Theoretical aspects regarding the selection of personal protective equipment intended for use in Ex., environments in order to avoid the danger of initiating explosive atmospheres generated by hydrogen

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Abstract. Personal protective equipment used by workers to protect them against one or more risks that could endanger their safety and health at work can acquire electrostatic charges as a result of the friction phenomenon that occurs during movements during work tasks, respectively the induction phenomenon, a situation in which the transfer of electrostatic charges occurs from highly electrostatically charged objects such as, for example, a FIBC into which a powdery material is poured. In the case of using personal protective equipment in environments with a risk of potentially explosive atmospheres and under the conditions mentioned above, they may constitute a risk, namely that of initiating potentially explosive atmospheres through electrostatic discharges that occur when dangerous electrostatic potentials accumulate. Personal protective equipment intended for use in explosive atmospheres must be designed and manufactured in such a way that it cannot be the source of an electric or electrostatic arc or spark which could ignite a potentially explosive atmosphere. To ensure the highest possible level of occupational health and safety, an important role is played by the selection of personal protective equipment intended for use in environments with a potentially explosive atmosphere, depending on the risk factors and the classification of hazardous areas Ex.

1 Introduction

Personal protective equipment used by workers during the performance of work tasks in potentially explosive atmospheres, to ensure their protection against one or more risks that could endanger their safety and health at work, must be designed and manufactured in such a way that it cannot constitute a source of ignition for explosive atmospheres generated by hydrogen.

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The category of ignition sources that can initiate explosive atmospheres generated by hydrogen as well as other flammable/combustible substances includes static electricity and electrostatic discharges originating from personal protective equipment (clothing, footwear, head, hand and arm, face and eye protection items), respectively from the people who use them.

Static electricity, which leads to electrostatic discharges, most often occurs as an unwanted and accidental phenomenon as part of technological processes, such as, for example, sorting products or applying coating substances in an electrostatic field, etc.

The occurrence of electrostatic discharges as a result of electrification of personal protective equipment and people constitutes a risk, such as the initiation of explosive atmospheres, the untimely detonation of electric detonating caps and pyrotechnic items, the destruction of sensitive command and control equipment.

Since the initiation of explosive atmospheres generated by hydrogen and other flammable/combustible substances, through electrostatic discharges, leads to an explosion and/or fire, it is necessary to apply technical and organizational measures to ensure the safety and health of workers and other persons involved in such events. Therefore, it is of particular importance to prevent the risk of explosion and/or fire in order to ensure the highest possible level of occupational health and safety.

A solution in this regard consists in the use of personal protective equipment suitable for use in environments with a risk of explosive atmospheres generated by hydrogen, whose protective performance makes it impossible to generate ignition sources of an electrical, mechanical or other nature.

On the other hand, another solution consists of preventing the formation of explosive atmospheres generated by gases, vapors, mists and/or dusts mixed with air in industrial spaces where combustible/flammable substances are processed, transported, or stored, due to technological processes or accidental leaks.

However, in order to reduce the risk of explosions due to the initiation of explosive atmospheres generated by hydrogen, through electrostatic discharges from personal protective equipment, the materials used in the manufacture of clothing, footwear, articles for protecting hands, arms, etc., must have antistatic properties to limit the accumulation of electrostatic charges and at the same time to dissipate them to the ground.

Given that personal protective equipment during use can accumulate electrostatic charges that subsequently lead to the occurrence of electrostatic discharges, special attention must be paid to their selection for use, taking into account the Ex. zones, the probability of charging, the explosion groups and the minimum energy of flammable substances that, when mixed with air, generate explosive atmospheres.

Considering the aforementioned aspects, it follows that the personal protective equipment selected for use in explosive atmospheres generated by hydrogen must satisfy the essential health and safety requirements relating to the danger of explosions by avoiding electrostatic ignition sources.

2 Essential safety requirements for personal protective equipment used in explosive atmospheres generated by hydrogen

Personal protective equipment to be used in explosive atmospheres generated by hydrogen must meet the applicable essential health and safety requirements, depending on the equipment category and the Ex. areas, regulated by Regulation (EU) 2016/425 of the European Parliament and of the Council of 9 March 2016 on personal protective equipment and repealing Council Directive 89/686/EEC.

According to requirement 2.6 of Regulation (EU) 2016/425 "PPE intended for use in potentially explosive atmospheres must be designed and manufactured in such a way that it cannot be the source of an arc or spark of an electrical, electrostatic or shock nature, which could ignite an explosive mixture" [1].

