type discharges,
- industry,
- explosive atmospheres, including hard coal mining,
- operating theatres.

The first hazard area is human safety and comfort. Comfort is regulated neither by legislation nor standards – no criteria or electrostatic property-testing methods have been defined. Wearing shoes or clothing classified with insulative or dissipative materials depends only on a given person. With regard to this area, a person is often electrified; electrostatic discharges tend to occur and are consequently followed by accidents (including fatal ones). As an example, we may consider limb injuries resulting from falls occurring as a consequence of an unconditioned reflex following a discharge from the human body to a metal handrail (a person in insulative shoes became electrified while walking).

From the point of view of electrostatic protection, human work safety is regulated under European law by directive [4] concerning personal protective equipment and under Polish law by the Ordinance of the Minister of Economy [5], the Ordinance of the Minister of Infrastructure [6], the Ordinance of the Minister of Infrastructure [7], and the Ordinance of the Minister of Labor and Social Policy [8]. The aforementioned ordinances constitute implementing acts to the following laws: Labor Law [9] and Building Code [10]. The requirements defined therein concern the protection from static electricity (with a particular stress on excess electrification).

The second hazard area encompasses the protection of electronic devices and devices susceptible to electrostatic discharges (so-called ESDS objects). This is an area rich in standards (PN-EN 61340 and IEC 61340 standard series). Unfortunately, this area is not regulated by legislation; i.e., the implementation of standards is not mandatory but instead constitutes a show of good will by the manufacturer or the willingness to invest in antistatic protection. However, manufacturers and clients have been increasingly demanding their suppliers to implement solutions from the PN-EN 61340 and IEC 61340 standard series because, in this way, they may guarantee the quality and durability of their products (for example, ruling out the occurrence of electrostatic discharges from an employee's clothing to an electronic system). Electronic system damage constitutes a hidden fault that surfaces only during operation and is otherwise impossible to detect during production.

A multitude of standards apply to the electronics and ESD-susceptible component industries that define the control methods, testing procedures, and preventive measures meant to guarantee the safe manipulation – most often during production – of electronic elements. Electronic components (circuit boards, microprocessors) may become damaged as a result of a 50V – potential discharge. In the electronics industry, applying standards describing these testing and control methods is neither mandatory nor required by law. All the more often, the application of these standard requirements by companies dealing with electronics results from the necessity to ensure product and production quality.

The third hazard area encompasses industry – particularly those branches related to hazardous and flammable materials [11]. From the point of view of electrostatic protection, human work safety is regulated under European law by directive [12] concerning machines and under Polish law by the Ordinance of the Minister of Economy [13].

Polish legislation also includes the Ordinance of the Minister of Economy [14], the Ordinance of the Minister of Transport [15], the Ordinance of the Minister of Interior and Administration [16], and the Ordinance of the Minister of Agriculture and Food Economy [17]. These constitute the implementation of acts to the following laws: Technical Inspection [18], Labor Law [9], Building Code [10], and Fire Protection [19]. The requirements defined therein concern the protection from excess electrification in areas susceptible to risks posed by electrostatic charges.

The fourth hazard area concerns explosion hazard zones. This is the most restrictive area, and the antistatic parameters defined for it arise from European Union directives, ordinances of competent ministers, and standards that constitute the implementation of the acts. Material electrostatic property control, evaluation, and certification is necessary if the said materials are to be utilized in explosion hazard zones.

Machinery Directive 2006/42/EC [12] requires machinery manufacturers to design and implement machines and devices to prevent and reduce the accumulation of dangerous electrostatic charges or have systems to discharge electrical loads.

The ATEX Directive 2014/34/EU [25] aims to harmonize the regulations of the European Union member states regarding electrical and non-electrical equipment and protective systems intended for use in potentially explosive atmospheres. The regulations contained in this provision relate to safety and the protection of life. The directive requires the prevention of explosions by applying appropriate measures to prevent the formation of electrostatic charges capable of causing dangerous discharges.

