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Comparison of Requirements and Directions of Development of Methods for Testing Protective Clothing for Firefighting

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Abstract
The subject of this work are requirements and test methods for clothing protecting from factors such as thermal radiation, flame, chemicals and resistance to leaking. In this publication, test methods and requirements for protective clothing for firefighting in Europe (in particular in Poland), USA and Russia are compared, presented in standards: NFPA 1971, НПБ 162-02, EN 469. Additional requirements in Poland were also taken into account, presented in Ordinance of the Ministry of the Interior (published Dz. U. of 2010 No. 85, item. 553). Based on the requirements analysis, it was found that they mostly focus on the requirements for protection against thermal factors (resistance to thermal radiation, flame, contact heat). Test methods for checking compliance with those requirements and test parameters established by standards are briefly discussed . Directions of development for test methods of firefighter protective clothing are also discussed. Current trends in the development of research and measuring equipment are presented.

Key words: *firefighting protective clothing, thermal protection, test methods, research stands.*

Introduction

Protective clothing for firefighters must comply with a number of requirements contained in standards, varying from country to country (ASTM, European Standards etc.). Before protective clothing, gloves, helmets and other personal protective equipment for firefighters are approved for use, they must pass demanding tests and obtain a certificate. Tests are used to determine the material properties and check whether the product fulfils the minimum safety requirements. Thanks to research into protective clothing and the high requirements of the standards, injuries to firefighters during action, in particular burns (which are especially dangerous), can be better prevented. In 2006 - 2008, 14% of the injuries of firefighters were caused by burns [1], thus representing third place in terms of the incidence of injuries by nature (after overexertion/strains and wounds).

Regarding the safety of firefighters, a number of studies have been carried out to determine the real properties of protective turnout. Many test methods have been standardised all over the world. Performance standards are developed by a number of government and non-profit organizations to establish guidelines for protective equipment and procedures for working in hazardous areas.

In Europe, standards in the area of protective clothing are presented in the EN standards, published by the European Committee for Standardization, which specifies research techniques in a wide spectrum of possibilities. Standards developed in the United States of America are the ASTM standards, introduced by the organization "American Society for Testing and Materials". Thanks to the cooperation of the ASTM with different companies involved in the implementation of new products on the market, with volunteers from testing organizations, and users, these standards take into consideration a number of important safety parameters. The other standards applicable in the USA are those introduced by the NFPA (National Fire Protection Association). Participants who serve on the NFPA are volunteers representing manufacturers, users, testing and special experts. The Russian standard for clothing for fire-fighters was developed by The Ministry of the Russian Federation for Civil Defence, Emergencies and Elimination of Consequences of Natural Disasters.

The subject of this work are requirements and test methods for firefighters' clothing in a range of protection against factors such as thermal radiation, flame, chemicals, leaking etc. In this review, test methods and requirements for firefighters' personal protective clothing in Europe (especially Poland), USA and Russia are compared.

Protection and firefighters' clothing

The major hazards during fire-fighting are from radiant or convective heat, explosions, falling objects, debris, fine airborne particles, limited oxygen supply, hot liquid, molten substances, noise, toxic chemicals, smoke and hot gases [2]. The main role of firefighters' clothing and equipment is to protect the firefighter from injuries from as many hazards as possible. A helmet protects against falling objects, an oxygen mask against limited oxygen supply, and protective clothing against radiant or convective heat, flame, hot liquids, toxic chemicals and water.

Table 1 presents a summary of requirements from thermal, mechanical and chemical factors in the standards chosen: NFPA 1971 „Standard on Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting", EN 469 „Protective clothing for firefighters - Performance requirements for protective clothing", НПБ 162-02 „Special Protect Clothing For Fire-Fighters Isolation Type. General Technical Requirements. Test Methods"[1]. An additional require-

Table 1. *Summary of requirements from thermal, mechanical and chemical factors in the standards chosen: NFPA 1971[3], EN 469[4], НПБ 162-02[5], Ordinance of the Ministry of the Interior of Poland [6].*