To establish the compliance of personal protective equipment with the essential health and safety requirements regulated by Regulation (EU) 2016/425, it is necessary to assess it in relation to its protective performance against dangerous static electricity.

Regarding the assessment of personal protective equipment in terms of its protection performance against static electricity, the requirements are given in Regulation (EU) 2016/425, as well as in a series of specific standards for types of personal protective equipment.

At the same time, the safety requirements applicable to personal protective equipment used in Ex areas are given in the standards: SR EN 1149-5:2019 Protective clothing. Electrostatic properties. Part 5: Performance requirements for materials and design requirements; SR EN ISO 20344:2022 Personal protective equipment. Test methods for footwear; SR EN ISO 21420:2020/A1:2024 Protective gloves. General requirements and test methods.

Requirements for the prevention of dangerous electrostatic discharges from humans are given in IEC 60079-32-1/TS/Ed1: Explosive atmospheres - Part 32-1: Electrostatic hazards, Guidance [2].

The safety requirements for antistatic protective clothing to avoid sparks that could cause an ignition, according to SR EN 1149-5:2008, are as follows:

2.1 Requirements for textile materials used in the manufacture of protective clothing used in Ex environments.

For textiles to be considered electrostatically dissipative, they must meet at least one of the following requirements, according to standard SR EN 1149-5:2019 [3]:

- either the geometric mean of t50% < 4 s when tested according to test method 2 (induction loading) of EN 1149-3:2004, or
- arithmetic mean of S > 0.2 tested in accordance with test method 2 (induction loading) of EN 1149-3:2004, or

the geometric mean surface resistivity is ≤ 2.5 x 109 Ω on at least one of the surfaces, when the material is tested in accordance with EN 11491-1.

For materials containing conductive threads (conductive surface fibers or conductive core fibers) in the form of a grid, the distance between the conductive threads in one direction shall not exceed 10 mm in any part of the material.

2.2 Design requirements for protective clothing used in Ex environments.

Antistatic protective clothing must allow all unsuitable materials to be covered at all times during normal use (including bending and body movement). If the antistatic protective clothing is made of multi-layer materials, one of which is for example an insulating material, etc., then the outer material must meet the material requirements mentioned above.

The antistatic protective clothing to be used must correspond to the user's body conformation according to the SR EN 340 standard so as to allow body movement with all closures provided according to the manufacturer's instructions.

If antistatic protective clothing is fitted with attachments made of non-conductive materials such as labels, reflective tapes, etc. essential from a safety point of view, these may

be used provided that they remain permanently attached in such a way as to avoid separations between the attachments and the personal protective equipment.

Conductive parts that ensure the closure of antistatic protective clothing, such as: zippers, snaps, buttons, are permitted provided that they are properly covered by the outer material when the clothing is worn in explosive atmospheres.

The safety requirements for footwear that provides protection against static electricity in people are given in specific standards, which classify footwear according to the electrical leakage resistance through the sole, into two categories, namely: electrostatic conductive footwear and antistatic footwear, according to SR EN ISO 20344:2022 [4]:

- antistatic footwear is footwear whose electrical resistance is between 100 kΩ and 1 GΩ.

It is recommended to use this type of antistatic footwear when it is necessary to limit the process of accumulation of electrostatic charges by dissipating them to the ground. It should be noted that antistatic footwear does not provide adequate protection against electric shock, because it only contains a resistor located between the foot and the floor.

If the risk of electric shock has not been completely eliminated, additional measures are necessary.

- electrostatically conductive footwear is footwear whose electrical resistance is less than100 kΩ.

It is recommended to use electrostatically conductive footwear when it is necessary to reduce the accumulation of electrostatic charges by dissipating them in a very short time, for example, when handling explosives.

It is very important that in industrial spaces where antistatic or electrostatically conductive footwear is worn, the ground or floor does not nullify the protection offered by the footwear, but has antistatic properties.

Other personal protective equipment, such as: helmets, gloves, respiratory protection devices, etc., must be designed and manufactured according to specific standards, so as to avoid the accumulation of potentials that could lead to dangerous electrostatic discharges.

3 Theoretical aspects regarding electrostatic charging of people and personal protective equipment used in areas with a risk of explosive atmospheres generated by hydrogen

Both users and the personal protective equipment used by them, during the performance of work tasks, can accumulate electrostatic charges, which subsequently lead to the occurrence of electrostatic discharges. In the case of people, protection against electrostatic discharges from people is to ensure that they are properly grounded by means of footwear and floors with antistatic properties.

