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## **Fire and Explosion Hazards Associated with Electrostatic Powder Coating**

### **Abstract**

This paper presents fire and explosion hazards during electrostatic powder coating, and describes the course of the process as well as the characteristics of powder coating as a combustible material. Potential sources of ignition that could initiate a fire of a dust layer or an explosion of a dust-air mixture have been identified. The minimum requirements and recommendations raising the level of safety in the area of coating installations are presented.

**Keywords:** fire hazard, explosion hazard, static electricity, powder coating

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## **Zagrożenia pożarowo-wybuchowe związane z elektrostatycznym nanoszeniem powłok z tworzyw sztucznych**

### **Abstrakt**

W niniejszym artykule przedstawiono zagrożenia pożarowo-wybuchowe występujące podczas nanoszenia powłok metodą elektrostatyczną, przedstawiono przebieg operacji oraz charakterystykę farb proszkowych jako materiału palnego. Zidentyfikowano potencjalne źródła zapłonu, które mogą zainicjować pożar warstwy pyłu lub wybuch mieszaniny pyłowo-powietrznej. Przedstawiono minimalne wymagania i rekomendacje podnoszące poziom bezpieczeństwa w obszarze instalacji lakierniczej.

**Słowa kluczowe:** zagrożenie pożarowe, zagrożenie wybuchowe, elektryczność statyczna, farba proszkowa

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## **Загрози пожежі та вибуху пов'язані з електростатичним нанесенням пластикових покриттів**

### **Анотація**

У цій статті представлені загрози пожежі та вибуху, що виникають під час нанесення покриттів електростатичним методом. Представлено перебіг операцій та властивості порошкових фарб як горючого матеріалу. Визначено потенційні джерела займання, які можуть спричинити загоряння пилового шару або вибух пилоповітряної суміші. Представлено мінімальні вимоги та рекомендації, що підвищують рівень безпеки в зоні накладання фарби.

**Ключові слова:** загроза пожежі, загроза вибуху, статична електрика, порошкове фарба

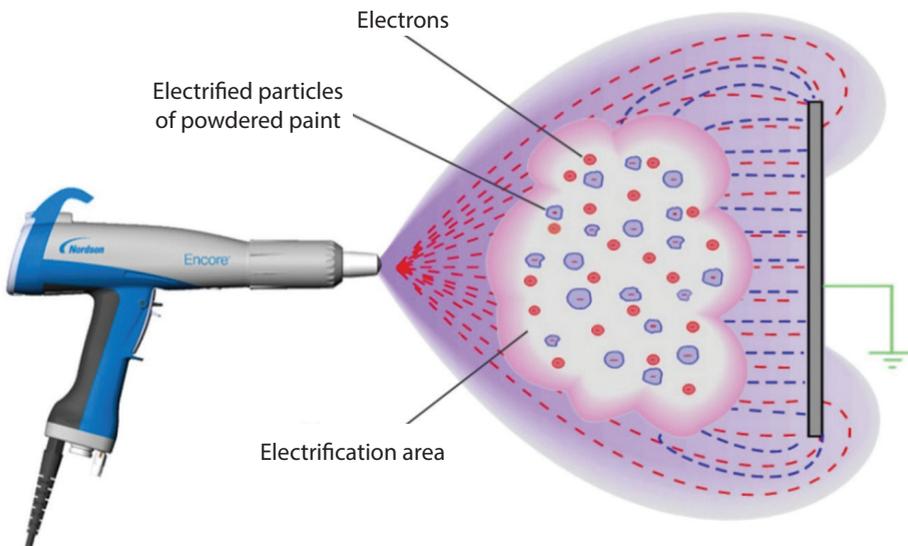
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### **1. Introduction**

In many industrial branches associated with mass production it is required that product surfaces have appropriate properties as regards protection from atmospheric corrosion, mechanical properties or aesthetic values. One of the most universally adopted methods of securing ready elements is the application of protective coats with the use of the electrostatic method. For this purpose use is made of powder paints based on thermoplastic and thermosetting materials. Polymer coating materials do not contain liquid combustibles, i.e. varnish solvents. The electrostatic method has a broad range of possible applications, among others for protecting furniture, household appliances, steel structural elements, pressurised containers and elements of electric devices. During the execution of technological process a layer of flammable powder may be formed. The phenomenon of explosion or fire poses a direct hazard for the life and health of operators of painting equipment. The present article contains a general outline of possible hazards and basic protective means.