Category		Standard for requirements		Parameter	Requirements	Standard for test method
Thermal	Radiant Heat	NFPA 1971		TPP (Thermal protection performance)	TPP ≥ 35.0 at: heat flux during test 84 kW/m^2	ISO 17492
				RPP (Radiant heat performance)	intersect time ≥ 25s	ASTM F 2702
				Transmitted and stored energy	time before 2nd degree burns ≥ 130s	ASTM F 2731
				Total Heat Loss	THL ≥ 205 W/m^2	ASTM F1868
		EN 469		$RHTI_{24}$ (heat transfer - radiation)	$RHTI_{24}$ ≥ 18.0 for level 2 at: heat flux during test 40 kW/m^2	EN ISO 6942
				$RHTI_{24}$ - $RHTI_{12}$ (heat transfer - radiation)	$RHTI_{24}$ ≥ 10,0 for level 1 at: heat flux during test 40 kW/m^2	
		НПБ 162-02		-	heat flux on inner surface not more than 2.5 kW/m^2 at: heat flux during test 40 kW/m^2	НПБ 161
	Flame	Flame	NFPA 1971	Flame Resistance	after flame no more than 2 s no melting or dripping	ASTM D 6413
			EN 469	HTI_{24} (heat transfer - flame)	HTI_{24} ≥ 13.0 for level 2 HTI_{24} ≥ 9.0 for level 1	EN ISO 9151
				HTI_{24} - HTI_{12} (heat transfer - flame)	HTI_{24} - HTI_{12} ≥ 4.0 for level 2 HTI_{24} - HTI_{12} ≥ 3.0 for level 1	
			EN 469	Flame spread	index 3 of prEN ISO 14116	EN ISO 15025
			НПБ 162-02	Flame Resistance	after flame no more than 2 s shrinkage ≤ 10%	ISO 6941
	Hot atmosphere	NFPA 1971		Heat resistance	shrinkage ≤ 5% at: temperature 180 ± 5 ºC exposure time: 5 min	ISO 17493
		EN 469			shrinkage ≤ 5% at: temperature 180 ± 5 ºC exposure time: 5 min	ISO 17493
		НПБ 162-02		-	shrinkage ≤ 5% at: temperature 150ºC	НПБ 161
	Contact heat	NFPA 1971		Conductive and Compressive Heat Resistance	time before 2nd degree burns ≥ 25 s	ASTM F1060
		EN 469		-	-	-
		НПБ 162-02		-	shrinkage ≤ 5% at: 400 ± 5 ºC exposure time: 5 s	НПБ 161
Liquid	Water	NFPA 1971		Resistance to water	water penetration resistance minimum 172 kPa	Method 5512 of Federal Test Method Standard 191A
		EN 469			water penetration resistance minimum 20 kPa	EN 20811
		Ordinance of the Ministry of the Interior (Poland)		Resistance to rain	inner layer cannot be wet after one hour of artificial rain on complete garment	Ordinance of the Ministry of the Interior (Poland)
	Other liquids	NFPA 1971		***Table 2*** (see page 134)	no liquid penetration to the innermost surface	ASTM F 903 procedure C
		EN 469		***Table 3*** (see page 134)	no liquid penetration to the innermost surface	EN ISO 6530
		НПБ 162-02		***Table 4*** (see page 134)	no liquid penetration to the innermost surface	НПБ 162-02
Mechanical		NFPA 1971		Tear resistance - outer material	≥ 100 N	ASTM D 5587
				Tear resistance - moisture and thermal barrier	≥ 22 N	
		EN 469		Tear strength - outer material	≥ 25 N	EN ISO 4674-1
				Tear strength - moisture and thermal barrier	not required	
		НПБ 162-02		Tear resistance weft/warp	≥ 35/30 N	ГОСТ 17074
				Tear strength weft/warp	≥ 600/700 N	ГОСТ 17316

ment for Poland has been taken into account: Ordinance of the Ministry of the Interior dated April 27, 2010, an amending regulation for the list of products used to ensure public safety or health, life and property, as well as the principles for issuing approvals for the use of these products (published Dz. U. of 2010 No. 85, item. 553).

