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Structural Fire fighting Suits : Futuristic Materials and Designs for Enhanced Comfort

Prasun Kumar Roy*, Praveen Rajput and Mahipal Meena*

Centre for Fire,Explosive and Environment Safety, DRDO, India

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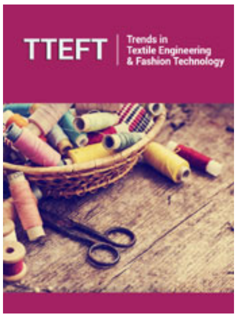

***Corresponding author:** Prasun Kumar Roy, Centre for Fire,Explosive and Environment Safety, DRDO, India

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Abstract

The present work aims to briefly overview the protective clothing being used by the fire fighters during structural fire fighting operations . Future directions towards improving the physiological comfort level offered by the ensemble without compromising on the level of protection against heat loads are also discussed.

Introduction

Structural fire fighting suits belong to the sub-class of protective functional clothing, which are designed with a view to protect our first responders who fight fired uring emergency operations.In the sescenarios,there is a possibility of the fire fighter being exposed to additional hazards like liquids pills and sparks as well[1]. Therefore, aproperly designed functional firefighting clothing is required which provides requisite level of protection not only against thermal loads but hazardous liquids, physical and electrical hazards as well. In-addition, it should be durable, washable, and most importantly, be comfortable forthewearer.

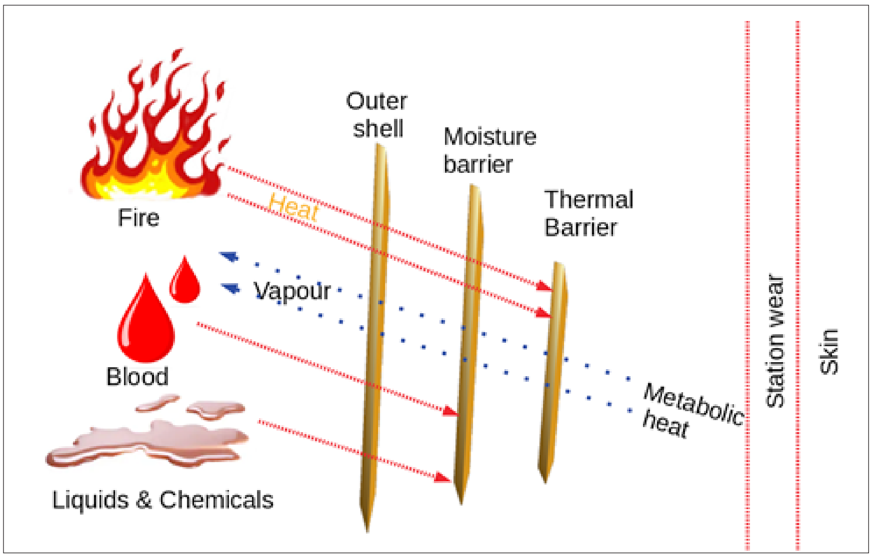

Figure 1: A schematic representation of the multilayer ensemble of structural firefighting suit.

Theentire firefighters' protective equipment include saturnout coat, pants, boots, hood, gloves, self-contained breathing apparatus, and ahelmet, as governed by the National Fire Protection Association) 1971 and 1981 standards. The firefighting suits (asperNFPA1971/ EN469orНПБ162-02orIS16890) a reall multi layer ensembles[2], are presentative assembly being shown in Figure1.The outer layer of the ensemble resist signition when subjected to thermal radiation or short periods of direct flame contact.It also im parts protection against abrasion, cuts and lacerations .Beneathit, exists a moisture barrier layer, which plays a critical role in the suit. Firstly, it prevents the entry of water to the under lying thermal layer, which ifenters will displace the air in the thermal barrier, there by decreasing the level of thermal insulation, subsequently leading to scald injuries. Secondly, the moisture barrieris required to permit the out ward movement of perspiration, leading to reduced metabolic heat build-up.

