

Firefighters' personal protective equipment

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Review

A firefighter's workplace is characterised by a number of external influences and hazards that can endanger their health and safety. Considering the fact that it is not possible in the risk assessment for the said workplace to determine all situations that firefighters may encounter on the fire interventions, it is necessary that firefighters use the personal protective equipment as part of the protective elements. This article provides an overview of the personal protective equipment used by firefighters during fire interventions. The clothing systems for protection against heat and flame are presented together with the relevant standards and the minimum performance requirements that they must fulfil. The personal protective equipment used by firefighters during firefighting operations is also described. In addition to maximising protection for firefighters, personal protective equipment must ensure comfort and the normal performance of work activities.

Key words: *firefighter; personal protective equipment; fire; clothing system for protection against heat and flame.*

Pregledni rad

Radno mjesto vatrogasca karakterizira izloženost nizu vanjskih utjecaja i opasnosti koje mogu ugroziti njegovo zdravlje i sigurnost. S obzirom da prilikom procjene rizika za spomenuto radno mjesto nije moguće utvrditi sve zahtjeve koji će se postaviti pred vatrogasca na intervenciji, nužna je primjena osobne zaštitne opreme kao jednog od elemenata zaštite vatrogasca. U radu je dan pregled osobne zaštitne opreme namijenjene vatrogascima na požarnim intervencijama. Prikazani su odjevni sustavi za zaštitu od topline i plamena, pripadajući standardi te zahtjevi zaštite koju isti trebaju ispuniti. Opisana je osobna zaštitna oprema koju vatrogasci koriste u svrhu zaštite tijekom intervencija. Uz maksimalnu razinu zaštite vatrogasca, primjenom osobne zaštitne opreme moraju se osigurati udobnost te normalno izvođenje radnih aktivnosti.

Ključne riječi: vatrogasac; osobna zaštitna oprema; požar; odjevni sustav za zaštitu od topline i plamena

1. Introduction

According to the Law on firefighting, NN 125/19, Article 1, the activity of the fire brigade is defined as a professional, non-profit activity with elements of humanitarian work, which represents a great contribution to the state and whose main objectives are: participating in the implementation of preventive measures against fires and technological explosions, firefighting and rescuing people and property endangered by fires and technological explosions, providing technical assistance in accidents and dangerous situations and performing other tasks in the various types of accidents [1].

Firefighters and other emergency personnel (e.g. special police, rescue workers, emergency medical assistance), whose task is to protect and rescue people, are exposed to various types of health and safety risks. In addition, the use of new types of chemicals and materials with different flammability and burning behaviour makes it very difficult to predict and plan all possible interventions, i.e. situations that firefighters may face [2].

From the aforementioned follows that with appropriate tactics, firefighter equipment, training and practicing the firefighters it is necessary for firefighters to use the personal protective equipment (PPE) during firefighting interventions. This article provides an overview of the personal protective equipment used by firefighters in fire interventions as well as the requirements that PPE must fulfil in order to provide adequate protection and comfort when worn.

2. Firefighters' personal protective equipment

Personal protective equipment (PPE) means equipment designed and manufactured to be worn or held by a person for protection against one or more risks to the person's health or safety [3]. PPE also includes any components or aids that are essential to the said equipment in order to achieve the same objective [4]. Personal protective equipment must be manufactured in accordance with the relevant standards, the Occupational Health and Safety Act, the Ordinance on the Use of PPE and the Ordinance on the Placing of PPE on the Market. In addition, in order to place it on the market in the European Union, PPE must be designed and manufactured in accordance with the European documents that have been incorporated into the legislation of the each Member State: 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 and Council Directive 89/656/EEC of 30

November 1989 on the minimum health and safety requirements for the use by workers of personal protective equipment at the workplace.

The selection of the necessary personal protective equipment (PPE) as well as the manner and frequency of its use is determined by the risk assessment of the workplace, the frequency of worker's exposure to the risk, the working conditions and the adaptation of the personal protective equipment to the specific working conditions and means of work where it shall be used. When used, it must provide maximum protection for a worker under conditions that ensure normal performance of work activities and comfort [5].