When people are grounded, there is no possibility of dangerous electrostatic discharges from them. However, electrostatic discharges from their protective clothing and other items of personal protective equipment may be possible, in which case electrostatic dissipative protective clothing should be used.

However, it should be noted that the use of electrostatic dissipative protective clothing cannot eliminate the risk of dangerous electrostatic discharges from isolated persons. Some personal protective equipment, for example antistatic or electrostatic conductive footwear, is intended to ensure an adequate connection between persons and earth, but these are only effective if the connection to earth is not compromised.

For example, antistatic or electrostatic conductive footwear is only effective when used in combination with dissipative or conductive flooring. Although electrostatic dissipative footwear and protective clothing can help reduce the risk of dangerous electrostatic discharges, they cannot be used as a substitute for proper grounding.

According to Directive 1999/92/EC, employers are required to eliminate all possible sources of ignition in areas where explosive atmospheres are known to be present. For example, if a person is working with a flammable gas, such as at a hydrogen filling station, there is a risk that a brush discharge from ordinary clothing could ignite the gas, as the energy of a brush discharge may be greater than the minimum ignition energy of the gas [5].

In this situation, according to Directive 1999/92/EC, the employer is obliged to provide electrostatic dissipative protective clothing if the danger associated with an explosive atmosphere cannot be eliminated by technical measures. On the other hand, in the case of handling a powder with a minimum ignition energy greater than 1 mJ, there is no risk that a brush discharge from ordinary clothing will cause an ignition of the powder.

In this case, the employer may provide any type of clothing for use, provided that he or she must still comply with Directive 1999/92/EC by ensuring that persons wearing such clothing are properly grounded.

The risk associated with electrostatic discharges from clothing depends on the presence and susceptibility to ignition of explosive atmospheres. To identify different levels of risk, the standards SR EN IEC 60079-10-1:2021 and SR EN IEC 60079-10-2:2015 classify hazardous areas into zones depending on the nature of the flammable material (gases, vapours, mists or dust) and the probability that an explosive atmosphere is present.

Another factor in determining the risk associated with electrostatic discharge is the likelihood of a charging mechanism occurring. The most common way clothing accumulates electrostatic charges is through contact and friction, a process known as triboelectric charging.

In this regard, some examples can be given such as the case of a jacket that can be triboelectrically charged when a person sits and then gets up from a chair, the jacket having friction with the chair surface. Therefore, the jacket can be considered as having a high probability of being exposed to a charging mechanism.

In contrast, a head protection article (cap) cannot come into contact with other objects and can therefore be considered to have a low probability of being exposed to a charging mechanism. Another mechanism of electrostatic charging, applicable only to insulated conductors, is induction, which is essentially the separation of charge in the presence of an electric field.

Therefore, the norms and standards in force require that conductive parts, which in this context also include people, be properly grounded in hazardous areas Ex., so that the risk of induction charging is insignificant.

Some examples of different situations with high and low loading probability are given in Table 1. The situations described in Table 1 are only representative examples and should not be considered as determining situations of actual loading behavior.

Loading is dependent on a number of factors and should be assessed on a case-by-case basis. Although the nature of the materials largely determines their loading tendency, environmental factors, namely temperature and relative humidity, also have a significant influence.

In general, as relative humidity decreases, the tendency of materials to acquire and retain electrostatic charge increases. The risk assessment should take into account the full range of environmental conditions to which workers may be exposed, including seasonal variations, whether they work outdoors or indoors or both, and the presence of heating and cooling devices in the workplace.

In the test standards SR EN 1149-1:2018, SR EN 1149-3:2004 the characteristic conditioning environment is (23 ± 1) °C and (25 ± 5) % relative humidity. This conditioning environment is a compromise between the worst case conditions that may occur in practice, and the practical limitations of the test.

However, if the risk assessment shows that workers may be exposed for prolonged periods to conditions of low relative humidity, testing of personal protective equipment should be carried out under conditions of low relative humidity.

