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A REVIEW OF THE FIREFIGHTING FABRICS FOR FLASHOVER TEMPERATURE

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ABSTRACT

In relatively recent year, concern for individual working in high risk environments, especially those with the potential of being exposed to thermal source, Fire fighters' protective clothing provides a limited amount of thermal protection from environmental exposures produced by fires. This amount of thermal protection depends on various parameters which are design, materials, construction, and fitting of the protective garments. These thermal protective clothing has specific unique structure as compared to normal clothing. The present review is an attempt to sum up the recent developments taking place in the modification of high performance fabric used against thermal hazards and the performance of these thermal protective clothing under flash over temperature.

Keywords: Firefighting, Thermal hazards, Flash over temperature, Protective clothing.

INTRODUCTION

Every year thousands of firefighters on the scene of the fire and severe heat environment and the emergency conditions were seriously burns and even killed. Some data indicate that the fire temperature can be between 600 ~ 1100°C and radiant heat flux of 1.5kW/m^2 to 200kW/m^2 [1, 2]. The human skin is very sensitive to temperature when the skin temperature reaches 45°C and the heat flux density of 2.68 J/cm^2 the person will have the burning feeling; When the heat flux increases to 5.02 J/cm2, and human skin temperature reach 72°C, it will cause second-degree burns of the skin [3].

In many industrial settings, workers face potential exposure to fire hazards, this especially true for firefighters who may be exposed to many different thermal environments including severe flash-over conditions. Durability makes firefighters wearing clothing to enter the high-temperature fire environment. The penetration of the temperature caused by the accumulation of radiant heat and the hot air of the surrounding material in the inner garment is an important indicator of the firefighter's activity. Thus the firefighting fabric focus is to reduce radiant heat penetration problems, reduce the thermal conductivity, so that clothing should slow down deep heating time to ensure that firemen have a longer working time.

In order to ensure the firefighters safety under the premise of normal work, textile materials were used in the high temperature environment and severe fire heat, through functional clothing to the effective protection of the insulation. The textile material have the effect of thermal protection and thermal degradation, the thermal degradation lead to changes in the mechanical, physical, chemical properties and morphology, as well as thermal protection abnormal behavior and loss of efficacy. Development and application of fire insulation textile materials has much of the scientist's attention, and has achieved many significant results.

Measurements of heat transfer characteristics to predict protection from burn injury are fundamentally important to evaluate of fabrics intended for use in heat resistant safety clothing. Laboratory methodology to characterize the insulative properties of protective fabrics has been extensively studied in recent years [4-8]. An important consideration is the nature of the heat source and the intensity of the thermal exposure.

The radiative properties of materials relate to how the materials respond to and transmit electromagnetic energy. Emissivity is closely related to the property of absorptivity and is measured as a comparison to the emissive power of a black body at the same temperature [9].

Nearly; a half century in the past, the development and application of multi-functional high performance thermal protection materials were obtained a larger development, especially the successful development of new materials of the fiber for integrated use of high-tech, and promote the rapid development of the thermal protection materials. The new materials were suitable for individual protection, lightweight, flexible, high-performance thermal protective clothing and materials constantly proposed development and in-depth study. The forming technology, practical products and characterization methods are constantly appearing and improvement. However, the high-tech advances put forward higher requirements, especially in lightweight, flexible, high-performance, intelligent human protective material. Fire insulation performance of the firefighting fabric at the open flame fire has not yet been solved especially to face; endurance and maintain at the environment of high temperature.

BACKGROUND

2.1 Thermal Exposure in Work Environment:

Firefighting environments are manifold and depend on the kind of fire ground which is for example residential, manufacturing, wildland, storage or mercantile fire. Despite the flash-over situation in which firefighters were surrounded by the fire are highly feared, such situation is rather rare. The severity of the thermal exposure depends on air temperature as well as radiative heat flux. Three levels of fire fighter exposure condition were defined by Hoscke [10] based on Abbott [11].