The standard operating procedures which detail all measures to be taken during firefighting interventions involving the fire brigade are set out in the Regulation of Standard Operating Procedures, NN 44/22. In this document as a minimum requirement under point 5 of Article 12 "Safety and protection measures during the intervention" is defined the specification of the hazards to which the firefighters are exposed during the specific firefighting intervention, the duties and tasks of all participants in the specific firefighting intervention in terms of safety and injury protection, the minimum protective equipment of the firefighters used for the specific firefighting intervention and the safety and injury protection measures for the firefighters. Firefighting interventions are categorised as: fire interventions, technical interventions, interventions involving hazardous substances and others (e.g. interventions with an increased risk of infectious diseases or ionising radiation). In the continuation of this article, individual items of personal protective equipment (PPE) used by firefighters during fire interventions are described. [6]

2.1. Clothing to protect against heat and flame

Clothing to protect against heat and flame is used in the situations when a person is exposed to heat through conduction, convection, thermal radiation, sudden short or long contact time with flame, splashing/pouring molten or glowing material as well as through the combination of mentioned influences [4, 7-8].

Basic requirements for materials and design along with the marking of protective clothing to protect against heat and flame are defined in the standard EN ISO 14116:2015 *Protective clothing – Protection against flame – Limited flame spread materials, material assemblies and clothing*. This standard specifies the requirements for the limited flame spread properties of clothing in the conditions when there is no significant thermal hazard in brief contact with small flames [9].

According to the above-mentioned standard, the required material properties are calculated through limited flame spread index based on ISO 15025:2016 test results (method A, surface ignition). Flame retardancy of materials is divided into three levels conforming to the limited flame spread index:

- index 1 – materials that don't spread flame nor give flaming or molten debris but have limited time of afterglow (≤ 2 s)
- index 2 – materials and their combinations which don't spread flame nor give flaming or molten debris, have limited time of afterglow (≤ 2 s) and also don't give hole formation of 5 mm or greater in any direction in contact with flame
- index 3 – materials and their combinations which don't spread flame nor give flaming or molten debris, have limited time of afterglow (≤ 2 s), don't give hole formation and also have limited after-flame time (≤ 2 s) [10, 11].

When the risk of heat is higher, than clothing to protect against heat and flame must be manufactured in accordance to ISO 11612:2015 *Protective clothing – Clothing to protect against heat and flame – Minimum performance requirements*. This standard, along with the requirement for limited flame spread properties (code A) covers following protection requirements:

- convective heat resistance – testing based on ISO 9151:2016, minimum requirement for heat transfer index HTI₂₄ is in the period 4-10 s; class B1
- radiant heat resistance – test method in accordance to ISO 6942:2002, minimum radiation heat transfer index RHTI₂₄ must be in the period 7-20 s; class C1
- resistance on splashing with molten aluminium – testing based on ISO 9185:2007, clothing must accomplish requirements defined for class D1 (100-200 g of molten aluminium)
- resistance on splashing with molten iron – testing in conforming to ISO 9185, clothing must accomplish requirements for class E1 (60-120 g of molten iron)
- contact heat resistance – test method defined in ISO 12127-2:2007, clothing must accomplish requirements defined in F1 class (threshold time: 5-10 s) [4].

Protective clothing must fulfil requirements for code A (limited flame spread) and at least one more of the aforementioned protection requirements (code B-F).

Textile materials used for clothing to protect against heat and flame must have good thermal insulation characteristics, be flame- and heat- resistant in contact with flame, resistant to melting and dropping, highly reflective to infrared radiation and be water-proof [4, 7]. Most often these are chemically modified

natural flame-resistant materials (e.g. Proban®, Pyrovatex®, Indura®), inherently flame-resistant synthetic materials (e.g. Nomex®, Kermel®, Kevlar®) or their combination [12].

These protective clothing can be made as a one-piece (coveralls) or two-pieces (jacket and trousers) provided that the entire clothing system completely covers the body, neck, legs and person's arms (protective suit, gaiters, hood, overboots). Thermal protective clothing shall be marked in accordance to standard ISO 13688:2012 *Protective clothing – general requirements*. Pictogram for protection against heat and flame as well as the example of thermal protective clothing are shown in the Fig.1.