Table 1. Some examples of situations with high and low load probability [6]

Situation	Loading probability	Observations
PPE rubbed when getting up from a seat (chair)	hight	
PPE rubbing against other PPE items worn by the same person, for example: - sleeves rubbing against the body of a jacket; - one trouser leg rubbing against the other; - clothing rubbing against a fall protection harness (belt)	hight	Charging can occur between layers of clothing (e.g. friction between an outer jacket and a T-shirt). However, the charge on one layer is balanced by the opposite charge on the other layer. The risk of electrostatic charging is low if the layers are not separated, i.e. the jacket is not removed, has not been opened and is not excessively opened.
Exposure to charged aerosols or mists, for example spray paint	hight	
Exposure to fire extinguishers that emit charged sprays or particles	hight	
Protective helmets that are not normally subject to friction	low	
Removing helmets – harness rubbing against hair	hight	PPE must not be removed while in hazardous areas.
Cleaning protective masks (visors)	hight	
PPE without insulated conductive parts exposed to high electric or electrostatic fields	low	Insulating materials do not easily charge by induction when exposed to high fields
PPE with insulated conductive parts exposed to electric or electrostatic fields	hight	Dangerous voltages can be induced on insulated conductive parts. Such components must be grounded to prevent charging, or should be of a low capacitance so that incendiary discharges cannot occur.

4 Selection of personal protective equipment intended for use in areas with a risk of explosive atmospheres generated by hydrogen

The selection of personal protective equipment is made according to the field of use established by the manufacturer and is based on the properties of the materials used in their manufacture to ensure protection against dangerous static electricity, taking into account environmental factors, the probability of occurrence of charging mechanisms and the sensitivity to initiation of explosive atmospheres generated by hydrogen through electrostatic discharges.

The relevant parameter when analysing the risk of initiation of explosive atmospheres generated by hydrogen through electrostatic discharges from personal protective equipment, such as protective clothing and other items of personal protective equipment, is the minimum ignition energy of the explosive atmosphere.

The performance requirements for electrostatic dissipative protective clothing, set out in SR EN 1149-5, are based on explosive atmospheres with MIE equal to or greater than the most flammable mixture of hydrogen in air.

Table 2 gives some guidance on the selection for use of electrostatic dissipative protective clothing and other personal protective equipment that is required, recommended or not required based on the overall risk assessment, which is a combination of the probability of an explosive atmosphere, the probability of a charging mechanism and the susceptibility of the explosive atmosphere to ignition by electrostatic discharge.

Where "required" or "recommended" is indicated, this refers to personal protective equipment, which has a single level of protection. Where "not required" is indicated, this means that electrostatic dissipative protective clothing or other personal protective equipment is not required, but that additional precautions are still required to prevent sources of ignition of an electrostatic nature, in particular grounding of persons and other conductors.

Table 2 Requirements for electrostatic dissipative protective clothing and other PPE [6, 7]

<table>
<tr><th rowspan="2">Dangerous areas</th><th rowspan="2">Loading probability</th><th rowspan="2">0,016 mJ ≤ MIE ≤ 0,2 mJ
Explosion groups IIB and IIC</th><th colspan="2">MIE > 0,2 mJ</th></tr>
<tr><th>Explosion groups IIA and IIB</th><th>Explosion groups IIIA, IIIB and IIIC</th></tr>
<tr><td rowspan="2">Zone 0</td><td>hight</td><td rowspan="3">required</td><td rowspan="2">required</td><td rowspan="4"></td></tr>
<tr><td>low</td></tr>
<tr><td rowspan="2">Zone 1</td><td>hight</td><td rowspan="2">recommended</td></tr>
<tr><td>low</td></tr>
<tr><td rowspan="2">Zone 2</td><td>hight</td><td>recommended</td></tr>
<tr><td>low</td><td>not required</td><td>not required</td></tr>
<tr><td rowspan="2">Zones 20, 21 and 22</td><td>hight</td><td colspan="2" rowspan="2"></td><td rowspan="2">not required</td></tr>
<tr><td>low</td></tr>
</table>

4.1 Selection for use of electrostatic dissipative protective clothing in areas with a risk of explosive atmospheres generated by hydrogen

Electrostatic dissipative protective clothing must meet the performance and design requirements specified in SR EN 1149-5 when used in areas with a risk of explosive atmospheres generated by hydrogen.

Undergarments worn under and completely covered by electrostatic dissipative protective clothing need not be made of electrostatic dissipative materials, provided that they do not impede electrical continuity between the wearer's body and the electrostatic dissipative protective clothing [7].

One of the minimum requirements given in Annex II to Directive 1992/92/EEC is "... appropriate measures must be taken to minimise the risks to workers posed by the physical effects of an explosion". This implies that protective clothing worn in hazardous areas must provide protection against heat and flames. The need for protection against heat and flames must be based on the results of a risk assessment.

In the event of an explosion, several physical effects result, the blast wave, the projection of fragments, etc. Therefore, electrostatic dissipative protective clothing must also provide protection against the thermal effects of an explosion, against heat and flames.