Nonetheless, data have been collected and information is available to provide a range of common thermal environmental conditions that were classified into three general categories. These classifications by Veghte, Day and Sturgeon [12,13]. Thermal environmental conditions were identified as routine, hazardous, and emergency, which are discussed below:

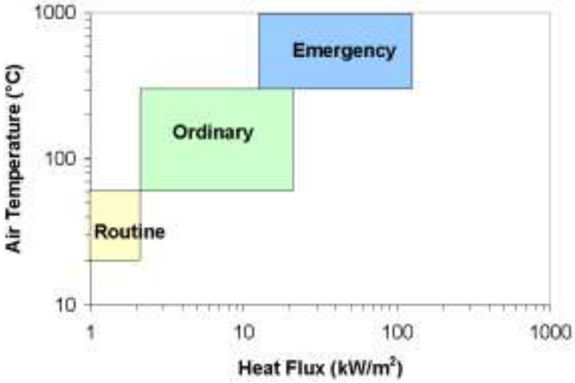
- The Routine region describes conditions where one or two objects, such as a bed or waste basket, are burning in a room. The thermal radiation and the air temperatures are virtually the same as those encountered on a hot summer day. Routine conditions are accompanied by a thermal radiation range of 0.025 to 0.05cal/cm2 second and by air temperatures ranging from 20° to 60°C. Firefighting clothing is easily able to handle this thermal load
- The Ordinary region describes temperatures encountered in fighting a more serious fire or being next to a “flash-over” room. Ordinary conditions are defined by a thermal range of 0.05 to 0.6cal/cm2sec, representing an air temperature range of 60 to 300°C. In general, protective clothing should afford the fire fighter 10 to 20 minutes of protection under Ordinary conditions. This usually allows sufficient time to extinguish the fire or to fight the fire until his or her nominal air supply is exhausted (usually less than 30 minutes).
- The Emergency region describes conditions in a severe and unusual exposure, such as those caused inside a “flashed-over” room or next to a flame front. In Emergency conditions, the thermal load exceeds 0.6cal/cm second and temperatures exceed 300°C. In such conditions, the function of fire fighters’ clothing and equipment is simply to provide the 15 to 30 seconds of protection for an escape.

2.2 Range of Temperature Causes Burn Injuries to human Body:

According to ASTM C 1055, Standard Guide for Heated Systems Surface conditions that produce contact burn injuries [14], and the range of temperatures that produce burn injuries are:

- The 20°C temperature represents room temperature,
- The 48°C represents a human tissue temperature at which a first degree burn occurs,
- The 55°C is the human tissue temperature that is likely to cause a second degree burn [15] and
- The 72°C is the human tissue temperature at which an instantaneous burn injury is likely to occur.

Veghte summarized his findings in a chart that defines the routine, ordinary and emergency conditions that a firefighter would experience. The definitions of such general terms are useful only if the firefighter has an intuitive understanding of what these conditions mean for him; as a retired firefighter, Veghte has a good feel for the specific needs of the job. As shown in Figure Error! ***No text of specified style in document.***



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Classification of firefighting conditions

2.3 Flash Fire and other High Heat Flux Exposures

One hazardous situation encountered in the petrochemical industry is the flash fire. Flash fire can result from the release of combustible gas, such as a leak at a well heat site, compressor station, or petrochemical plant. They are short duration, typically less than 5seconds, and involve intense heat fluxes. Thermal protective clothing for this high intensity, short duration firefighting fabrics were designed to protect the worker for several seconds if they happen to be exposed to a flash fire, giving them an opportunity to escape. Therefore it is different from protective clothing which was designed for other applications, where long exposures to different heat fluxes occur. However, this clothing would not be appropriate for workers at a well site, and it can so a good job to protecting the workers if they were caught in a flash fire, the coats would certainly be uncomfortable to wear during the course of their normal duties, especially during summer months

2.4 Skin Burns Injury Prediction

When human tissue is exposed to heat, the reaction is an increase in temperature. After a critical temperature level has been reached, irreversible damage of exposed tissue begins and proceeds progressively when temperature increases. If the damage area is large, severe medical problems appear which may lead to death.

The traditional ranking system of burns is based on the depth of damage to the tissue and the level of necrosis. Critics of this system point to the lack of correlation between the initial appearance and the depth of injury. The latter is considered the most accurate indication of the severity of a burn [16].

