Technical requirements and materials used in firefighters gloves manufacturing

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Abstract. Ensuring the safety of the operational personnel involved in the intervention actions is a priority for the institutions responsible for the prevention and management of the emergency situations, that's why special attention is paid to the protective performances of the individual protective equipment used. The safety and health of rescuers depend on how the materials used in the manufacture of protective equipment for the action of risk factors behave. This paper presents the conditions that fire protection gloves have to meet, materials used in their manufacture and protective features that ensure the safety of users.

1. Introduction
Everyday, by means of media, we are aware of the occurrence of exceptional non-militar events that threaten the human life or health, the environment or the cultural or material values. In order to restore the normal order, in this case, it is necessary to take urgent measures and actions, to allocate specialized resources and manage the land forces and equipments involved. According to the National System for Emergency Situation Management, Emergency Ordinance no. 21/2004 of the Romanian Government, these events that can produce human accidents or material damages are generally, known as emergency situations.

In order to reduce or eliminate the effects created by the emergency situations allocated to the specialized services, during the interventions the professional/voluntary staff are exposed to a multitude of risk factors. The risk assessment for work-related accidents and occupational diseases aims to identify and evaluate the gravity and consequences, as well as, the possibility of taking place of the specific risks, followed by the development of different preventive measures, such as: technical, organizational, hygienic-sanitary or other [1-5].

Based on the risk assessment conclusion and results, for each workplace/workstation, it is necessary to ensure protection against the specific risk factors, which are related to the type of work and the environmental system, such as: mechanical, thermal, electrical, chemical or biological [1].

Considering the fact that, the priority order of applying the preventive measures (remove the risk, replace the risk, isolate the workers, change the operating condition and protect the workers by means of personal protective equipments), in order to ensure adequate protection against injury for the professional emergency services staff, their personal protective equipment’s must withstand to the present risk from the environment where the mission is taking place. Anyway, the personal protective equipment’s must be used only when there is no possibility to remove the risk by other means [6-7].
In case of firefighters, the protective equipment’s are designed to protect against the effects of water, heat, smoke, toxic gases, mechanical blows, height falls or other environmental conditions that can represent a danger for the human operator [8-14]. It is hard even to imagine that, there can be an emergency situation where the firefighter does not need to use his hands. Therefore, in case of lifting, transporting, pulling, pushing, wearing and handling of work equipment, everything depends mostly on hands and their specific abilities [15-17]. Thus, in order to protect the human operator against different types of risks, the internal regulation regarding using of personal protective equipments recomends protective gloves for all the operative staff.

2. Protective gloves for firefighters

After analyzing the General Inspectorate for Emergency Situations statistics, it can be observed that most of the interventions are related, by legal framework, with the main support functions: fires localization and extinguishing, access routes unbloking or extrication and emergency medical assistance, i.e. first aid.

According to the risk identification and assessment for safety and health during interventions, the factors with the highest frequency of occurrence that can produce accidents which can affect the firemen upper limbs are mechanical and thermal risks. Therefore, the personal protective equipments for hand protection available on market includes protective gloves for firefighter’s, that ensuring them the safety and health in hostile environment in which they operate [18, 19].

Most of the problems encountered by the rescuers are generally related to the protective equipment, which, in some cases, provides limited protection against the environment risks.

Protective Gloves for Firefighters - Technical Specification, issued by the General Inspectorate for Emergency Situations, registered under no. 85209 from 11.09.2017, presents the characteristics for mechanical and thermal risks that must be possess by the protective gloves, according to the requirements of SR EN 659 + A1: 2009 - Protective gloves for firefighters, based on the methods described in the related standards: SR EN 388: 2017 - Protective gloves against mechanical shocks, SR EN 420 + A1: 2010 Protective gloves. General requirements and testing methods and SR EN 407: 2005 - Protective gloves against thermal (heat and fire) risks.

It should be noted that thermal protective gloves intended to be used by fire-fighters provide limited protection for contact temperature because these can’t be used to handle objects whose temperature exceeds 250 °C. Also, according to the technical specifications these types of gloves can not be used for chemical solution handling.

Another common hazard to which the emergency intervention staff is ussually exposed is electricity. SR EN 659 + A1: 2009 standard recommandation and the technical specifications provided by the manufacturers do not present the protection against electric shock of the gloves. Therefore, during real situation the users should take compensatory protection measures that, ussually, consist in interrupting the power supply of the target or area.

There are different types of raw materials used at firefighter’s protective gloves manufacture, such as:
- the palm area: a combination of aramid fibers (meta-aramid or para-aramid) in case of the first layer, with a second elastic layer for fire protection;
- gloves back area: a combination of aramid fibers (meta-aramid) with a second elastic layer for fire protection;

The multilayer materials must be fire resistant, in order to provide protection against convective heat, radiant heat, contact heat, fire, mechanical risks (abrasion, cutting, tearing, punching) and water or chemicals penetration [20, 21].