Therefore, the moisture barrier should offer a minimum level ofbreath ability along with conferring penetration resistance against body fluids and chemicals like battery acids, gasoline, hydraulicfluide tc which keeps thefire-fighter dry and protected. Next in these quence is the thermal barrier layer, the role of which is to impart there quisite level of thermal insulation to the wearer. This layer is usually made up of an on-woven fabric which traps air pockets for enhance dinsulation.

It is to be noted that the expectations from a fire fighter suit are rather contradictory. On one hand,the fire fighter needs to be protected from thermal loads, how ever increasing the thermal insulation results in physiological discomfort. Being home other mic, humans need to maintain a stable internal body temperature regardless of the external environment, the inability of which leads to heat strain[3]. Notably, burn injuries experienced by firefighters may reducedue to increased number of layers, but can lead to increase in incidents related to fatigue, exhaustion, heat strain and fatalities[4].

The efficiency of a firefighter clothing is evaluated primarily on the basis of two criteria: firstly, there striction on the amount of heat load reaching the wearer and secondly, the ease of removal of the metabolic heat produced by the fire fighter himself during the strenuous physical activities. In NFPA1971, these requirements are quantified interms of the Total Heat Loss(THL) and Thermal Protective Performance(TPP) and anideal suit would be one which exhibits an optimal balance of these two[5]. The former parameter, i.e. THL is a measure of breathability, and is evaluated at the fabric level (garmentcomposite),and the latter, i.e. TPP is an indication of the materials ability to protect against thermal loads, both being inversely proportional. As per NFPA1971,aminimum TPP rating of 35 and aTHL of 205W/m^2 is mandatory for a structural firefighting suit.In the other standards EN469 and IS16890, these are measured in terms of heat transfer (flameexposureandradiantexposure) and water vapour resistance.

It is to be noted that the tests mentioned above are a function of the fabric materials in the three-layer system only, and do not consider additional padding, trim, labels, pockets and other reinforcements. Inpractice, however these suits are wornonthe3-D human form which create additional air gaps between the layers, which further vary at different locations; an issue which is not catered for in the present standards. Also, there is a requirement of a manikinTHL benchmark for reducing heat strains,ascurrently, only fabric level heat loss values are used in NFPA standards. In the near future, there are primarily two broad domains, where developments in firefighter suit designs can be expected:namely material development and design improvisations.

Innovative materials for futuristic firefighter suits

The present- day material choices for thermal protective clothing include fabrics which are formed from fibers which are flame resistant inview of their inherent structure[6]. Polybenzimidazoles, polybenzoxazoles and melamine formal dehyde based fibers possess hetero cyclic moieties in the main chain,modacrylic fibers containvinyl/ vinylidene chloride groups,polyimides possess a rigid(laddertype) structure and the double bond character of the C-N bond available in them-and p-aramids conjugate between the amide groups and the aromaticrings resulting in increased chain rigidity and liquid crystalline nature[7]. Polyphenylene sulphide fibers consist of aromaticrings linked together by sulphide functionality. All**t**heabove-mentioned features help the fibers retain their physical properties atelevated temperatures. It is to be noted that all the commercially available fabrics are prepared from blends of different fibers ,each having its own desirable property.

The characteristic property for screening polymers forfirefighting application is its susceptibility to combustion, which is quantified interms of the Limiting Oxygen Index(LOI): the minimum oxygen concentration required for its sustained burning. For all practical purposes, all the flame resistant fibers have an LOIof>27. However, LOI gives only a partial evidence of the materials behaviour towards heat or flames, and there are several other thermal factors which are important in the context of clothing, particularly thermal conductivity and heat capacity.

Future developments in this area would primarily aimatusinglighter materials to reduce the over all weight of the fire suit, which will reflect on increased physiological comfort.Recent studies have revealed that introducing nano materials can reduce the flammability of polymers by reducing the heat release rate, increased flame-outandauto-extinguishment properties.The underlying mechanisms is the alteration in the degradation path way,i.e. formation of nano particle rein forced charred protective layers on the surface[8].

