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ENHANCED METHOD FOR MEASURING MATERIAL RESISTANCE TO BURNING NAPALM MIXTURE

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Abstract: *This paper introduces an advanced method for evaluating the resistance of materials to the effects of a burning napalm mixture. This enhanced method integrates more accurate and rapid temperature measurement and control of experimental conditions, advanced thermo graphic and quantitative analysis. The study involves a comparative analysis of thermal resistance results for various protective materials obtained using the new method. The enhanced measurement approach demonstrates significant improvements in data accuracy and processing speed, offering valuable insights into material performance under extreme thermal stress. This advancement is crucial for developing and accessing materials designed for high-temperature resistance applications.*

Keywords: *thermal resistance, material testing, napalm, high-temperature measurement, protective materials, temperature sensors, data accuracy, comparative analysis..*

1. INTRODUCTION

The method for testing material resistance to burning napalm mixtures was developed to examine the characteristics of military uniforms and protective gear under extreme thermal conditions. Fires and burnings are often a consequence of conventional weapons use, occurring frequently in various types of accidents. Extreme thermal effects are seen during nuclear explosions and when projectiles filled with napalm explode, dispersing the incendiary napalm mixture as drops of varying sizes. Despite international conventions banning the use of napalm and nuclear weapons, these weapons remain in many military arsenals, meaning their use cannot be entirely ruled out [1].

Napalm, a weaponized chemical mixture designed to produce a highly flammable gel-like substance, has garnered attention and concern for its destructive power and inherent toxicity. Its composition, which includes aluminum salts, polystyrene, and benzene, leads to explosive ignition and devastating effects in military operations. The harmful impacts of napalm exposure and the risk of severe burn injuries from explosive delivery devices are considerable [2].

The original thickening agent in napalm was a blend of naphthenic and palmitic acids, giving rise to the trade name "napalm," though it was more commonly referred to as a firebomb fuel-gel mixture. Numerous variations of the chemicals used in napalm have been developed. The most common modern formulation includes aluminum salts, polystyrene, and benzene. Detonation is achieved through various explosive compounds that ignite phosphorus, which burns at a temperature sufficient to ignite the fuel mixture.

Due to its consistency, napalm adheres to exposed surfaces, increasing its lethality and destructive power. Additionally, its increased viscosity allows the ignited liquid to maintain a directed stream when dispersed under pressure, making it suitable for use in military flamethrowers. Napalm burns at the same temperature as the flammable liquids in its composition, typically

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gasoline, kerosene, diesel fuel, or benzene. Direct contact with burning napalm causes full-thickness burns. Extensive contact can lead to a rapid drop in blood pressure, loss of consciousness, and death.

Military uniforms are crafted from high-quality fabrics integrated with flame retardants. These flame retardant textiles are primarily designed to lower ignition susceptibility and slow down flame propagation. Conventional textiles can be made flame retardant through chemical after-treatments, incorporating co-monomers into their structures, or by adding flame retardant additives during the extrusion process. High-performance fibers, which possess inherently high levels of flame and heat resistance, require the synthesis of entirely aromatic structures. However, these fibers are expensive and are utilized only when the performance requirements warrant the cost [3, 4].

When exposed to the effects of burning napalm mixture the soldier's clothing, intended to protect the body, is subjected to intense thermal effects that cause it to burn through, resulting in severe burns to the skin. The extent of skin damage depends on several factors, including the intensity of the heat source, duration of heat exposure, the area of skin affected, the mode of heat transfer, the age and health condition of the injured person, and the anatomical structures of the skin exposed to heat. Generally, first-degree burns can be expected in temperature ranges of 40 to 45°C, second-degree burns between 45 and 60°C, and third-degree burns above 60°C.

The following section will describe an advanced method for measuring the resistance of materials to the effects of burning napalm mixture. Additionally, twelve types of materials used in CBRN protection for various protective equipment will be tested [5].

2. METHODS AND MATERIALS

2.1. Methods

The method for measuring the resistance of materials to the effects of burning napalm mixture consists of a measuring head with seven temperature sensors (Figure 1), a control box, and a display screen for real-time observation of temperature changes (Figure 2). The data is collected by a computer, which provides the results in the form of tables and graphs, showing the temperature change over time during exposure to the napalm mixture (current temperature, average temperature, maximum temperature, and minimum temperature) [6, 7].