## 2. Description of the powder coating process

Powder coating is a process connected with a continuous occurrence of the electrostatic field, which is generated between the electrode on the head of the powder coating device and earthed coated elements. Painting devices are powered by DC voltage with a value of 40–100 kV for hand guns and up to 150 kV for automatic devices. Electrification of particles of the coating material takes place due to contact with the head surface and ionised air, induction, as well as ion adsorption in the sprayed cloud. Figure 1 presents a general diagram of plastic powder coating onto an earthed element.



**Fig. 1.** General drawing of powder coating process using the electrostatic method

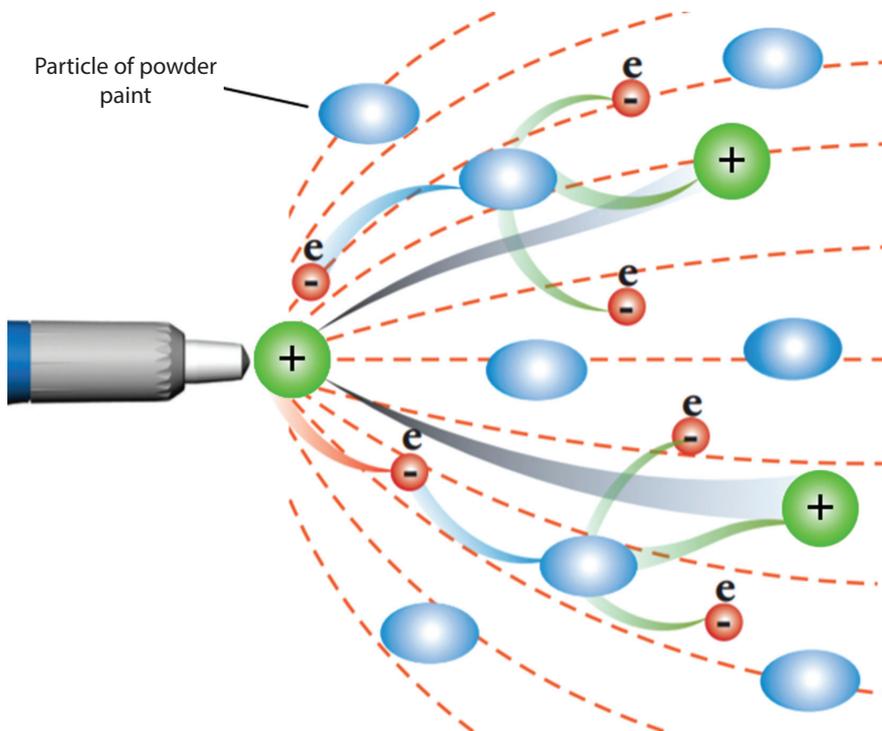
Source: own study based on [12]

As a consequence of the occurrence of a considerable difference between electric potentials in the space between the gun head and the element being coated, air molecules become ionised. The presence of the electrostatic field affects the movement of electrified particles. As an effect of the appearance of a powder paint particle in the area of active air ions, electrical charges become collected on its surface [3]. A point electrical charge of a single powder paint particle depends on dielectric properties of plastic material, electric field intensity as well as shape and diameter, according to the formula [1]:

$$q = k \cdot E \cdot r^2$$

$q$  – electric load [C];  
 $k$  – coefficient ( $k = \frac{3\varepsilon}{\varepsilon + 2}$ ) [-];  
 $\varepsilon$  – dielectric constant of plastic material [F/m];  
 $E$  – field intensity [N/C];  
 $r$  – radius of particle [m].