- First-degree burns are superficial burns, and only involve the epidermis. The skin will become red and painful but blistering will not occur. Severe sunburns are the most common form of first-degree burns.
- Second-degree burns occur when the entire epidermis are destroyed. Second-degree burns can be sub-divided into superficial and deep classifications. A superficial second-degree burn involves no damage to the dermis. The skin will be blistered, red, and painful, with a moist look to it. If there is some damage to the dermis, then it is considered a deep second-degree burn. The skin will be blistered with a pale white color under the blisters.
- Third-degree burns involve complete destruction of the dermis, with necrosis possibly extending into the subcutaneous tissue. The skin will not blister, but instead be dry, gray and possibly leathery. There is usually no feeling, and little to no possibility for regeneration.
- Fourth-degree burns require skin grafts. Fifth and sixth-degree burns involve destruction of muscles and or bones respectively.

2.5 Stoll Second Degree Burn Criterion

Stoll performed experimental research to estimate the time it takes for second degree burn damage to occur for a given heat flux exposure. Her experiments involved exposing a blackened area of the forearm to radiation of known intensity for certain lengths of time. These exposure time lengths were time to unbearable pain for the test subject, as well as time for blistering to occur [17]. The radiation source used was a 1000 W projection lamp attached to a variable resistor to obtain the desired irradiation. Experimental data were obtained for heat fluxes of 0.1 to 0.4cal/cm^{2}s (4.2 to 16.8kW/m^2) [18]. These results can be theoretically extended to include heat fluxes from 0.4 to 1.0cal/cm2 (16.8 to 42.0kW/m^2) as well. The Stoll curve showing time to a second degree burn for various heat fluxes is shown in Figure 1.

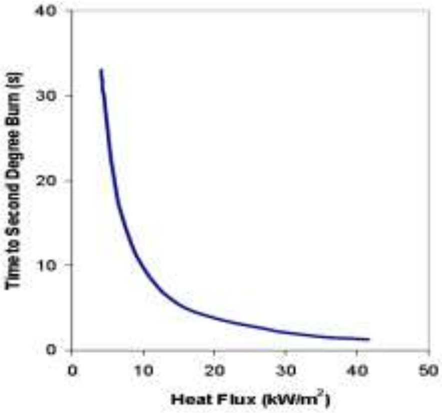

Figure 1. Stoll Criterion Time to Second Degree Burn for Various Incident Heat Fluxes on Bare Human Skin

The exposure time and heat flux come directly from Stoll's work, as this is what is plotted in Figure 2. This curve can be represented by the following equation [18].

$$q = 50.123t^{0.7087} \quad (1)$$

where q is the incident heat flux in kW/m^2 and t is the time to second degree burn in seconds.

The calorimeter equivalent values in the standard tables are again based on Stoll's work and allow the temperature rise of the sensor used in the test, such as an 18 g copper disk calorimeter, to be compared directly with exposure time to determine time to a second degree burn. A second degree burn is said to have occurred when:

$$To = T + (8.871465^{0.2905449}\, t) \quad (2)$$

where To is the initial temperature of the sensor.

A few disadvantages of the Stoll second degree burn criterion technique to be aware of are that this criterion is based on limited data obtained using a rectangular heat pulse [19], and that it only yields information on predicted second degree burns.

2.5 Henriques Criteria

Henriques was one of the first researchers in the area of skin burn injury. He performed many experiments on pig skin, initially exposing the skin to hot water of varying temperatures and observing the physical changes in the skin [20]. When analyzing the experimental data it was found that skin damage could be represented by a first order Arrhenius rate equation, just like many other chemical and physical rate processes [21]. The rate of tissue damage is given by

$$\frac{d\Omega}{dt} = P \exp\left(\frac{-\Delta E}{RT}\right) \qquad (3)$$

This can be integrated to obtain

$$\Omega = \int_0^t P \exp\left(\frac{-\Delta E}{RT}\right) dt \qquad (4)$$

This integration is carried out over the time the basal layer temperature, T, is greater than or equal to 44°C, which is the threshold temperature for thermal damage to the skin.

Second degree burns were said to occur when Ω, the value of Henriques. Burn integral (non-dimensional), is equal to 1.0. With this arbitrary value set and knowing the universal gas constant, R, the pre-exponential factor, P and the activation energy, ΔE were graphically determined from the experimental burn data. The activation energy, ΔE, was found to be 150 000 calories per mol. This is very close to that of thermal denaturation of proteins, which is thought to be what happens in the skin during heating. The pre-exponential factor, P, was found to be 3.1x1098 sec-1. Knowing these values, times to second degree burn of the skin could be determined for various temperature-time exposures. Further work found that a critical value of Ω=0.53 can be used to predict the time for a first degree burn and that by using the temperature at the base of the dermis of the skin in Equation (1-4) and a critical value of Ω=1.0, third degree burn times can be predicted. For this research, temperature-time data from skin simulant sensors can be used in conjunction with a skin heat transfer model and Henriques burn integral to compute times of the second and third degree burns of human skin.