Most of the testing methods are used to determine the thermal (heat, flame and conductive heat) resistance of personal protective clothing for firefighters. These are the most important parameters when it comes to protecting the health and life of firefighters. There are many standards which present requirements and test methods for protective clothing for heat factors, for example flame, radiant heat,

Table 2. *Chemical penetration testing - requirements for testing in accordance with NFPA 1971.*

Chemical	Concentration
Aquaeus film-forming foam (AFFF)	3% concentration
Battery acid	3% by weight sulfuric acid to water
Fire resistant hydraulic fluid	phosphate ester base
Surrogate gasolic fuel C	50/50 by volume of toluene and iso-octane
Swimming pool chlorinating chemical	at least 65% free chlorine, saturated solution

Table 3. *Chemical penetration testing - requirements for testing in accordance with EN 469. * Temperature of all chemicals: 20 ± 2 °C.*

Chemical*	Concentration weight, %
NaOH	40
HCl	36
H_2SO_4	30
C_8H_{10} (o-xylene)	100

Table 4. *Chemical penetration testing - requirements for testing in accordance with НПБ 162-02.*

Chemical	Concentration weight, %	Time of protective action in contact with aggressive media, not less than, minutes, at temperature		
		minus 40 - 40 °C	40 - 100 °C	100 - 150 °C
NaOH	50	90	30	5
H_2SO_4				
KNO_3				
HCl	30			
1,2- dichloroethane	100	20	10	-
Benzene				
CH_3COOH	70			
Oil and petroleum products	100			
NH_3		60	30	5
Cl_2				

conductive heat and those standards have different requirements.

In standard NFPA 1971 there are three tests for determining the behaviour of materials for protective clothing for firefighting during exposure to radiant heat. Parameters tested in those methods are as follows: Thermal Protection Performance, Conductive and Compressive Heat Resistance, Radiant Heat Performance

Thermal Protection Performance (TPP) is a parameter crucial to assess compliance with NFPA standards. The test method is presented in Standard ISO 17492 [7]. In the test method material samples of protective clothing are exposed to a bench-scale test of constant external heat flux.

Figure 1. *Test stand for thermal protection performance [9].*

To predict the injures, the sample is put on a test stand consisting of two radiant panels and trolley assembly. The value of the index TPP required replaces an earlier requirement for a minimum thickness of material for protective clothing. During the test of heat flow through a sample, the ability of the material tested to protect against radiant heat is measured. For protective clothing it is required to achieve a TPP of at least 35, which corresponds to 17.5 seconds of protection against of second-degree skin burns during exposure to an external constant heat flux of 84 kW/m^2 (2 cal/cm^2-sec) [8]. The TPP method uses a combination of heat sources, which gives a better reflection of the fire conditions.

In the Radiant Protective Performance test in accordance with test method ASTM 1939, two standard sets of exposure conditions are specified:

- 21 kW/m^2 (0.5 cal/cm^{2}s) and
- 84 kW/m^2 (2.0 cal/cm^{2}s) [10],

either of which can be used. In this test a series of quartz lamps are used as an energy source rather than a burner. This test method is used for determination of the radiant heat resistance value of a material, and skin burn injury is predicted based on Stoll burn criteria.

ASTM F2731 [11] for the Transmitted and Stored Energy test method is the result of reports from firefighters on cases of burns under clothing, where there were no signs of damage to the outer and inner layers of clothing. The transmission of low-level energy and the combination of transmission energy and releasing energy stored inside clothing layers may be sufficient to cause this type of injury. This method allows to determine stored and transmitted energy. The specimen is subjected to radiant heat of 21 kW/m^2 (0.5 cal/cm^2) for 120 seconds and then compressed with a force of 2 MPa for 60 seconds.

For the safety of fire fighters during action, the heat accumulated in the inner layers of protective clothing should be considered as a threat to them that could lead to burns. The survey[2)] conducted in CNBOP-PIB among firefighters shows that 9% of respondents experienced burns while the surface of the clothing remained intact. European standards do not have requirements for testing Transmitted and Stored Energy and there is no equivalent test. US standard require protection from heat gathered in clothes, thereby ensuring a better level of protection.

In standard EN ISO 6942 [12], appointed by EN 469, there are described two complementary methods (A and B) for determining the behaviour of materials for protective clothing for firefighting during exposure to radiant heat. Method A serves for visual assessment of any changes in the material after a heat radiation of 10 kW/m². The exposure time is 3 minutes.
Method A is required only for fire fighters' protective clothing. Method B determines the protective performance in the Radiative Heat Transfer Index (RHTI) of the materials. The radiation is produced by silicon carbide heating rods, and a thermocouple is used to measure the temperature behind the test samples. A heat flux density of 40 kW/m² is used to measure the performance against radiant heat.