The general diagram of ion bombardment of particles of powder paint during spraying was presented on figure 2.



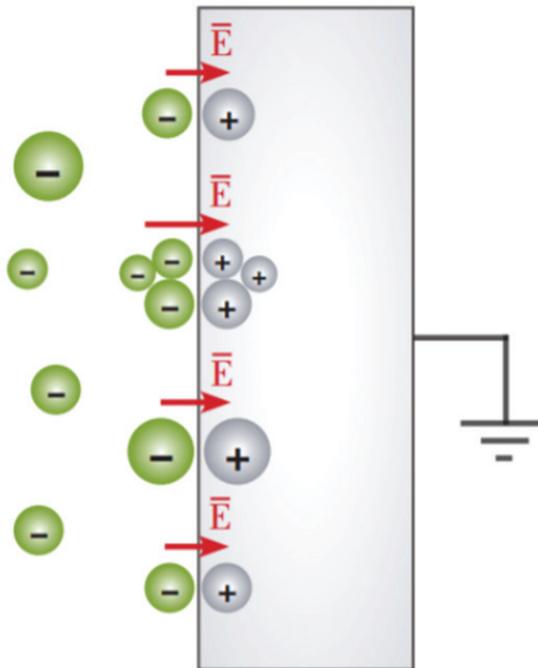
**Fig. 2.** Electrification of particles of powder paint during spraying

Source: own study based on [12]

Forces of the electrostatic field direct electrified particles along the line of the field, in such a way allowing their transport. Settlement of powder paint is possible in a situation of occurrence of earthed coated elements serving as the positive pole inside the

field line. If the coated element is too far away from the head of the painting device, the stream of paint being sprayed may be directed onto the device or the operator. The flow rate of powder particles is ca. 2 m/s and is a resultant of the flow rate of air stream and rate of movement caused by forces of the electrostatic field [1].

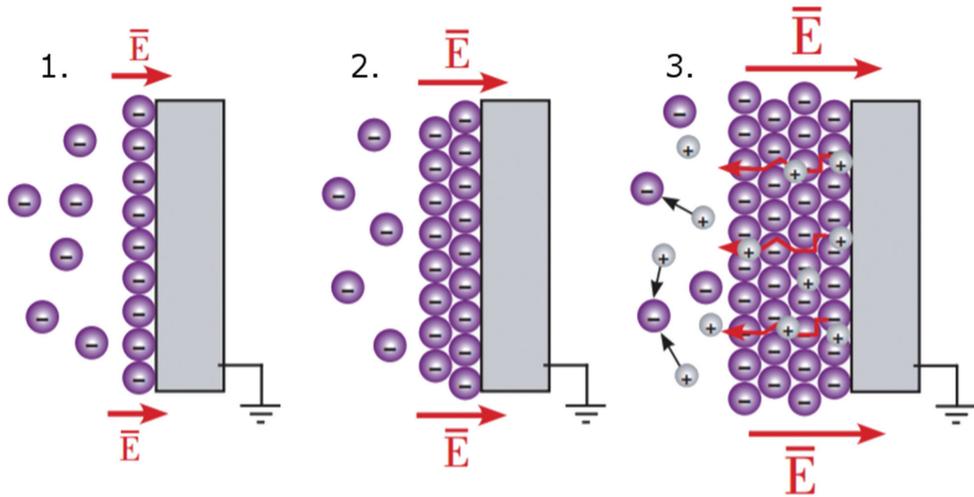
Settlement of powder on the element surface lasts until the moment when the pull of particles exerted by the earthed element becomes balanced by the total of repulsive forces acting between electrified grains [1]. The general mechanism of powdered paint particle settlement was presented on figure 3.



**Fig. 3.** Mechanism of coat formation

Source: own study based on [12]

If the operation is continued, the state of electrical balance of the coat becomes disturbed. Electrons would not become dissipated, because electrified particles would not settle on the surface of the element being coated, in such a way forming a coat of increasing thickness. This may lead to violent chipping of single grains or clusters of powder paint from the element [1]. The general course of this phenomenon has been presented on figure 4.