ATEX Directive USERS 1999/92/EC [26] aims to set minimum requirements for the safety and health protection of employees in places where an explosive atmosphere may occur as well as impose specific obligations on the employer in this area. The employer's duty is risk assessment and the undertaking of technical measures to eliminate and minimize the threat, among others. The prevention of ignition is to consider the possibility of electrostatic discharge in places where the employees or work environment can be sources or carriers of voltage.

The directive on personal protective equipment 89/686/EEC [4] aims to harmonize the requirements for personal protective equipment and conformity assessment methods in the EU member states. The directive requires that personal protective equipment intended for use in potentially explosive atmospheres cannot be a source of spark or electric arc caused by electrification. The directive specifies protection measures in potentially explosive atmospheres, as antistatic products for the entire period of their application (that is, unchanging parameters). Protective measures must be made of materials that pose no threat in terms of static electricity.

Technical report CLC/TR 50404 [22] was prepared on the basis of a mandate given by the European Commission. The report contains a number of important practical information related to the implementation of antistatic protection measures. The report contains detailed information on the safe use of the majority of commonly used materials and products in mining and potentially explosive areas. The technical report has many connections with scientific publications as well as the results of experimental work.

The Act of Geological and Mining Law [2] indicates the proper minister for the economy as responsible for defining detailed requirements for the operation of particular types of mining plants in the field of occupational health and safety.

3. STATIC ELECTRICITY

In electrostatics, materials are divided based on their electrostatic properties. These divisions depend on the field of application – they vary for electronics, explosion safety, and other areas.

Using the surface resistivity criterion, materials were divided into the following categories (Fig. 1): electrostatically conductive (including screening materials), electrostatically dissipative, and insulative [20].

Electrostatic charges form during electrification. Electrification (i.e., the separation of negative electric charges from positive ones) consists of isolating charges from matter or removing them from each other [21]. Electrification occurs during actions such as friction, separation, splashing, spilling, grinding, thermal shifts, mechanical processes, phase transitions, and electric induction. All of these phenomena can be easily identified not only in everyday life but also in many technological and production processes.

During electrification ability evaluations, the triboelectric series should be analyzed; i.e., the arrangement of materials based on polarity and the electric charge magnitude generated when using contact friction methods. Some materials lose electrons more easily while others accumulate them more easily (Fig. 2).

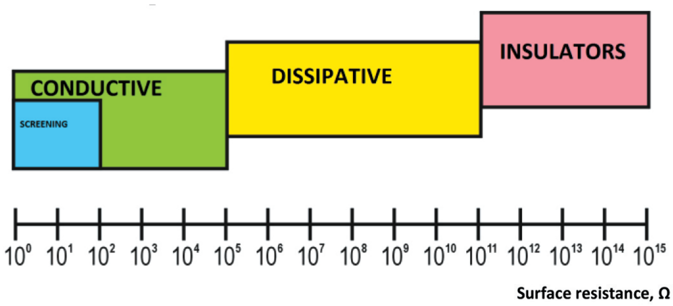

Fig. 1. Material division based on their electrostatic properties

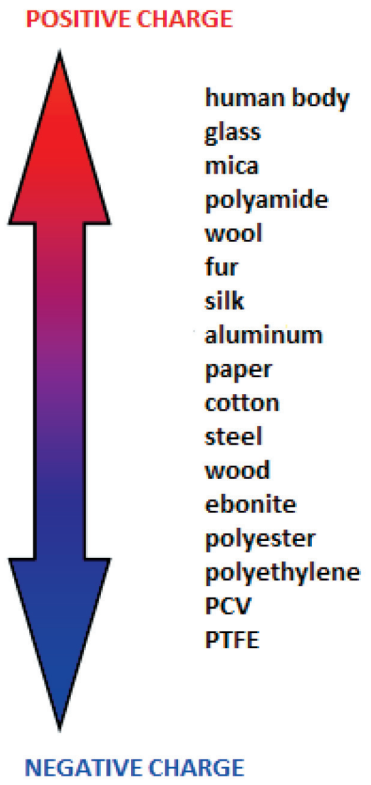

Fig. 2. Triboelectric series

The most common electrification method is electrification through contact and friction, also called contract friction or the contact point method. An electron exchange occurs at the contact point between two bodies – a so-called double layer. Once the bodies are separated, an excess of electrons (negative charges) will occur on one of them while a shortage of electrons (positive charges) will occur on the other. The number of generated excess charges is dependent on the surface properties, material type, and environmental parameters.