The latest developments in this area are in the field of aerogels and phase change materials.The former represents a class of material which are extremely lightand offer excellent thermal insulation as well,while the phase change materials can absorb heat energy [9].The use of shape memory alloys and thermo responsive polymers [10]which can maintain or create insulating layer sorair gaps with ingarment systems are also being researched[11].In view of the extremely low density of the hollow glass micro balloons, along with their low thermal conductivity, the potential of syntactic films can also be explored[12]. However, these ideas are presently in the experimental stages primarily because of thes low response of the sematerials,economic factors and limited durability.

Reducing the fibre dimensions can also alter the performance of fibers under fire scenario. Lately, nano fibrous flame resistant coatings formed by electro spinning process have been reported[13].It is to be noted that these porous fibers have enormous potential as a breath able moisture barrier layer[14].Thepresenceofporescanfacilitatefreemovementofthewatervapourformedduringperspiration,leadingtoincreasedlevelofcomfort[15,16].

However, it is to be noted that irrespective of the improvement in breathability, any compromise on the protection level (asindicatedbyTPP)is unacceptable.This is primarily the reason why many nove lmaterials that have found wide acceptance in norma louter wear have not yet been accepted in firefighting clothing (e.g. moisture wicking, highstretch, and ultra- ligh tweightfabrics).In this context,the use ofmodelling techniques for screening potential materials for suit applications should be explored[17].

Designmodifications

The most obvious strategy towards improvingthe comfort level of a firefighter is the introduction of passive or active ventillation. Passivevents are the ones which wil always be in place,while activevents are those which remain open under normal conditions but have to be closed during the fire scenario.Other possibilities include alteration in the assembly of the layers, reduction in the air gap volume and system modularity. Recently, as a part of the "Revolutionary Modern Turnoutsuit" project,sponsored by the United States Department of Homeland Security, all these a fore mentioned design modifications have been explored[18].A significant improvement in heat loss was observed when ventilation openings and modularity were introduced to the clothing system[19]. Inview of these studies, the next generation firefighter suits are expected to have ventilation at appropriate locations to help relieve heat stress. Studies have also revealed that the addition of just a single layer of anouter shell fabric leads to significant increase in TPP(from38to53),associated with a concomitant decrease in THL as well (205W/m^{2}from263W/m^2). Forall practical purposes, firefighter suitsare not only fitted with pockets, they are also fitted with additional rein forcements in the knee and shoulder areas as well as reflective layers,all of which affect the physiological response of the firefighter adversely; an issue which needs to be addressed. Another point of concern is the availability of the present generation fire fighter suits for a single sex work force[20].Withtheincreaseinthenumberoffemalefirefighters,the futuristic suits should be ergonomically designed keeping in view the difference in the buildand the anthropometric data for the targeted work force.

It is to be noted that in addition to the basic fibre material, there areaplethora of other factors which affect the behaviour of the fabrics under afires cenario, particularly the weave pattern, fabric direction and the torsion of the constituentyarns[21]. Closed fabric constructions, functional blended fibers,changes in the direction ,weight and torsion of the constituentyarns can also lead to improved flame resistance.

Recent developments in the field of nanotechnology permit the integration of flexible textile sensors with the protective clothing to form smart textiles[21,22]. These can be used to record vital physiological data of the firefighters such as respiratory & cardiacactivity, bloodpressure, body temperature and transmit the same to the base station,which can help in taking informed decisions. The light weight fire fighter gear of the future will have integrated vital-sign sensors as well in do or tracking, which will definitely reduce the number of injuries and fatalities of our fireresponders.