**Fig. 4.** Formation of a layer of ionised particles

Source: own study based on [12]

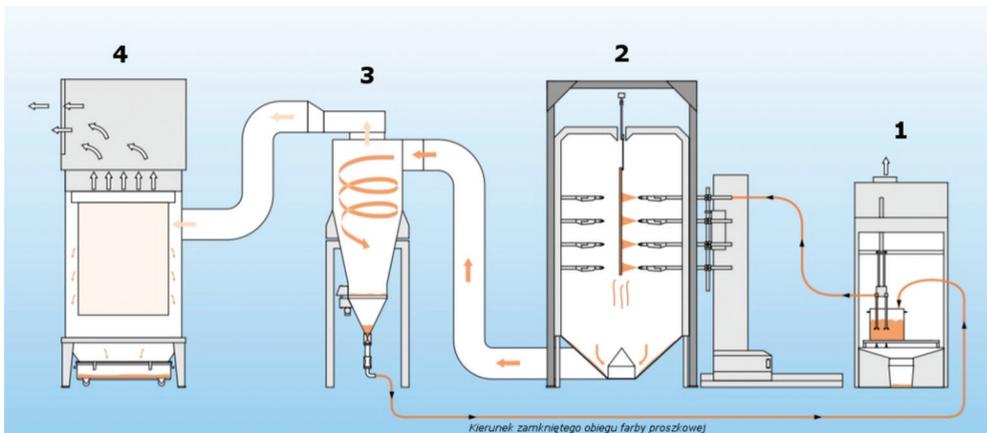
An important factor is grading of dust, which has a considerable impact on abilities of dispersion and coat formation. Optimum parameters of coat adherence are generally achieved when the used powder paints have grading within the range of 40–100  $\mu\text{m}$  [1]. Below that range clusters or lumps may form in containers and then a strong spattering could occur during the application. Furthermore, during spraying of particles with diameters larger than 100  $\mu\text{m}$  single grains or clusters fall off from the surface of the element [1]. Figure 5 presents the electrostatic coating method applied by operators in the paint booth.

Excess of sprayed powder paint gets into the closed recovery system, which comprises a cyclone and then an air filter. The movement of unsettled particles is caused by the flow of air generated by exhaust mechanical ventilation from the area of the paint booth. The function of the cyclone is to separate the powder paint from air sucked in as a consequence of centrifugal forces. The precipitated powder is fed to the supply system of the powder coating cabin for re-use in subsequent coating operation [1]. The air sucked in then flows to the filter, where its final treatment takes place. Particles of powder paint settle on filter cartridges or bags, while air flows through their structure [3]. Figure 6 presents a diagram of typical installation for electrostatic application of plastic coat, which consists of system that supplies powder paint (1), paint booth equipped with automatic painting devices (2), cyclone (3) and air filter (4).



**Fig. 5.** Powder coating using manual devices by operators

Source: [11]



**Fig. 6.** Diagram of typical painting installation

Source: [10]

### 3. Fire and explosion hazards connected with usage of powder paints

As regards the application of plastic paint coats by the electrostatic method one should take into consideration the hazard of initiating a combustion reaction of the settled powder layer, which could potentially give rise to a fire. It is also necessary to analyse a hazard of explosion due to the presence of sprayed cloud of powder paint.

A fire may break out in the event of concurrent presence of three factors: fuel, oxidiser and source of ignition. In the event of an explosion it is also possible that a mixture could occur with a concentration between the lower and upper explosion limit, as well as limited space.

#### 3.1. Features of fuel

Powder paints are compositions of plastic materials containing additives with specific grading, which are used to form a coat of the desired thickness strictly adherent to a given surface and assuring the required chemical and mechanical features.