According to the triboelectric series principle, materials give away or receive electrons depending on their electron affinity during separation, resulting in an electric imbalance in the materials (an excess of electrons in one and a shortage in the other). Examples may be found in lifting feet from the ground (Fig. 3) or opening a book with a foil cover.

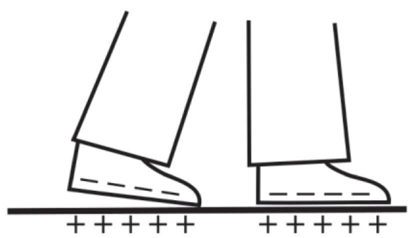

Fig. 3. Example of electrification through contact – lifting feet from ground

Similar as through contact, electrification through friction is related to the triboelectric series. As a result of mechanical friction, a transfer of electric charges occurs between two bodies; this results in their electrification with an excess electric charge. When studying electric charge signs during electrification through contact friction methods, it can be concluded that, in many cases, the charge sign depends on the electrification method. No studies have been conducted concerning the influence of electrification through friction could have on electrification through contact or vice versa (including separation and striking). Electrification by breaking contact is a form of electrification through friction.

4. ANTISTATIC PROCESSING

Antistatic processing (i.e., applying antistatic properties to a material) is a procedure based on changing the electric properties of a product realized in order to increase the charge dissipation (offtake) speed, decrease the electrification ability, or to both increase the charge dissipation (offtake) speed and decrease the electrification ability.

Some antistatic agents (fillers) added in order to impart certain features (e.g., color) possess antistatic properties and influence the electric property changes of the modified material, but they are not treated as antistatic agents (while their use is not treated as antistatic processing).

From the point of view of electrostatic properties [22], materials are divided into screening, conductive, dissipative, and insulative properties. Surface resistivity is the criterion for this division. Due to the above, antistatic processing can be considered a procedure based on the resistivity change of a material (i.e., its change from dissipative to conductive, from insulative to dissipative, or from insulative to conductive). Antistatic processing is presented in Figure 4.

Electric capacity also has an influence on the charge dissipation speed (Relationship 1); however, antistatic processing is not identified as a change in product electric capacity, for instance, because it is hard to modify and control the electric capacity of plastics. Furthermore, there are no defined standard methods for product electric capacity measurements. Adding metal elements to a product, for example, modifies not only its electric capacity but also its resistivity.

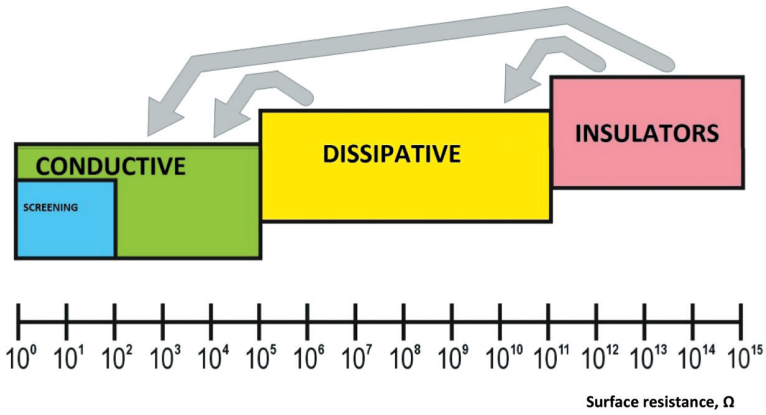

Fig. 4. Material division based on resistivity (antistatic processing)

Assuming that the antistatically processed material is grounded, then electrostatic discharges (excess electrostatic charge discharge or dissipation from the object to the earth or the grounding) can be described with the following exponential function:

$$Q(t) = Q_0 e^{-\frac{t}{RC}} \quad (1)$$

Relationship (1) shows that product electric capacity and resistivity have a decisive influence on the dissipation speed. In the article, product electric capacity has been treated as a product feature defining its ability to accumulate charges.