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References

1. Guowen S, Faming W (2018) Firefighters' clothing and equipment. Taylor & Francis, CRC Press, USA.
2. Jacek R, Karolina S, Daria K, Maciej B (2016) Comparison of requirements and directions of development of methods for testing protective clothing for firefighting. Fibers Text East Eur 5(119): 132-136.
3. Mcquerry M, Barker R, Denhartog E (2018) Relationship between novel design modifications and heat stress relief in structural fire fighters ' protective clothing. Appl Ergon 70: 260-268.
4. Su Y, Yang J, Song G, Li R, Xiang C, et al. (2018) Development of a numerical model to predict physiological strain of firefighter in fire hazard. Sci Rep 8(1): 3628.
5. Kim JH, Kim DH, Lee JY, Coca A (2017) Relationship between total heat loss and thermal protective performance of firefighter protective clothing and consequent influence on burn injury prediction *via* flame-engulfment manikin test. Proc Hum Factors Ergon Soc Annu Meet 61(1): 1468-1471.
6. Bajaj P (1992) Flame retardant materials. Bull Mater Sci 15(1): 67-76.
7. Jassal M, Ghosh S (2002) Aramid fibres - An overview. Indian J Fibre Text Res 27(3): 290-306.
8. Nayak R, Houshyar S, Padhye R (2014) Recent trends and future scope in the protection and comfort of fire-fighters' personal protective clothing. Fire Sci Rev 3(1): 1-19.
9. Shaid A, Wang L, Padhye R (2015) The thermal protection and comfort properties of aerogel and PCM-coated fabric for firefighter garment. J Ind Text 45(4): 611-625.
10. Mukhopadhyay A, Vinay Kumar M (2008) A review on designing the waterproof breathable fabrics part I: Fundamental principles and designing aspects of breathable fabrics. Journal of Industrial Textiles 37(3): 225-262.
11. Bartkowiak G, Dabrowska A, Greszta A (2020) Development of smart textile materials with shape memory alloys for application in protective clothing. Materials (Basel) 13(3): 689.
12. Ullas AV, Kumar D, Roy PK (2019) Epoxy-glass micro balloon syntactic foams: Rheological optimization of the processing window. Adv Polym Technol.
13. Gallo E, Fan Z, Schartel B, Greiner A (2011) Electrospun nanofiber mats coating-new route to flame retardancy. Polym Adv Technol 22(7): 1205-1210.
14. Yu X, Wu X, Si Y, Wang X, Yu J, et al. (2019) Waterproof and breathable electrospun nanofibrous membranes. Macromol Rapid Commun 40(8): 1-19.
15. Li X, Xiao X, Tian T, Yuan X, Ming L, et al (2019) Waterproof-breathable PTFE nano- and microfiber membrane as high efficiency PM2.5 filter. Polymers 11(4): 1-14.
16. Tripathi M, Parthasarathy S, Roy PK (2020) Mechanically robust polyurea nanofibers processed through electrospinning technique. Mater Today Commun 22: 100771.
17. Udayraj, Talukdar P, Das A, Alagirusamy R (2016) Heat and mass transfer through thermal protective clothing - A review. International Journal of Thermal Sciences 106: 32-56.

18. McQuerry M, DenHartog E, Barker R (2017) Evaluating turnout composite layering strategies for reducing thermal burden in structural firefighter protective clothing systems. Text Res J 87(10): 1217-1225.

19. McQuerry M, Barker R, DenHartog E (2018) Functional design and evaluation of structural firefighter turnout suits for improved thermal comfort: Thermal manikin and physiological modelling. Cloth Text Res J 36(3): 165-179.

20. McQuerry M (2018) Effect of structural turnout suit fit on female versus male firefighter range of motion. Appl Ergon 82: 102974.

21. Silva MC, Peixoto JJ, Fangueiro R, Gasi F, Baruque J (2019) The influence of textile materials on flame resistance ratings of professional uniforms. SN Appl Sci 1(12): 1650.

22. Islam GM, Ali A, Collie S (2020) Textile sensors for wearable applications: A comprehensive review. Cellulose 27(11): 6103-6131.