The main component of powder paints are polymeric multi-molecule compounds. The structure of polymers consists of given initial particles, the so-called “monomers” interconnected by physical forces. The polymerisation degree is a parameter that defines the number of monomers in the particle, and for plastics its value is generally over 1000. On the basis of macro-particle structure a distinction is made of the used thermoplastic materials, such as polyethylene, polyamide, polyvinylchloride, bitumen, bitumen-epoxy compositions, polycarbonate and thermosetting materials, such as epoxy resin, polyester resin, alkyd resin and acrylic resin. The structure of the powder paint also comprises hardeners used to cross-link the polymer during the baking process, pigments necessary to assure the selected product colour and other additives that affect properties of the paint, such as UV stabilisers.

Requirements imposed on coating materials to be applied when using the electrostatic method determine values of parameters of resistivity and electrical permeability. Resistivity should be contained within the range of  $10^4$  to  $5 \cdot 10^{10}$   $\Omega \cdot \text{cm}$ . Below this range the electrostatic adhesion decreases and particles fall off due to force of gravity, and when resistivity exceeds  $5 \cdot 10^{10}$   $\Omega \cdot \text{cm}$ , an electrostatic field is created with high intensity and a local inherent spark discharge may take place. The high value of electrical permeability is characterised by a stronger influence of the field exerted on the charge and reduces the trends of particle unloading in the air.

Sprayed powder paints form dust explosion atmospheres with air. Conducted studies pertaining to paints based on polyester and epoxy resins allowed making the following conclusions pertaining to the percentual composition of explosive parameters. For all the tested samples similar values of the maximum explosion pressure have been ascertained. The value of the maximum increase rate of explosion pressure tends to decrease with the increase of the contents of dye and particle dimensions. The value of minimum ignition energy increases with dimensions of particles. The value of the lower explosion limit grows in proportion with the growth of dye contents [4].

Taking into account the diversity of composition and percentual composition, it is necessary to determine the fire and explosion parameters individually for each powder paint. Typical values of the lower explosion limit for powder paints remain within the range of 20–70 g/m<sup>3</sup> [5]. If there is no information available concerning the value of LEL of the given powder paint, the value of 20 g/m<sup>3</sup> may be assumed [6]. Based on the conducted studies a typical range of values of minimum ignition energy of powder paints was recorded within the range of 3–20 mJ [4]. Explosive parameters of selected powder paints from the database of standard NFPA 33:2018 were presented in Table 1.

**Table 1.** Explosiveness parameters of selected powder paints

Item	Base polymer of powder paint	Coefficient K <sub>st</sub>	Explosiveness class of powder	Maximum explosion pressure	Lower explosion limit	Self-ignition temperature of dust cloud
		m-bar/s	–	bar	g/m <sup>3</sup>	°C
1.	Epoxy resin	152	St 1	6.7	95	500
2.		194	St 1	7.5	60	477
3.		228	St 2	8.1	45	472
4.	Polyester resin	204	St 2	8.3	75	458
5.		154	St 1	8.1	65	457
6.		70	St 1	6.5	70	446
7.*		177	St 1	8.1	65	452
8.*		148	St 1	7.6	60	464
9.*		184	St 1	8	50	460
10.		Epoxy-polyester resin	149	St 1	7.6	45
11.	101		St 1	6.5	115	478
12.	152		St 1	7.2	115	475
13.*	189		St 1	8.2	45	482

\* Powder paint contains less than 10% of aluminium based pigments.

Source: own study based on [9]

### 3.2. Availability of oxidiser

In regular process conditions in which operators are present in the work environment, oxidiser consisting of oxygen from atmospheric air occurs always. Imposed air flow also serves as a factor that transports powder paint and is present in all technological appliances.