Assuming that the antistatically processed material is insulated, then the total electrostatic charge generated on the material will remain on it. Whether the electrostatic charge dissipates over the entire material surface or volume or remains in its place of generation (accumulation) depends on the material's resistivity. The charge surface distribution on the insulated material has great significance because it determines the electric charge magnitude on its surface. The electric potential of the electrified object and, consequently, the electrostatic discharge energy depends on product electric capacity regardless of the electrostatic charge magnitude accumulated on it.

5. ANTISTATIC PROCESSING REALIZATION METHODS

Based on the author's own studies, observations, and conclusions, antistatic processing has been divided (Fig. 5) with regard to three characteristics: the type of antistatic processing, type of preparation (utilized filler), and stage at which antistatic processing is conducted in the overall production process [23]. Using the antistatic processing division presented in Figure 5, eight methods of the antistatic processing realization methods of plastics were identified; these determine eight different types of antistatically processed materials (Fig. 6).

Each antistatically processed product may be examined according to the division pictured in Figure 5, characterizing it with regard to the type of antistatic processing, type of preparation, and stage of conduction (classifying it as one of the eight types of antistatically processed materials).

Determining eight antistatic processing realization methods of materials is significant during the evaluation of antistatic processing realization [24].

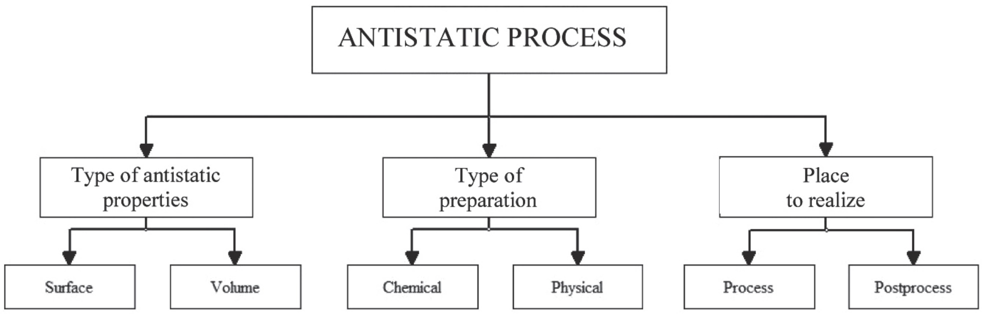

Fig. 5. Antistatic processing division

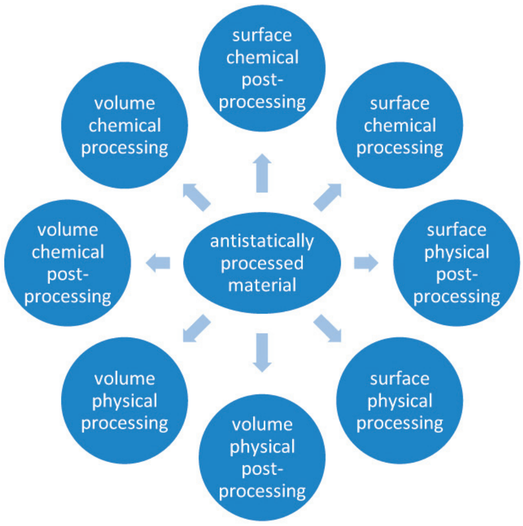

Fig. 6. Types of antistatically processed materials

6. SUMMARY

The article attempted to identify, characterize, and evaluate various antistatic processing realization methods of plastics commonly utilized in hard coal mining. It could seem that antistatic processing is an easy way to decrease material electrification ability. The performed identification is the author's own proposal devised on the basis of years of studies and observations as well as electric parameter correlation evaluations (interdependences and mutual relation). Based on studies and observations, different antistatic processing realization methods were identified, which are characterized by different properties directly related to explosion safety in mines. The identified antistatic processing methods were evaluated from the point of view of their safe utilization.