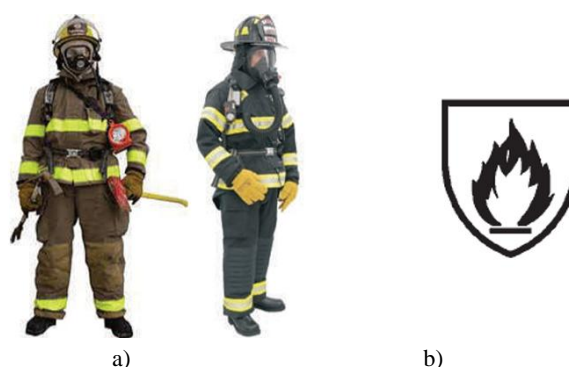


Fig.1 Clothing to protect against heat and flame: a) as a part of clothing ensemble to protect against heat, flame and RCB agents [13], b) pictogram in accordance with ISO 13688 [7]

2.2. Protective clothing for firefighters

Protective clothing for firefighters is part of the personal protective equipment for firefighters used during fire interventions. Fire interventions are categorised into the following subgroups in accordance with the Regulation of Standard Operating Procedures, NN 44/22, Article 4:

- structural fires in/on bungalows and buildings with ground floor and first floor
- structural fires in/on buildings with a height up to 22 m
- structural fires in/on tall buildings with a height of more than 22 m
- structural fires in/on industrial buildings
- fires in road traffic
- wildfires on open space or open space wildfires [6].

Protective clothing for firefighters is categorised according to the above-mentioned classification:

- protective clothing for firefighting activities (structural firefighting)
- wildland firefighting clothing and
- reflective clothing for specialised firefighting.

All three subgroups are labelled in accordance with ISO 13688 and the corresponding pictogram for this clothing is shown in Fig.2.



Fig.2 Pictogram of protective clothing for firefighters according to ISO 13688 [7]

2.2.1. Protective clothing for firefighting activities (structural firefighting)

Structural fires are fires that occur in residential, commercial, industrial or institutional buildings. These fires are mostly indoor fires, which often require not only firefighting but also the rescue of people and the preservation of the structural integrity of the building. In this context, protective clothing has been developed for firefighting in connection with structural firefighting, which protects firefighters when carrying out the above-mentioned activities and whose protection requirements are described in the standard EN 469:2020 *Protective clothing for firefighters – Performance requirements for protective clothing for firefighting activities*.

In the view of the risk that occurs while fighting fires, firefighting activities are divided into two levels of performance:

- level 1 (the lower requirement, outdoor firefighting and associated activities)
- level 2 (the higher requirement, clothing worn during structural firefighting operations).



Fig.3 A two-piece suit (jacket and overalls) for structural firefighting from MSA company [14]

Fig.3 shows a structural firefighting garment (two-piece suit; jacket and overalls) produced by MSA company. As this is a two-piece suit, there must be a sufficient overlap between jacket and overalls in all working positions (usually 30 cm) [4]. As a rule, the suits for this purpose consist of three or four layers, which make up:

- an outer layer: flame-resistant fabrics with the trade names Nomex®Tough, Titan 1220, Titan 1250, consisting of aramid (Nomex®, Kevlar®) and carbon (P140) fibres
- a moisture barrier that prevents water from penetrating the clothing but allows perspiration and heat to escape to the outside atmosphere: Gore-Tex®Fireblocker (ePTFE fibres), Gore-Tex®Flameline (ePTFE membrane laminated to a fabric made of aramid and viscose fibres (FR fibres))
- a thermal barrier: Eco-Drycool or Eco-Dryactive, thin one- or two-layer fabric consisting of m-aramid (Nomex®), wool and FR viscose (Lenzing™ FR), which draws the moisture in the form of perspiration from the body to the outer layers of the garment [15, 16].

Some of the basic protection requirements that this protective clothing must fulfil can be found in Tab.1. Marking of this protective clothing is done according to the ISO 13688 and contains the number and name of the standard, a pictogram and the level/grade of performance achieved (X1/X2; Y1/Y2 and Z1/Z2).

2.2.2. Wildland firefighting clothing

Open space wildfires, i.e. wildfires or wildland fires are usually large fires (covering a minimum area of one hectare) that, depending on the area of vegetation affected and the rate of spread, directly endanger human lives and large properties or cause considerable material damage to property [18, 19]. This includes the uncontrolled burning of forests, crops, plantations, grasslands and other wild plants as well as agricultural crops. The risk of wildfires depends on several factors: climatic conditions, type of vegetation, forest management and other socio-economic factors [20].

Protective clothing for firefighters used while fighting wildland fires must be manufactured in accordance with the standard ISO 15384:2018 *Protective clothing for firefighters - Laboratory test methods and performance requirements for wildland firefighting*. As these types of fires usually take place in summer due to prolonged periods of drought with high temperatures, this protective clothing must be lightweight, breathable and flexible so that the firefighter's body does not suffer from heat stress.