Initially developed for space applications, the high performance and quality aramid materials are now used at industrial scale, especially in the field of protective equipment manufacturing [8].

2.1. Technical requirements, specifications and materials used for protective gloves manufacturing

Mechanical shock protection. Table 1 presents the technical requirements, specifications and the test that must be carried on according to the SR EN 659+A1:2008/AC:2009 for protective gloves.
Table 1. SR EN 659+A1:2008/AC:2009 protective gloves mechanical specifications.

| Specification                               | Technical requirements                                      |
|---------------------------------------------|-------------------------------------------------------------|
| Glove palm material resistance to abrasion  | Cycles until penetration<br>Point 3.3 of EN 659 + A1:2008<br>Performance level, min. 3 – EN 388 |
| Glove palm and back cutting resistance      | Cycles, min. 2000<br>Point 3.4 of EN 659 + A1:2008<br>Performance level, min. 3 – EN 388 |
| Glove palm material tear resistance         | Cutting index<br>Point 3.3 of EN 659 + A1:2008<br>Performance level, min. 3 – EN 388 |
| Glove palm material resistance to penetration| Tearing force<br>Point 3.3 of EN 659 + A1:2008<br>Performance level, min. 3 – EN 388 |
| Penetration force                           | Penetration force<br>Point 3.3 of EN 659 + A1:2008<br>Performance level, min. 3 – EN 388 |

Para-aramides are aramid fibers high resistant to mechanical stress, these are usualy used as reinforcements, friction materials or mechanical shock protection materials, especially due to the following characteristics [3, 4]:
- high tensile strength;
- high toughness and fatigue resistance;
- vibration-dampening.

Among the most common para-aramid fibers are: Kevlar, Kevlar HT, Kevlar HM, Kevlar HC - DUPONT trademark and Twaron - ENKA trademark.

Table 2 presents the comparition between the main mechanical properties of aramid fibers [4].

Table 2. Mechanical properties of aramid and the most used fibers.

| Fiber class | Para-aramid | Meta-aramid |
|-------------|-------------|-------------|
| Trademark   | Kevlar 129  | Nomex       |
| Chemical composition | Poliparafenilen Tereftalamida | Poliparafenilen Izoftalamida |
| Specific weight (g/cm³) | 1.44 | 1.38 |
| Tenacity (N/tex) | 2.35 | 0.4 |
| Tensile strength (MPa) | 3320 | 552 |
| Elasticity modulus (GPa) | 75 | 17 |
| Elongation at break (%) | 3.6 | 35 |

Due to its structure, the Kevlar material presents high thermal and dimensional stability, high chemical corrosion resistance for most chemical agents and good behavior when exposed to flames and heat. Also, it possesses excellent dielectric properties and wear resistance. According to the Schopper study [3] (procedure consist in loops bi-directional testing stretching during alternative bending by means of a metal plate) the Kevlar fibers can be bended without tearing, exhibiting high total elongation of about 100%.

Twaron fiber presents high elasticity modulus, non-corrosive behaviour, negative thermal expansion coefficient, good insulation features and high wear resistance. The twaron microfibers of 0.93 dtex has been developed by the subsidiary company from Netherlands. These microfibers are 10
% more tenacious, being ideal for protective gloves in order to increase the cutting resistance and dexterity [3].

According to Ionesi S.D. et al. study, Twaron wires presents the best mechanical properties combination, due to thread fineness, respectively to the cross-section number of fibers, also the Kevlar-Stainless steel combination presents the lowest friction coefficient due to the high slip coefficient of the stainless steel, when tested to tensile strength, loop strength and solid-wire friction [7].

**Thermal shock protection.** Table 3 presents the technical requirements, specifications and the test that must be carried on according to the SR EN 659+A1:2008/AC:2009 for protective gloves.

| Specification                          | Technical requirements                                      |
|----------------------------------------|------------------------------------------------------------|
| Comportarea la flacără:               | Point 3.7 of EN 659 + A1:2009 Performance level min. 4    |
| Flame exposure time                    | 0 secunde                                                  |
| The residual incandescence time        | 0 secunde                                                  |
| Exposure time until stitches break     | Breaks after 15 seconds.                                   |
| Convection heat resistance (at a heat flux density of 80 kW/m²) | Point 3.8 of EN 659 + A1:2009 Performance level min. 4 – EN 407 |
| Heat transmission index, HTI 24 in the glove palm and back | ≥24 secunde  |
| Radiant heat resistance (at a heat flux density of 40 kW/m²) | Point 3.9 of EN 659 + A1:2009                              |
| Radiant heat transmission index HTI 24 | ≥25 seconds                                                |
| Contact heat resistance at 250 °C temperature, wet and dry conditioning | Point 3.10 of EN 659 + A1:2009                            |
| Threshold time t₁                      | ≥15 secunde                                                |
| Lining heat resistance material at 180 °C, 5 minutes exposure time | Point 3.11 of EN 659 + A1:2009 The insulating material shouldn’t melt or flashover. Point 3.12 of EN 659 + A1:2009 The protective gloves should not shrink more than 2% |
| Heat-shrink, at 180 °C                 |                                                            |

Meta-aramides are high temperature resistant fibers, commonly used for thermal protection materials fabrication, due to the following characteristics [22]:
- do not melt, but starts to gradually carbonize at temperatures above 370 °C;
- after long time exposure to 250 °C the tensile strength decreases to 60% of the initial values;
- do not flashover.