An appropriate material antistatic property study methodology was selected. The adopted study catalog based on the analysis of suitability for antistatic processing identification made it possible to unambiguously define the antistatic processing realization methods. Some study methods (e.g., electrification ability) were not classified as appropriate measuring methods for antistatic processing method identification. The study methods were selected in such a way so that the measurement results would provide information concerning the antistatic processing method. The proposed study method division into static and dynamic parameters made it possible to formulate conclusions concerning the interdependence of these parameters. The mutual relationships of specific electrostatic parameters (understood as the tendency of their interdependences and mutual relationships as explained in the beginning chapters of the article) describe the product according to the division adopted by the author, which includes the type of antistatic processing, type of preparation, and antistatic processing stage of conduction.

Two antistatic processing procedures were conducted for the article. A plastic material was modified during the first one – technical foil. During the second procedure, the mining foil was modified by using three different antistatic agents; additionally, each of them featured two different concentrations. The antistatic processing procedures were conducted according to the antistatic processing realization methods identified in the article.

It was also attempted to evaluate the efficiency of various antistatic processing realization methods. Efficiency should be understood as a final product evaluation and fulfilment of the planned requirements concerning the product antistatic properties. It has been proven that a part of the identified antistatic processing methods was characterized by the significant heterogeneity of the final product, the instability of its antistatic properties over time, or its influence on the environment via the exudation or flaking processes of the antistatically processed material. It was observed that the property durability of materials antistatically processed with some methods is dependent on various factors present in mines, such as the relative humidity or mine atmosphere – the materials lose their antistatic properties after being flushed with water, for example.

7. CONCLUSIONS

The products utilized in hard coal mining must meet the requirements concerning the technical parameters defined by Polish law, ensuring their safe use. The Ordinance of the Minister of Economy, (dated June 28, 2002) concerning industrial safety, mining plant operations, and specialist fire protection in underground mining facilities [Dz.U. dated 2002, No. 139, Item 1169] constituting an implementing act to Mining Law [Dz.U. dated 2016, item 1131] permits products manufactured from plastics for use in underground mine workings if they are characterized by slow-burning, antistatic, and non-toxic properties. A literature analysis shows that a great majority of plastics do not possess antistatic properties. It can be stated that all products manufactured from plastics utilized in mining are antistatically processed because the law requires them to possess antistatic parameters. The quality of the final product utilized in a mine depends on the method and type of antistatic processing. An antistatically processed product should be durable over time and should not negatively influence the work comfort of miners, because the safety of the people working in explosion hazard zones in Polish underground coal mining depends on the antistatic processing realization method.

When conducting work for this article, it was observed that products utilized in underground mine workings do not meet the full safety requirements concerning the stable and safe antistatic parameters. There are products that fulfill the antistatic requirements during testing, but their properties fade after a certain amount of time. It was also observed that there are no unambiguous legal requirements concerning the electrostatic property evaluation of a product. Defining a requirement for a product to "possess antistatic qualities" is definitely too limited. They would need to be made more specific and precise. It can be concluded (for example, based on the lack of mutual electric parameter relationships of the antistatically processed products) that the current legal status qualifies products fulfilling the resistivity criterion as safe when they do not meet the charge decay time criterion or vice versa.

A dynamic increase in the contribution of plastics in the manufacturing of products utilized in industry results in the increase of the amount of plastics used in mines. The conclusions formulated in the article should be used by manufacturers of plastics utilized in Polish hard coal mining. Even through higher expenditure, the manufacturers should manufacture products that pose no risk of explosion throughout their entire period of utilization that would have stable antistatic parameters and whose antistatic processing realization methods would have no negative influence on the environment or work comfort of the underground mine personnel.

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