Tab.1 Some of the basic requirements for materials and manufacturing protective clothing for fighting structural fires [4, 17]

Property	Level/Grade 1	Level/Grade 2	Test method
limited flame spread	index 3		ISO 14116 testing in accordance with ISO 15025, procedure A
contact heat	/	threshold time: 10 s	ISO 12127-1
heat transfer (flame)	$X1 = \begin{cases} HTI_{24} \geq 9.0 \text{ s} \\ HTI_{24} - HTI_{12} \geq 3.0 \text{ s} \end{cases}$	$X2 = \begin{cases} HTI_{24} \geq 13.0 \text{ s} \\ HTI_{24} - HTI_{12} \geq 4.0 \text{ s} \end{cases}$	ISO 9151, heat flux density: 80 kW/m ²
heat transfer (radiation)	$X1 = \begin{cases} RHTI_{24} \geq 10.0 \text{ s} \\ RHTI_{24} - RHTI_{12} \geq 3.0 \text{ s} \end{cases}$	$X2 = \begin{cases} RHTI_{24} \geq 18.0 \text{ s} \\ RHTI_{24} - RHTI_{12} \geq 4.0 \text{ s} \end{cases}$	ISO 6942, heat flux density: 40 kW/m ²
resistance to water penetration	Y1 < 20 kPa, clothing without moisture barrier	Y2 ≥ 20 kPa, clothing with moisture barrier	ISO 811, water pressure rising speed: (0.98 ± 0.05) kPa/min
water vapour resistance	Z1 > 30 m ² Pa/W	Z2 ≤ 30 m ² Pa/W	ISO 11092
Other requirements connected with: mechanical properties of materials and seams, heat resistance, resistance to penetration test by liquid chemicals, visibility, comfort and optional garment testing			

In view of this, this clothing is usually made of single-layer flame-resistant fabric, e.g. the coveralls in Fig.4 made of Nomex® Comfort (93% m-aramid, 5% p-aramid and 2% antistatic fibre) [4, 21].

This type of protective clothing as well as that for fighting structural fires can be manufactured as coveralls or two-piece suits, which must completely cover the human body and not restrict freedom of movement during work. This clothing is labelled in accordance with ISO 13688 and includes the number and name of the standard, a pictogram and the performance level achieved (A1, A2 or both) [4]. The basic requirements that the materials must fulfil can be found in Tab.2.



Fig.4 A coveralls from Hemco LLC for wildland firefighting [21]

Tab.2 Some of the basic requirements for materials and manufacture of wildland firefighting clothing [4, 22]

Property	Requirement	Test method
heat transfer - radiation	$RHTI_{24} \geq 11,0 \text{ s}$ $RHTI_{24} - RHTI_{12} \geq 4,0 \text{ s}$	ISO 6942, heat flux density: 20 kW/m ² , method B
tear strength	≥ 25 N	ISO 4674 – 1 (method B) or ISO 13937 – 2
tensile strength of outer material	≥ 600 N	ISO 13934 - 1
dimensional change	≤ 3%	/
heat resistance	all materials, including reflective strips, labels, signs, accessories, closure system and others must withstand 5 minutes at a temperature of (180 ± 5) °C which implies that they must not ignite, melt, shrink by more than 5% and accessories must function after testing	
visibility	retroreflective/ fluorescent/ combined materials must accomplish the performance requirements defined in HRN EN ISO 20471	

2.2.3. Reflective clothing for specialised firefighting

Specialised firefighting includes firefighting interventions characterised by large amounts of radiant, convective and contact heat, e.g. fires with large amounts of flammable gases or liquids [4].

With this type of protective clothing, the protective function is based on the ability of the outer material to reflect intense radiant heat (in contrast to the two previously mentioned). However, it should be noted that the use of this clothing is limited to the short periods of time (usually 10 s) in which firefighters find themselves in special, high-risk firefighting and rescue situations.

The standard EN 1486:2007 *Protective clothing for firefighters - Test methods and requirements for reflective clothing for specialised firefighting* specifies the protection requirements for the entire body including head, hands and feet as well as the design of the protective suit; it must consist of one or more garments, hood (may or may not be integrated), gloves and overboots.