Human skin is sensitive to temperature. Human skin and other properties are different depending on people. It is reasonable to take the average properties of skin to study burn injury prediction studies by Henriques, Stoll and Derksen, establish criteria for relating heat transferred to the skin to burn injury that have been used in the development of test procedures for thermal protective garments [22-24]

2.6 The Limiting Oxygen Index (LOI) of Fibers

The Limiting Oxygen Index is the lowest concentration of oxygen necessary to support combustion in fabric samples. This test is conducted by igniting the top of a vertically oriented sample with a hydrogen flame. In this test, the flame itself does not assist in burning the test fabric; therefore, repeatable results are easily obtained. Following fabric igniting, the ratio of oxygen and nitrogen are adjusted until the sample is completely consumed at a slow and steady rate.

The LOI entrusted as the minimum fraction of oxygen in the chamber respond to maintain slow and steady combustion [19]. The limiting oxygen indexes of common flame retardant fibers were shown in **Error! Reference source not found.**.

Table** Error! No text of specified style in document.. **The limiting-oxygen indexes of common flame-retardant fibers

Fiber	LOI
Flame retardant Polyester	30
Flame retardant Acrylic	27
Flame retardant Nylon	27
Flame retardant Polypropylene	28
Flame retardant Vinylon	33
Polyvinyl chloride fiber	35
Dimensional polyvinyl chloride fiber	30
Phenolic Fiber	30
Kevlar	29
Nomex	30
Kynol	38
PBI	41
PBO	68
PTFE	95
Basofil	32
Polyarylsulphonamide	33
Polyether ether ketone	38

Later, in order to meet the fire and other environmental dangerous and to resistance high temperature radiation; the thermal stability, high-performance requirements of structural materials demand, and many countries in the world are committed to high-tech fiber were developed. Characteristics of the molecular structure of the polymer itself developed the inherent heat-resistant of the fire retardant fiber**.**

MATERIALS AND METHODS

3.1 Fire Insulation Fiber

Faster, stronger, lighter, safer, these demands are constantly being pushed upon today's researchers and manufacturers, including protective clothing, routine or specialized. A heat protective fiber is classified as, A synthetic fiber with a continuous operating temperature ranging from 375°F to 600°F. Conversely, high performance fibers are driven by special technical functions that require specific physical properties unique to these fibers. Some of the most prominent of these properties are: tensile strength, operating temperature, limiting oxygen index and chemical resistance.

Flame-resistant fibers can be divided into two classes: inherently flame-retardant fibers and chemically modified fibers and fabrics. Inherently flame resistant fibers are those in which the flame resistant properties are built into the polymer or fiber structure, such as aramid, modacrylic, polybenzimidazole (PBI), semi-carbon, and phenolic fibers. The molecular chains of heat resistant fibers have a “stiff backbone” due to the aromatic groups which limit bond rotation, thus resulting in high decomposition and melting temperatures and low thermal shrinkage [25].

The design of the high temperature and firefighting protective clothing based on flame retardant clothing materials, which are mainly high performance fiber and high reflected fiber. Development of the flame-retardant can be through add chemical additives in the fiber, deposition by adsorption, chemical bonding, non-polar van der Waals binding or adhesion, fixing of the flame retardant on the fiber to obtain a flame-retardant fiber in order to obtain the flame-retardant effect, but modified limited performance [26], mainly because of the poor thermal stability of the fibrous material in high temperature environments.

Normally flammable fibers, such as cotton and wool, can be treated to make them suitable for use in thermal protective garments. Proban 210, which is phosphorus- and nitrogen-containing flame-retardant, is one of the most successful cellulose fire retardant finishes [27] . It self-polymerizes to form a three-dimensional-network polymer within the found in cotton fibers. Curing is followed by a post-oxidative treatment, which raises the phosphorus to the more stable oxidation state[28].