The area of tests for flame resistance is very well developed and allows to check the parameters sufficiently. The survey [11] conducted in CNBOP-PIB among firefighters shows that only 2,5% of respondents experienced burns caused by the flame, with the charring of clothes at the same time, and only in one case was hospitalization needed.

Test methods for clothing resistance to flame do not differ significantly in comparable standards. Material subjected to a flame should not drip, and afterwards the fire should not last longer than a few seconds. The main differences lie in the alignment of the specimen relative to the flame.

In the flame resistance test conducted in accordance with the standard ASTM D 6413 (required by NFPA 1971) the specimen is placed vertically with the flame from below. The exposure time is 12 s time.

Russian Standard НПБ 162-02 requires testing in accordance with ISO 6941. In this test method. The specimen is also placed vertically with the flame from below. The exposure time is 5 or 15 s. The time in seconds that it takes for the temperature in the calorimeter to rise to 24 + 0.2 °C is recorded. The mean result for three test specimens is calculated as the Heat Transfer Index (HTI).

European standard EN 469 recommends two tests to be performed: in accordance with EN ISO 9151 and EN ISO 15025. In test method "heat transmission on exposure to flame" described in EN ISO 9151, the specimen is placed horizontally. The heat transfer index, which is an indication of the relative heat transmission, is checked. In test method "limited flame spread" described in EN ISO 15025, the specimen is placed vertically. There are two test methods: A and B. In method A the burner is positioned perpendicular to the surface of the test fabric, and surface ignition is tested. In method A the burner is below the test specimen and inclined upwards at a 30° angle. In both test methods, the exposure time is 10 s.

Only the NFPA 1971 standard and НПБ 162-02 have a requirement for protection against contact heat.

The method for testing appointed by NFPA is ASTM F1060 for Conductive and Compressive Heat Resistance. In the test Conductive and Compressive Heat Resistance (CCHR) layer, a composite of clothing originating from the area of the elbows and knees is used. The test is carried out in two ways: using a dry or wet sample. Depending on the area from which the test sample comes from, the pressure applied is:
- 140 g/cm^2 (± 1,4 g/cm^2) for the arm,
- 562 g/cm^2 (± 56 g/cm^2) for the knees.

The samples should be exposed to temperature 280°C ($^{+3}/_{-0}$ °C). It the test is determined if the time to second-degree burns is equal to or exceeds 25 s.

The presence of moisture within clothing can affect heat transfer significantly. It can reduce the effective thermal insulation of the clothing and increase the effective water vapour resistance [13]. Moisture can come from both water from the environment (rain, extinguishing water) or can be a result of sweating. It is important to test personal protective clothing for firefighters for water resistance. Testing a small specimen is important, but it does not reflect the actual conditions of use. The weakest element of clothing i.e. the most prone to leaking, are the seams. The test required in Poland by the Ordinance of the Ministry of the Interior and developed in CNBOP-PIB is the resistance to rain test. CNBOP-PIB has introduced an additional procedure to test the resistance to leaking of complete protective clothing, involving the exposure of a dressed manikin to artificial rain for 60 minutes. The test is positive if in a lined jacket and trousers no soaking is detect after the test [14].

Development direction

Along with the development of technology and electronics, protective clothing is more and more advanced. A number of studies investigated smart or intelligent protective clothing systems. Sensors can be used to record physiological data related to health and safety, such as the heart rate or location of fire fighters without changing the clothing characteristics of flexibility and comfort [15].

In project No. O ROB/0011/03/01/001, financed by the National Centre for Research and Development (NCBiR), and implemented by a consortium consisting of The Main School of the Fire Service, CNBOP-PIB, Warsaw University of Technology, Aspirants School of the State Fire Service in Krakow, and Thermolab sc, advanced test stands for innovative test methods for fire-fighters' protective clothing were developed, combining the possibility to evaluate samples subjected to the influence of radiant heat, flame and contact heat in an innovative way compared to existing standards, with the possibility (after minor modifications) to test samples in accordance with existing standards. The end result of the project will also be physical and mathematical models of heat and moisture transport in parts of personal protection taking into account the different materials and possible configurations [16].