The tests of the clothing ensemble with hood, gloves and overboots are carried out after pre-treatment and include testing of the thermal and mechanical properties. The minimum requirements for the thermal properties of reflective clothing for specialised firefighting are listed in Tab.3.

Reflective clothing for specialised firefighting is marked in accordance with EN 340 (latest version: EN ISO 13688) and consists of the pictogram, the number and name of this standard (EN 1486:2007).

The example of this clothing system, which consists of a coveralls along with a hood, a face shield, gloves and overboots, all combined in one suit, is shown in the Fig.5. This clothing system consists of three layers:

- an outer layer: aluminised glass fibre



Fig.5 IST company's reflective suit for specialised firefighting [24]

- a heat barrier: 100% non-woven fabric (Kermel® aramid fibre)
- an inner layer: 65% FR viscose fibre Lenzing™ FR, 22% aramid, 12% polyamide, 1% bicomponent fibre Belltron® (PES/PA matrix, i.e. base polymer, carbon as conductive layer) [24, 25].

2.3. Protective gloves for firefighters

According to the annual analyses of occupational injuries conducted by the Croatian Institute for Health Protection and Safety at Work over the last five years, the majority of injuries at work, 38% on average, are injuries of the upper extremities, 26% of which are hand and wrist injuries [26]. These data indicate on the importance of using personal protective equipment for hand protection at work in order to protect the hands from threats and hazards that can cause hand injuries.

Tab.3 The requirements placed on the thermal properties of reflective clothing for specialised firefighting [4, 23]

Thermal property	Requirement	Test method
limited flame spread	index 3	ISO 14116, testing in accordance with ISO 15025, procedure A (all materials and seams shall be tested)
heat transfer (radiant heat)	$RHT_{24} \geq 120$ s	ISO 6942, heat flux density: 40 kW/m ²
heat transfer (convective heat)	$HTI_{24} \geq 21$ s	EN 367 (latest version: EN ISO 9151)
contact heat	threshold time ≥ 15 s	EN 702 (latest version: EN ISO 12127-1), contact temperature: 300 °C
heat resistance	all materials (including closure system and face shield) must withstand 5 minutes at a temperature of (255 ± 10) °C which implies that they must not ignite, melt nor shrink by more than 5%	ISO 17493

Protective gloves for firefighters are manufactured in line with the EN 659:2003 *Protective gloves for firefighters* and are intended for use in normal fire-fighting, search and rescue [27]. Although they provide some protection against accidental contact with chemicals, they are not intended for the intentional handling of liquid chemicals [4].

These gloves must meet the general requirements, such as the requirements for the design and manufacture of the gloves, the resistance of the glove material to the penetration of water, sizing (list of glove sizes), marking, instructions for use, etc., specified in EN 420:2004 *Protective gloves - General requirements and test methods* (latest version: ISO 21420:2020). The pictogram with the specified standard above it corresponds to the pictogram used for labelling protective clothing for firefighters, Fig.2.

In addition to the general requirements, firefighter gloves must also provide mechanical and thermal protection, dexterity, protection against water penetration and protection against liquid chemicals (Tab.4).

Like protective clothing, protective gloves for firefighters, usually consist of three layers:

- an outer shell of woven or knitted flame-resistant fabric, Fig.6a (Kevlar® i Nomex®) or leather, whose flame resistance can be improved by tanning, Fig.6b
- a moisture barrier (Gore-Tex Crosstech® or Pyrotect® membrane)



Fig.6 Firefighter gloves: a) textile gloves from Hemco LLC [21], b) leather gloves TechNote [29]

- a thermal barrier (liner) that prevents the hands from heating up (e.g. Kevlar®/Nomex® combination) [29, 30].

2.4. Firefighting footwear

According to Article 8 of the Ordinance on technical requirements for protective and other personal equipment used by members of fire departments during firefighting interventions, NN 31/11, footwear for firefighters is used in firefighting and other interventions where exists the risk of heat, flame, hazardous materials or mechanical injuries [31]. The types of footwear for firefighters and the protection requirements that they must fulfil are defined in EN 15090:2012 *Footwear for firefighters*.