3.2 Fire Fighting Fabrics

Since the 1960s, there has existed a great development on the high heat resistant fibers, such as meta-aramid fiber (Nomex), Kevlar fiber, etc., and many experts and scholars were studied the thermal stability of the fibers of Kevlar, Nomex, PBO fire insulation [29-31]. Research and application of inorganic fibers are more, but generally not used for human protection material Meanwhile, polyphenylene benzimidazole PBI, Kynol fiber, fire resistance Rayon, Basofil fiber, Kermel, Polyarylsulphonamide fiber, P84, and pre-oxidized PAN based fibers, among others, as well as better FR finishes for cotton and new blends of fibers [32] have made possible far more effective garments.

Polymer molecular chain of these fibers are mainly constituted by a heterocyclic ring-containing aromatic chain region, and the structure was stabilized due to this resonance, the high strength and stiffness, and the low amount of hydrogen of fiber macromolecules. In 2007, Kotresh and coworkers studied the fabric assemblies used by combat paratrooper in the Cone Calorimeter by using three types of surface fabrics and two types of insulative materials [33].

The heat-resistant fiber flame retardant performance detail of some materials and their operating temperatures are given in Table1.

Table1. List of synthetic fabrics and their operating temperatures.

Type of Fibers	Common Name	Operating Temperature (°C)
Meta-aramid	Nomex	204
Para-aramid	Kevlar	190
Fluorocarbon fibers (PTFE)	Teflon	260
Polyphenylene sulfide	Ryton	260
Melamine	Basofil	204
Poly-phenylene benzobisoxazole	Toyobo’s Zylon	315
High Density Polyethylene (HDPE)	Spectra	121
Polybenzimidazole (PBI)	Celanese	250
Polyimide (PI)	Inspec	260
Carbon		537
Novoloid Phenolaldehyde	Kynol	350
Polyphenylenebenzobisoxazole	PBO	650
Aromatic polyimide-amide	Kermel	400
Polyarylsulphonamide		420
Polyether ether ketone		335

The studies were focused on thermal stability of the fibrous material of the fire insulation class, because the thermal stability of the fiber largely determines the thermal stability and practical performance of the fabric. Thermal analysis is a technique of measuring the temperature conditions of the controlled application of the relationship with the temperature changes as a function of the physical properties of the test sample and its reaction product. The temperature program generally uses linear program, but also may be the logarithm of the temperature or countdown procedure. It can be obtained not only the structural aspects of the information, but also to evaluate its performance, as measured the multiple transition temperature[34].

Requirements for the protection of the human body in the fire and other harsh environments were satisfied by often using high performance aromatic polymer fibers or glass fibers, and other inorganic fibers spun in pure or blended to solve the thermal stability of the material. The results showed that these fibers had an excellent fire retardant effect [35], while the decomposition temperature of the aromatic fibers with high temperature resistant were relatively low, and also not stable long used alone at a temperature of above 400°C. It is obviously difficult to achieve the requirements of long-term use in severe heat environments of the scene at high; while the use of the woven fabric made of inorganic fibers can achieve excellent thermal stability, but the fabric is thick and heavy, and difficult to achieve flexible requirements. Therefore, the nonwoven fabric gives a good solution to obtain the thermal stability and to achieve the flexible requirement.

3.3 The Functional Structure Design of the Firefighting Clothing:

Thermal protective clothing is designed to prevent or minimize skin burn from flash fires by reducing the heat transfer from the fire to the skin underneath the clothing. The garment must also maintain its integrity during the exposure, so that it will not rupture as a worker attempts to escape from a fire.

3.3.1 Design Principles and Processes of Protective Clothing:

Some of the desired properties of thermal protective clothing are required. The first desired properties of thermal protective clothing are the constituent fibers which should be flame resistant, non-melting, shrink-resistant, and maintain their strength and flexibility even at high temperatures, they should not emit toxic gases at high temperature. The fiber should also have a low thermal conductivity so that they transmit as little and not split when exposed to flam, have low air permeability, and be free of flammable finishes or coatings. The garment itself should have a proper fit and be easy to maintain. Closures and waistbands should be designed so as to reduce possible chimney effects during exposures. Garments must also be comfortable to wear during the normal course of work [36].