### 3.3. Features of ignition sources

Several factors should be taken into consideration, the occurrence of which may lead to initiation of a fire or an explosion. According to the standard PN-EN 1127:2019-10 there are 13 groups of ignition sources that need to be analysed. Given the working environment and parameters of the process of electrostatic coating of plastic materials, the following most probable effective sources of ignition were selected [8]:

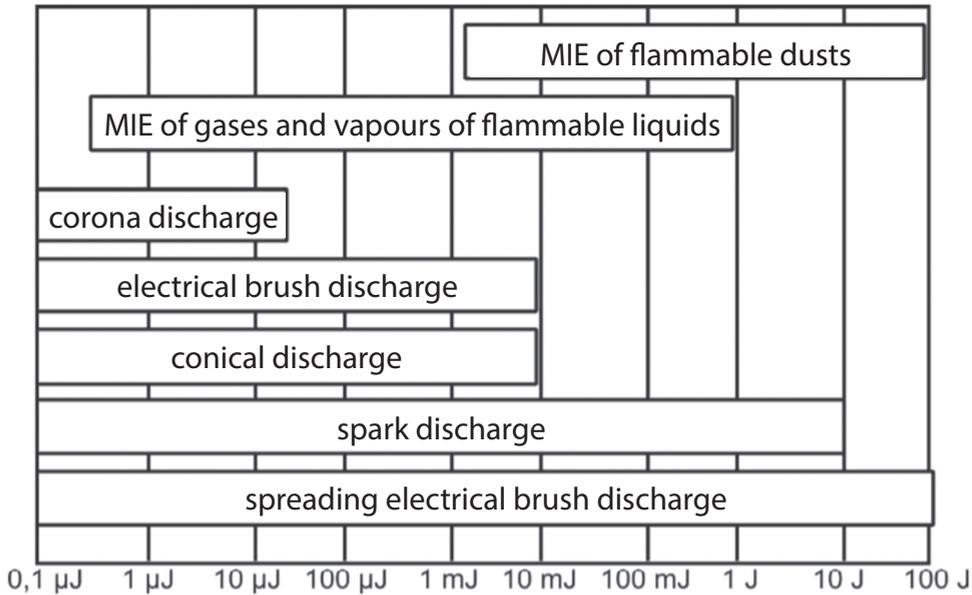
- hot surfaces,
- flame and hot gases (including hot particles),
- mechanical spark,
- electrical appliance,
- electrostatic discharge,
- exothermal reactions (including self-ignition of powder).

Continuous generation of the electrostatic field increases the likelihood of initiating ignition of a powder and air mixture from electrostatic discharge. Dust explosive atmosphere are characterised by a relatively high minimum ignition energy, much higher than that of gaseous explosive atmosphere. Not every type of electrostatic discharge can initiate an explosion of a mixture of flammable dust with air. Typical values of energy released during the given type of discharge taking into account ignition abilities of explosive atmospheres were presented on figure 7.

A particular hazard is constituted by the spreading electrical brush discharge, the energy of discharge of which may even be as high as a few thousand joules and may initiate the explosion of any explosive atmosphere. In industrial practice this type of electrostatic discharge may occur among others between the surface of electrified dielectric, which covers the conductive material and the surface of approaching earthed conductive object or puncture of the dielectric coat applied onto an earthed conductive surface. On the basis of studies and experiments it was concluded that there are many factors that determine the occurrence of such a phenomenon. An analysis should be

carried out of the possibility of a spreading electrical brush discharge as a potential source of ignition, if [2]:

- surface density of the charge is at least  $0.25 \text{ C/m}^2$ ,
- thickness of the dielectric layer is less than 10 mm,
- dielectric resistance of the material is below 4 kV/m.



**Fig. 7.** Value of released energy of electrostatic discharge and values of the minimum ignition energy (MIE) of flammable substances

Source: [2]

### 3.4. Possibility of a fire

The fire hazard arises from the presence of powder paint in the given space as a side effect of the spraying operation or due to accidental spillage. The combustion reaction of a formed powder layer may be initiated due to external ignition sources, such as hot air, flames, and mechanically generated sparks or during an exothermal reaction through self-ignition. The cause of its occurrence may be a human factor, i.e. failure to follow applicable OHS and fire protection regulations or inappropriately selected electric and non-electric tools for work with flammable dusts. A potential fire may spread in a very short time as a result of inappropriate storage of powder paint.