Tab.4 Performance requirements for firefighter gloves [4, 27, 28]

Test/Property	Minimum requirement	Test standard
abrasion	level 3 (2000 cycles)	EN 388
cut resistance	level 2 (factor 2.5)	EN 388
tear resistance	level 3 (50N)	EN 388
puncture resistance	level 3 (100N)	EN 388
burning behaviour	level 4	EN 407
contact heat	level 2 ($t_t \geq 10$ s with $T = 250$ °C, diameter = 80 mm)	EN 702 (latest version: EN ISO 12127 – 1)
convective heat	level 3 ($HTI_{24} \geq 13$)	EN 367 (latest version: EN ISO 9151)
radiant heat	≥ 20 s	EN ISO 6942
heat resistance of lining material	$T = 180$ °C shall not ignite, melt or drip	ISO 17493
size, dexterity	> 1	EN 420 (latest version: EN ISO 21420)
seam breaking strength	> 350 N	EN ISO 13935 – 2
time for removal of glove	< 3 s	ISO 15383
resistance to water penetration (optional)	level 1 (30 min) level 2 (60 min) level 3 (120 min)	EN ISO 20344 (leather) EN 20811 (textile) (latest version: EN ISO 811)
glove integrity	no leakage	ISO 15383
resistance to penetration by liquid chemicals	without penetration of 30 % H_2SO_4 , 40 % NaOH, 36 % HCl and heptane after exposure time of 10 s	EN 368 (latest version: EN ISO 6530)

The standard defines three types of firefighter footwear:

- Type 1: For general outdoor rescue and fire-fighting.
- Type 2: Used in general rescue, firefighting and property conservation in buildings, vehicles, vessels or in similar objects affected by fire or in similar accident, without chemical protection.
- Type 3: Suitable for use in special risk situations, e.g. interventions where hazardous materials are present (release of dangerous chemicals into the environment, etc.) and for all other fire interventions. This footwear may only be made of rubber [4, 32].

All the upper materials must fulfil the requirements for tear strength, heat transfer (radiation), flame resistance, resistance to penetration and water absorption, antistatic properties and heat and cold insulation. All these requirements are defined in ISO 20345:2021 *Personal protective equipment – Safety footwear* (revised 2022) and ISO 20344:2011 *Personal protective equipment – Test methods for footwear* (revised 2021). In addition, the ISO 20345 standard specifies basic and additional requirements for protective footwear, which include thermal and mechanical risks, slip resistance and ergonomic behaviour [32].

An example of defining heat insulation with three different levels of heat resistance is given in Tab.5.

All designs of footwear (B-E) explained in the standard ISO 20346:2004 *Personal protective equipment – Protective footwear* (revised 2022) are suitable for firefighters, with the exception of design A (low shoe) [4]. Each piece of footwear for firefighters must be clearly and permanently marked by placing a stamp with the size of the footwear, the identification of the manufacturer, the designation of the footwear, the year and quarter of manufacture and the number and year of the ISO 15090 standard, additional symbols identifying the characteristics of the footwear and the pictogram mark in the size 30 x 30 mm (Fig.2) in the visible place on the outside of the footwear together with one of the symbols for marking footwear properties [4]. Based on the material, firefighting footwear is divided into two classes:

- Class/Code 1: footwear made of leather or other material with the exception of all-rubber or all-polymer footwear (Fig.7a)



Fig.7 Firefighter Firefighting boots: a) leather boots from Vökl company [33], b) rubber boots produced by Harvik Rubber Industries Sdn Bhd [34]

- Class/Code 2: all-rubber or all-polymer footwear (Fig.7b) [32].

The firefighting boots shown in Fig.7 are made entirely of waterproof leather or rubber uppers with high heat resistance and low flammability; the lining in the first case is made by Sympatex company (Moisture-Tech® membrane), which ensures a suitable microclimate inside the boot, i.e. the cotton fabric that is used in the second boots; a flame-retardant rubber outsole that is resistant to fuel and oil and has excellent mechanical properties, in which in both cases is embedded steel toe cap is embedded to protect against sharp objects and impacts [33, 34].

2.5. Firefighter helmets

Firefighter helmets are part of the personal protective equipment for firefighters, which protect the firefighter's head from struck-by-object accidents (e.g. falling objects, bumping into objects) while performing work. The main function of firefighter helmets is to absorb and disperse the mechanical forces acting on the firefighter's head [35].