Henriques Burn Integral (HBI), used in the calculation in the project, allows to calculate the second degree burns of human skin as a result of heat flux. The study conducted within the project concluded that for a high level of heat flux the HBI criterion is stronger than the HTI criterion.

When heat flux has greater intensity, the HBI criterion becomes increasingly important. The exact level of superiority of one criterion over the other differs depending on the material composition and garment's thermal insulation. This relationship is also visible for a flame as the heat source. For the heat flux level 43 kW/m² the HBI criterion is almost 3 times stronger.

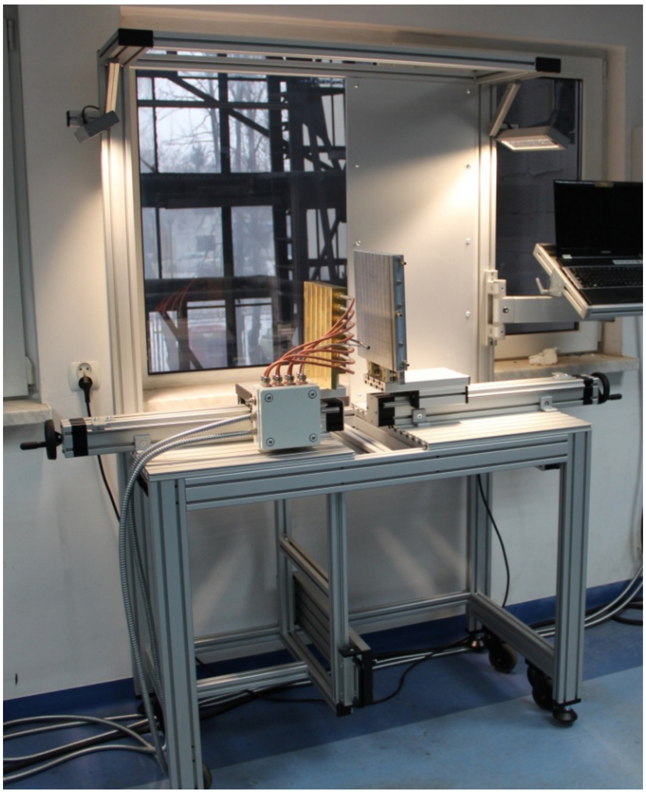

***Figure 2.** Stand for testing contact heat in an innovative way developed in CNBOP-PIB[3]).*

The use of the HBI criterion instead of the HTI criterion allows for more extensive analysis of the issues and more accurate results. This is a more stringent criterion, and it provides greater safety for firefighters. Therefore this technique, by calculating second-degree burn injuries using the HBI criterion, is a good development direction.

Conclusions

Standard НПБ 162-02 has the highest requirements in terms of resistance to contact with aggressive media. It also specifies requirements depending on the temperature of the substance. On the other hand, the NFPA 1971 standard includes testing with aggressive media that are in common use.

Only the NFPA 1971 standard includes a test of contact heat in the context of safety (time before 2nd degree burns). In EN 469, a test of contact heat in not included at all, but in НПБ 162-02 there is a test of the shrinkage of material caused by contact heat.

The difference between TPP and RPP is that the heat source in RPP is 100% radiant heat and TPP has both radiant heat and heat from burners.

Test methods for clothing resistance to flame does not differ significantly in comparable standards - they vary the position of the specimen relative to the flame.

Only the Polish standard (Ordinance of the Ministry of the Interior) includes thre requirement for resistance to rain and leaking.

The big disadvantage of current test methods for protective clothing is that they donot take into account actual fire conditions. The test is carried out in a static way on a small specimen and often does not take into account the seams, reflective trim, reinforcements, pockets etc.

Development directions in the area of protective clothing are new kinds of clothing (that use sensors) and new test methods.

Editorial note

1) Original title: НПБ 162-02 „ Специальная защитная одежда пожарных изолирующего типа. Общие технические требования. Методы испытаний".
2) Internal research conducted in CNBOP-PIB on a group of 120 professional fire-fighters.
3) One of test stands developed in project No. O ROB/0011/03/01/001, photo CNBOP-PIB.

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