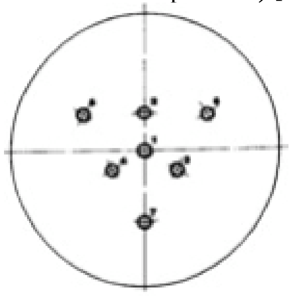

Figure 1. Position of the sensors on the measuring head

The measuring head is first placed on the sample holder, followed by the test material sample on the measuring head. A drop of the prepared napalm mixture with a volume of 2 cm³ is then dispensed onto the outer surface of the material sample using a syringe and ignited. At the moment the napalm mixture is ignited, temperature measurement and software data processing are initiated. The measurement is conducted over a 60-second interval because the napalm mixture naturally extinguishes itself after 45 to 50 seconds. Materials that do not contain flame retardants burn for a longer duration.

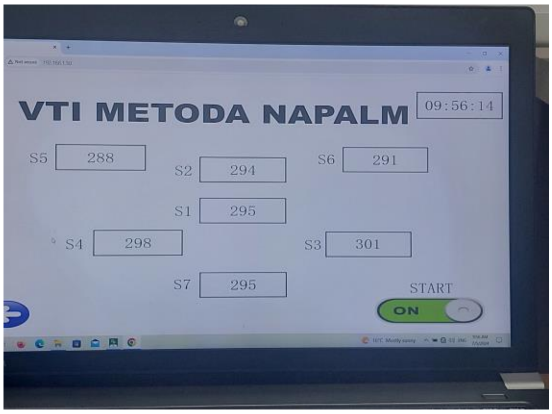

Figure 2. Display screen for real-time observation of temperature changes

Figure 3 illustrates an example of a graph displayed on the device's screen. In this case, the graph shows of the average temperature as a function of the burning time of the napalm mixture. Table 1 provides an example of a table shown on the device's screen after measurements have been taken and shows temperature measurements on temperature sensors S1 to S7, under the Protective coverall M5.

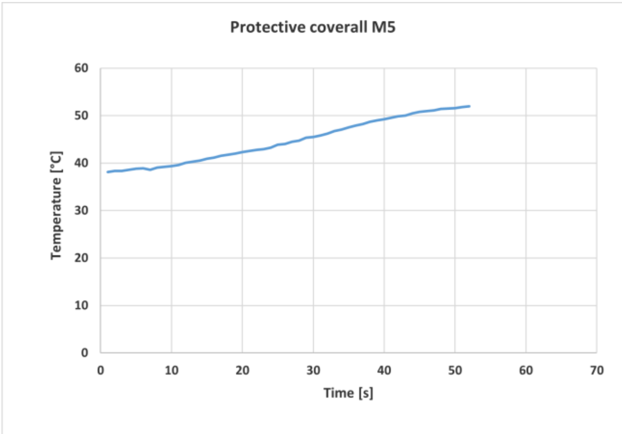

Figure 3. Graph for Protective coverall M5.

Table 1. Temperature measurements on sensors S1 to S7 under the M5 Protective coverall

Protective coverall M5						
N.o.	**T_{S1} [°C]**	**…**	**T_{S7} [°C]**	**Average T [°C]**	**Min [°C]**	**Max [°C]**
1	40.00		39.90	39.60	36.70	40.70
2	40.40		40.50	40.03	37.10	41.20
3	40.70		40.80	40.29	37.30	41.50
4	41.00		41.10	40.56	37.50	41.90

5	41.30		41.30	40.89	37.90	42.30
6	41.60		41.50	41.11	38.10	42.70
7	42.10		41.90	41.51	38.50	43.20
8	42.40		42.10	41.73	38.70	43.50
9	42.70		42.40	42.00	39.00	43.70

Unlike the old method, which consisted of three procedures based on the visual abilities of the observer, which includes: measuring the burn-through time of the material sample, measuring the temperature on the opposite side of the material exposed to the effects of napalm, and visually assessing the material's behavior, the method provides a more accurate picture by measuring temperature in real-time (measurements per second), utilizing more sensitive temperature sensors capable of detecting changes as small as 0.05 ºC. It also collects data and presents the measurements both graphically and in tabular form.

2.2. Materials

Various types of materials (insulating and filtering) used for the production of CBRN equipment were tested. These include rubberized materials for the production of protective gloves (Protective gloves M3, M4 in Serbian army and chemical resistant gloves Shown Best 879-09 used by inspector of OPCW), protective overshoes (Protective overshoes M1 in Serbian army and Exoskin B1 CBRN protective boots used by inspector of OPCW), Protective mask M3 and material for decontamination tents, as well as textile materials which consists in an outer layer of nylon/cotton with a water-repellent coating and an inner layer with activated carbon to adsorb a wide library of toxic agents (protective suits OFZ, protective coverall M3, M5 and textile material for Ballistic protective vest).

3. THE EXPERIMENTAL RESULTS AND DISSCUSION

Observing various materials burning under a napalm mixture, it can be seen that some materials do not burn through for the entire duration of the napalm mixture's combustion, while others burn through in a very short time (Table 2).