Depending on the type of fire intervention, i.e. firefighter's activities on the firefighter during interventions, there is a distinction between the firefighter helmets, i.e. their purpose and the performance requirements they must fulfil. All the requirements that these helmets must fulfil are set out in the following standards:

- EN 443:2008 *Helmets for firefighting in buildings and other structures*
- EN 16471:2015 *Firefighters helmets – Helmets for wildland fire fighting*

Tab.5 An example of defining heat insulation with three different levels of heat resistance [4]

Level	HL ₁	HL ₂	HL ₃
sand bath temperature	150 °C	250 °C	250 °C
temperature inside the footwear	after 30 min inside the footwear must be < 42 °C	after 10 min inside the footwear must be < 42 °C	after 10 min inside the footwear must be < 42 °C
type	allowed for Type 1	minimum requirement for Type 2 and Type 3	/



Fig.8 Firefighter helmets: a) for structural firefighting, MSA company [14], b) for fighting wildland fires and technical rescue, producer PAB Akrapović LLC [36]

- EN 16473:2014 *Firefighters helmets – Helmets for technical rescue.*

Along to the protection against mechanical hazards, firefighter helmets must also offer protection against heat, flame and electricity and at the same time have an aesthetic component [4]. In this context, the standards set requirements for the protection body area, shock absorption, resistance to penetration by sharp objects, strength, heat and flame resistance, radiant heat and electrical properties [4]. The materials used to achieve the above-mentioned properties are synthetic polymer materials (thermoplastics/duromers) from which the helmet shell is made.

Together with the head protection, firefighter helmets have additional parts that can be attached to them and serve to protect other parts of the body, e.g. the neck (neck curtain), ears (earmuffs), face (face shield) and eyes (built-in safety goggles).

2.6. Respiratory protective equipment

Fires release many gases, vapours, dusts and fibres that can be inhaled through the lungs of firefighters. To prevent this inhalation-risk and to protect the health and safety of firefighters, it is obligatory to use respiratory protective equipment. Firefighters must wear it at all times while firefighting and take them off last during de-robing (after decontamination) [37]. The face mask is part of firefighter's personal protective equipment used in combination with filters, fresh-air self-contained breathing apparatus (SCBAs), air systems and powered air-purifying respirators (PAPRs) [7]. Depending on the part that covers the face, face mask can be a full- face mask (covering the breathing openings, face and eyes), a half- mask (half-face piece that protects nose and mouth) and a quarter- mask (quarter-face part that protects nose and mouth). Fig.9a shows a full- face mask with two filters for protection against particles. It is made of natural rubber, which ensures a good seal with the wearer's face and thus the impermeability between the two. An essential component of the full-

face mask is the acrylic visor, which should be scratch-resistant, anti-fog and dew-resistant and at the same time offer a wide field of vision, Fig.9a [7].

The self-contained breathing apparatus (Fig. 9b) is used in interventions where there is a risk of a toxic and hazardous atmosphere with oxygen deficiency, e.g. in unfavourable hazardous conditions in an enclosed space [31]. Its use ensures that a firefighter is supplied with a sufficient amount of breathing air (oxygen) to be able to work and survive in a specific location for a certain period of time [7].



Fig.9 Respiratory protection equipment: a) full-face mask with filter, manufacturer Moldex-Metric, Inc. [38], b) self-contained breathing apparatus BG ProAir, Dräger company [39]

2.7. Eye and face protection

A fire generates heat and produces smoke, dust, gases and other irritating and corrosive substances that can cause facial burns, eye irritation to firefighters, mechanical injuries (debris embedding or penetrating the eyes) and injuries from visible and invisible radiation. It is therefore necessary to wear eye and face protection.

Protection is most commonly achieved by helmets with an integrated visor, i.e. face shield made of highly heat-resistant plastic (Fig.8a) or with a retractable ocular visor (Fig.8b), as well as by the use of full- face masks (Fig.9a). In addition, eye protection is also achieved through the use of firefighter goggles.

3. Conclusion

This paper provides an overview of the personal protective equipment (PPE) worn by firefighters during fire interventions. It describes the basic requirements that protective clothing systems must fulfil, as well as the requirements for the materials used in their manufacture and the way in which they

are produced. It lists the standards in which the aforementioned requirements are specified and the test methods used to test certain properties. Considering the complexity of firefighters' working conditions and the impossibility of determining all situations that firefighters may encounter during their interventions, it can be concluded that the use of protective clothing ensembles during firefighting operations is necessary to protect the safety and health of firefighters. In addition to providing maximum protection for firefighters, these systems must be manufactured according to ergonomic principles and allow firefighters to carry out their work activities normally.

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