### 3.5. Possibility of explosion

The explosion hazard occurs much more frequently than a fire hazard due to the continuous movements of powder paint in the paint booth and the recovery system. Inside technological appliances there is limited space and a high dispersion level. The presence of a dust explosive atmosphere and the occurrence of the ignition source, and namely hot surfaces, flames, electrical appliances, electrostatic discharge or mechanically generated sparks may give rise to initiation of an explosion. Particular attention should be drawn to protection from static electricity to make sure that the value of earthing resistance in conductive materials does not exceed 1 M $\Omega$  [7]. Electrification of particles occurs regularly during coating and may take place as a result of friction during pneumatic transport in the recovery system or during filling of flexible powder paint containers.

## 4. Minimum requirements and rules of safety

For need of eliminating or significant limiting of possible hazards resulting from the presence of a powder explosion atmosphere during electrostatic powder coating, basic requirements and principles of technical standards should be followed with respect to fire and explosion safety [6, 7]:

- 1) organisational protective means:
  - a) operators of manually operated painting devices should be trained and made familiar with the following hazards:
  - b) should a spillage take place, its elimination should be started without delay with the use of devices appropriate for work with flammable dust, such as for example explosion-proof industrial vacuum cleaner,
  - c) smoking and the use of open fire should be absolutely prohibited on the plant premises,
  - d) earthing elements should be inspected on a regular basis, and if the conductors become disconnected the resistance value should be measured,
  - e) mounting elements designated for coated elements should be regularly cleaned to assure appropriate earthing of the element,
  - f) zones of explosion hazard should be delimited in the area of the paint booth and the recovery system,
  - g) no plates, screens or signs made of plastic should be used of a thickness of less than 10 mm or the value of breakdown current below 4 kV inside the paint booth,

- h) type FIBC containers should be connected to earthing during the operation of filling or emptying,
  - i) explosion parameters of each powder paint should be set out individually;
- 2) technical protection means:
- a) the spray booth should be equipped with a fire detection system,
  - b) the provided exhaust ventilation from the paint booth should have an output assuring that the average concentration of powder paint does not exceed 50% of the lower explosion limit,
  - c) only electrical appliances adopted for use in the given explosion hazard zone may be used,
  - d) the possibility of securing the recovery system using systems protecting from consequences of explosions should be analysed,
  - e) earthing should be assured for all conductive elements in the area of the paint booth with resistance value below 1 M $\Omega$ ,
  - f) conductive flooring should be assured with resistance value below 100 M $\Omega$  in the area of the paint booth,
  - g) operators of manually operated painting devices should use personal protection means with anti-static properties,
  - h) only filter cartridges/bags with anti-static properties may be used.

## 5. Recapitulation and conclusions

During the process of powder coating of plastic materials a possibility exists of an explosion or a fire. The specific nature of the process imposes continuous spraying, as a consequence of which an explosion atmosphere may occur in confined spaces during routine operation. Powder paints based on thermoplastic or thermosetting polymers are flammable materials, and when in a mixture with air they form explosion atmospheres. The generation of an electrostatic field with the use of appliances powered by high voltage assures conditions conducive to discharges of static electricity. Given the potential hazards and their impact on the life and health of people working with painting installations, it is necessary to assure a high technical safety level with respect to dissipation of electrical charges and the state of electrical and non-electric appliances. Requirements of legal regulations and technical standards concern in particular explosion protection, but the occurrence of a fire is also highly probable and may pose a direct hazard for life and health. In practical terms complete ruling

out of an effective source of ignition is impossible, and hence the introduction of fire and explosion protection protective systems to painting installations is of considerable importance for maintaining the required safety level.

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**Jakub Bielawski** – absolwent Szkoły Głównej Służby Pożarniczej studiów I stopnia na kierunku inżynieria bezpieczeństwa w zakresie inżynierii bezpieczeństwa pożarowego.