Among the most common meta-aramid fibers resistant to high temperature are: Nomex, Nomex Delta A, Nomex Delta T, Nomex Delta K, Nomex Delta T Rip Stop - DU PONT trademarks and Kermel - KERMEL INC trademark.

Aramids are high temperatures resistant and flame-retardant due to their structure, being capable to maintain their tensile strength and physical properties even after long time exposure under severe conditions (eg. decrease to approximately 60% of the initial value after exposure to 250 °C for 1000 hours) [4]. This type of fibers does not melt, but starts to decompose at temperatures above 500 °C [3].

Aromatic polyamides of poly(metaphenyleneisophthalamide) type - which generate meta-aramid fibers, are converted into slags at temperatures above 400 °C and can withstand for short exposures time at temperatures above 700 °C [4]. Usually the “para” structures present higher temperature resistance compared to the “meta” structures. Para-aramid structures made of poly(paraffenyl-
terephthalamide) are commonly used as flame protection materials, especially for its flame retardants properties and superior mechanical stability [23-24].

Polyamideimide fiber, commercialy known as Kermel, iniially manufactured by Rhone-Poulenc in
two versions are used in environment with a high fire threat, due to the fact that these fibers do not melts, but starts to carbonize at temperatures above 300 °C. Therefore, Kermel fibers presents good mechanical properties at temperatures above the melting point of the most common synthetic fibers. After long time exposure of 500 hours at 250 °C, its mechanical properties decrease with 33 % [25].

However, when exposed to high temperatures for long period some types of aramid fibers start to contract and fail [26]. In order to overcome this disadvantages, the aramid fibers must be mixed with different types of fibers to provide adequate thermal decomposition. In the same time, by creating this mix of fibers, cheaper products with higher properties can be obtained, such as [4]:

a. meta-aramide fibers mixtures - Nomex with 5% para-aramid fibers - Kevlar, known as Nomex III, trademark of Du Pont;

b. Kermel mixed with fire-retardant viscoste in 65/35 % proportion.

Table 4 presents the comparision between the main fibers and aramid fibers thermal properties [4].

| Fiber class | Para-aramid | Meta-aramid |
|-------------|-------------|-------------|
| Trademark   | Kevlar 129  | Kevlar 149  | Twaron | Nomex | Kermel |
| Glass transition temperature (°C) | 280-290 | 285 |
| Degradation temperature (°C) | 500 | 500 | 500 | 370 | 420 |
| Limiting oxygen index LOI (%) | 29-32 | 29-32 | 29 | 29 | 32 |
| Heat capacity (J/kg/K) | 1400 | 1420 | 1420 | 1214 | 1250 |
| Thermal conductivity W/m/K | 0.04 | 0.04 | 0.04 | 0.13 | 0.075 |
| Rezistență termomecanică | 90% after 48 h at 200 °C | 65% after 1000 h at 250 °C | 67% after 500 h at 250 °C |

3. Conclusions
Firefighter’s gloves offer protection against mechanical and thermal risks, but do not provide, in the same time, electrical safety. Where electrocution risk is present, the protection of the human operator must be ensured by individual electro-insulating protective equipment or, where appropriate, by organizational measures described in specific intervention procedures.

It is well known that there is no protective glove on the market that can ensure all the protective feature in one, regarding the main risks to which the firefighters are exposed during high risk activities.

In places where biological or chemical risks (including radiological / nuclear) are known to exist, specialized staff with special personal protective equipments that must meet necessary requirements and characteristics are involved.

The characteristics of materials made from aramid fibers from which fire-resistant gloves are used for the interventions they normally perform provide adequate hand protection to ensure the safety of the servants for mechanical and thermal risks.

The protective gloves manufactured of aramid fibers, which are used at usual interventions, provide adequate firefighters hands protection in case of mechanical or thermal risks.

By comparing the physico-mechanical properties of the aramid treated and untreated materials, it can be seen that the treatments can significantly increase the protective capabilities of the aramid
materials, for example, by reinforcing it with graphite particles the thermal protection increases significantly, also, a treatment with metal particles increases significantly the protection against mechanical shock.

The aramid fibers chemical structure is the main reason of its superior performance, characterized by high mechanical and thermal properties, which justify their use as an ideal base material for composite materials reinforcement used in individual fire protection equipment manufacture.

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