As an alternative to the above situation, the user may wear an ensemble consisting of heat and flame protective clothing and electrostatic dissipative protective clothing, in which case the electrostatic dissipative protective clothing must be the outermost layer and must completely cover the heat protective clothing.

The outer layer represented in this case by the electrostatic dissipative protective clothing must also have flame-retardant properties.

Since Directive 1999/92/EEC may require employers to provide workers with protective clothing appropriate to the area of use and the risk factors against which it provides protection, the requirements for such clothing are given in Regulation (EU) 2016/425, it is not necessary to bear the conformity markings required for ATEX equipment, unless the clothing contains electrical or electronic components.

4.2 Selection of protective gloves for use in areas with a risk of explosive atmospheres generated by hydrogen

In general, the wearing of gloves is necessary to protect the wearer from various hazards, to protect the products being handled, or to improve manual handling. If protective gloves are worn in hazardous areas as recommended in Table 2, for any of these reasons, then the gloves must also protect against electrostatic hazards.

At the same time, protective gloves must ensure electrical continuity when using metal hand tools and other conductive objects that can be held in the hand and that cannot be grounded except through the user's hand.

It is very important that protective gloves used in explosive hydrogen atmospheres ensure a proper electrical connection between the wearer's hands and any conductive object being held in the hand, so that the resistance to ground is within acceptable limits.

The materials used to make the palms, fingers and any areas extending above the user's wrist must meet the requirements for electrostatic dissipative protective gloves, specified in SR EN 16350.

4.3 Selection of protective footwear and foot protection for use in areas with a risk of explosive atmospheres generated by hydrogen

To dissipate electrostatic charges accumulated by workers and the protective clothing worn by them, footwear and flooring in industrial spaces play a very important role.

Electrostatic conductive and antistatic footwear as defined in standards SR EN ISO 20345, SR EN ISO 20346 and SR EN ISO 20347, are intended primarily to provide means of grounding the user. In most cases only the soles of the footwear are made of conductive or antistatic materials.

In these cases, areas of insulating materials that form the upper part of the footwear and that may extend to the lower part of the foot, such as boots, may present an electrostatic risk if subjected to high electrostatic potentials.

Considering this aspect, in such cases the upper part of the footwear must be made of electrostatic dissipative materials as in the case of other elements of electrostatic dissipative clothing.

Leg protection in the form of knee pads and shin guards is usually worn over clothing. If the outer layers are made of textile materials, they must meet the safety requirements of the SR EN 1149-5 standard, as must the other elements of electrostatic dissipative protective clothing.

4.4 Selection for use of head protection in areas with a risk of explosive atmospheres generated by hydrogen

Head protection articles such as hoods, caps, hats, etc., made of textile materials must comply with the safety requirements of SR EN 1149-5 and can be tested using the test methods given in standards SR EN 1149-1 or SR EN 1149-3.

In the case of protective articles made of rigid materials, they cannot be tested using the test methods specified in SR EN 1149-1 or SR EN 1149-3 and therefore the general testing recommendations given in IEC TS 60079-32-1:2013 and SR EN 60079-32-2:2015 must be used.

In the case of hard hats containing a hard outer structure and an inner strap system, the outer shell must be made of conductive or dissipative materials, and electrical continuity between the outer shell and the wearer's head must be ensured and maintained by using conductive or dissipative materials for the strap system and lining.

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5 Conclusions

Both users and the personal protective equipment used by them, during the performance of work tasks, are subject to the electrification process, the result being the generation of dangerous electrostatic potentials, which subsequently leads to the occurrence of electrostatic discharges.

The generation of electrostatic charges and their accumulation on users and on the personal protective equipment worn by them, presents a danger in the presence of explosive atmospheres generated by hydrogen from the point of view of their initiation, through electrostatic discharges.

The presence of the danger of explosion as a result of the initiation of explosive atmospheres generated by hydrogen, through electrostatic discharges, requires the taking of appropriate protective measures to prevent electrostatic discharges from users, by selecting for use individual protective equipment that meets the safety requirements relating to the prevention of static electricity, in addition to ensuring paths for the dissipation of charges to earth.

To ensure the highest possible level of safety in industrial spaces where explosive atmospheres generated by hydrogen may be present, special attention must be paid to the selection of personal protective equipment in relation to their performance in protecting against static electricity, given that the electrostatic ignition sources they generate can lead to an explosion and/or fire.

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