Table 2. Burn-through time and maximal temperature

Name of protective gear	Burn-through time [s]	Max temperature [ºC]
Protective coverall M3	35 s	85.5
Protective coverall M5	/	56.3
New material M5 PC	/	56
Protective suit OFZ	upper layer 25 s	57
Protective mask M3	/	28.7
Textile material for Ballistic protective vest	8 s	74
Protective gloves M3	15 s	81.2
Protective gloves M4	/	37.8
Material for decontamination tent	/	44.5
Protective overshoes M1 upper part	35 s	64
Protective overshoes M1 sole	/	46.3
Protective gloves OPCW	10 s	69.6
Protective boots OPCW	15 s	50.2

When discussing burns, second and third-degree burns incapacitate soldiers from continuing combat and other activities and necessitate medical treatment. In Figure 4, the maximum temperatures beneath different materials during the burning of the napalm mixture are shown. It is shown that only the materials intended for the M3 mask and the M4 gloves provide adequate protection against burning napalm mixtures and cannot cause first-degree burns.

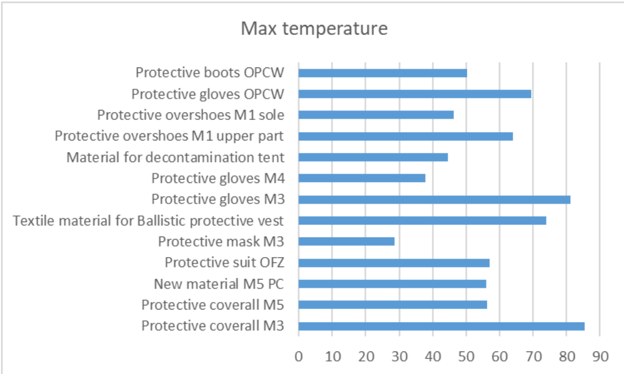

Figure 4. The maximum temperatures beneath the material with burning napalm mixture.

During the development phase, protective garments and gear must satisfy a range of tactical and technical requirements before they can be approved for use in armaments and military equipment. Regarding the thermal protective properties of body protection means, they must shield the user from burning napalm mixture for a minimum of 15 seconds.

It is obvious that materials that burn through in a short time may not show high temperatures on the sensors, as they are in brief contact with them, but they certainly do not provide the necessary time protection sufficient to allow a soldier to neutralize the effects of napalm. In this case, the M3 protective gloves, OPCW gloves Shown Best 879-09, and OPCW protective boots Exoskin B1 CBRN do not meet the required standards of thermal protection.

On the other hand, equipment such as the protective coverall M5, protective mask M3, and protective gloves M4, fully meet the thermal protection requirements. They are made from insulating materials such as as elastomers (butyl rubber) and thermoplastics (polyethylene). Insulating gear possess good protective properties but poor thermoregulatory characteristic. Their function is to shield the body, legs, and arms from CBR contamination.

They are used in scenarios involving CBR weapons, decontamination processes, reconnaissance missions, and stays on contaminated grounds, where protection for just a few hours is necessary. Also, the fire resistance of material are improved with additives or coatings. While the specific mechanisms may vary, the goal is to either prevent combustion or increase the thermal energy needed to initiate it. These mechanisms might involve creating an oxygen barrier, stabilizing intermediate pyrolysis products, and forming a char to inhibit the formation of flammable, volatile substances.

The material used for the floor and lower edges of the decontamination tent also falls under insulating materials and provides satisfactory thermal protection. It could be considered to make the roof of the tent from the same insulating material for complete thermal protection.

The textile material for the ballistic protective vest is only a part of the materials used in the vest's construction and does not provide an adequate picture of thermal protection. A ballistic vest is an item of body armor that helps absorb the impact and reduce or stop penetration to the torso by firearm fired projectiles and fragmentation from explosions and is made from aramid, an aromatic polyamide fiber. It is a class of synthetic fibers known for its exceptional strength, heat resistance, and chemical stability. Heat resistance strongly depends on the thickness of the material. Aramid fibers are used in various high-tech applications, including ballistic protection, fire-resistant clothing, composite materials for the aerospace and automotive industries, as well as in high-strength cables and ropes. The most well-known examples of aramid fibers are Kevlar and Nomex, both products of DuPont.

Garments made from filtrosorption materials, such as protective suit OFZ, are superior to those made from isolating materials. They allow for extended stays in contaminated zones and the performance of higher physical and mental tasks. Additionally, these garments provide excellent protection against RCB agents. For personal body protection during prolonged exposure to contaminated environments and while performing strenuous tasks in warm conditions, the filtering protective suit is unrivaled. The materials used in OFZ, unlike those in isolating garments, are permeable to air and water vapor, making them more physiologically suitable and reducing the risk of heat stress during task execution. The protective suit OFZ consists in an outer layer of nylon/cotton with a water-repellent coating and an inner layer with activated carbon to adsorb a wide library of toxic agents. This filtering material demonstrated good protection against burning napalm mixtures as it did not completely burn through during exposure to the burning napalm mixture.

In Figure 5, it can be seen that the OFZ material reaches a temperature of 40-45°C in 35 seconds, which provides sufficient time for the development of procedures and timeframes that a soldier can use to mitigate the effects of napalm.

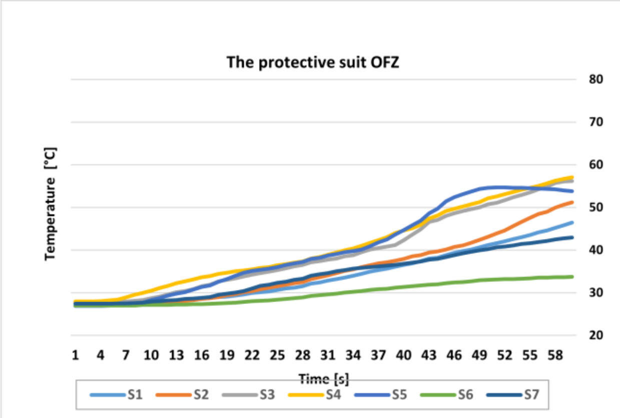

Figure 5. The temperatures beneath the OFZ material with burning napalm mixture (S1 to S7 are temperature measurements on seven sensors).

Additionally, the graph shows that the material does not transfer heat evenly, so areas not affected by the napalm mixture will not cause burns.

Similarly, the following conclusions can be drawn for the other materials: protective suits M5 and M3 do not adequately protect against burns. M5 barely covers a period of 15 seconds, while M3 cannot provide protection for less than 12 seconds (Figure 6 and 7).

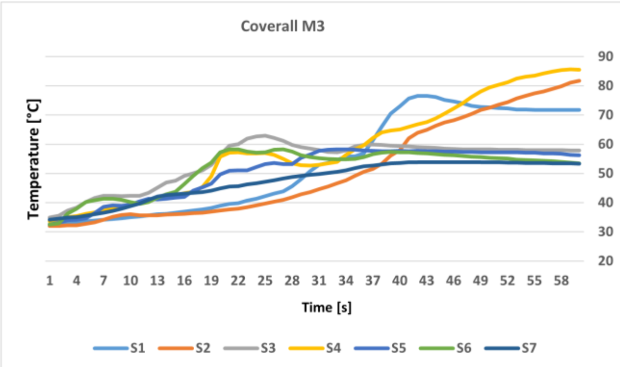

Figure 6. The temperatures beneath the material M5 coverall with burning napalm mixture (S1 to S7 are temperature measurements on seven sensors).

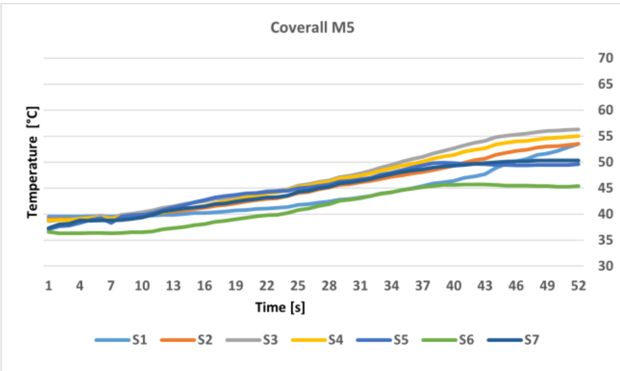

Figure 7. The temperatures beneath the material M3 coverall with burning napalm mixture(S1 to S7 are temperature measurements on seven sensors).

4. CONCLUSION

From the above, it can be inferred that this method incorporates more precise and faster temperature measurement and control of experimental conditions, along with advanced thermographic and quantitative analysis compares to the old method based on measuring the burn-through time of the material sample and the temperature on the opposite side of the material exposed to the effects of napalm. This enhanced approach significantly improves data accuracy and processing speed, providing valuable insights into material performance under extreme thermal stress. This progress is essential for developing and evaluating materials intended for high-temperature resistance applications.

The tested materials exhibited varying levels of resistance to burning napalm mixtures, with OFZ showing the best thermal resistance among textile materials, and M4 gloves and M3 mask demonstrating superior insulating properties due to the added flame retardants. These findings underscore the importance of enhancing thermal resistance to ensure adequate protection in extreme conditions.

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