In order to achieve the desired effect fabric functional structure designed for the specific application of the fabric, primarily depend on fiber material, the organizational structure and the composite level structure of the fabric chosen to design. A fire fighter's protective ensemble is typically constructed of three layers of fabric: the outer shell, the moisture barrier and the thermal liner. The outer shell is designed to provide maximal protection from heat and flame as well as cuts and abrasion. Outer shells are usually made of polymeric weaves that incorporate high strength and excellent thermal resistance. The moisture barrier is designed to protect the firefighter from external fluid exposures. As technology has improved, these moisture barriers are now designed to allow water vapor to be transpired from the body, reducing the chance of injury due to steam burns on the skin of the fire fighter. The thermal liner can be removable or permanent and is designed to provide an insulating layer to protect the firefighter from heat or cold [37].

3.3.2 The Development of Fire Retardant Fabric

To achieve the effect of fire retardant fabric through one of the following process, fire retardant treatment or coating and finishing, or covering the flame retardant substances or mixtures with a high temperature polymer coating to improve the general effect [38]. Later, people realize the necessity and effectiveness of the protection of the radiant heat, the physics-based radiation - reflective mechanism for researchers more choice of metal fibers or metal or metal oxide coated or laminated on the fabric surface, using composite technologies to produce the fabric, in order to improve the reflection coefficient of the surface of the fabric, to achieve a good reflective insulation effect. Such as aluminum foil compound flame retardant fabric and aluminum vacuum flame retardant fabrics.

Currently the best reflective insulation clothing is aluminum reflective clothing, because aluminum has a higher reflectance to ultraviolet, visible and infrared, and has better stability in the thermal environment. In the strong field of radiant heat, the thermal efficiency of the radiation of an aluminum foil can reach more than 90%; and significantly can reduce the body heat stress. The surface metal coated fabric almost has no air permeability, to hinder the evaporation of sweat, easily lead to the accumulation of body heat; metal film the face of the open flame high temperature environment. Due to the limitation of its own melting point and easy to be melted, it is more suitable for long distance operations.

Phase change materials (PCMs) can store or release thermal energy as they go through phase transitions. In early efforts, researchers used organic (PCMs) for this purpose. Recent research has investigated the incorporation of organic PCMs directly into the fabric fibers [39], or coated on the substrate surface [40]. With the rapid development of microencapsulation technology, nano-technology and high-tech, many researchers through the fabric phase change material microcapsules the coatings [41] or inorganic nano coating [42, 43], or multi-layer fabric laminated technology [44], obtained the thermal protective fabrics with good flame retardant insulation effect.

The phase change material (PCM) in textile materials has decades of history. The (PCM) was first used in the textile materials during the first Gulf War because of high temperatures and sunlight in the Gulf region, Banta and Burr [45] reported on the efficacy of a 6-pack ice vest on the reducing of the heat stress experienced by the engine and fire room personnel on-board US ships stationed in the Persian Gulf during the summer of 1989. The ship deck surface temperature above 60°C, which prompted the U.S. military to seek cooling garment the Triangle developed based on a containing phase change material capsules jacket, a partial solution to the deck sliders. The cooling problems in this jacket improved for three anti serving in the Marines in 2001. The jacket in 40°C temperatures to maintain service in the comfort of 1 to 2 hours [46], and easily renewable, effectively extending the duty time of U.S. combat troops in the field under very hot conditions.

Wang, at all, studied the phase change material of intelligent thermal protective fabrics [47]. ML Nuckols [48] researched the dry suit containing low temperature microencapsulated phase change materials research, and the establishment of the analytical model for predicting clothing thermal performance in a simulated marine environment. FL Tan and SC Fok [49] designed a helmet, for refrigeration systems contained phase change material, to make the wearer feel the best comfort. Allegedly, completeness melting of the phase change material in the helmet can make people feel comfortable as long as two hours, and the helmet can be used repeatedly. For a polyethylene glycol phase change material with the average molecular weight of 1000, it was sealed in the microcapsules, and the coated on the surface of the fabric, made of the exotherm temperature to 11°C, the endotherm temperature of 28 to 31°C.

The phase change material is applied into textiles more and more, but the phase change material is also limited to the low temperature range (30 to 50°C), and mainly through the phase change material encapsulated in a carrier system (diameter1.0 ~ 10.0μm microcapsules). The fabric coating or the microcapsules mixed into the spinning solution was conducted. The efficiency and long applicability of fabrics and fibers are unclear and pending, which should be further studied, while there have been a few researches on the high-temperature phase change materials in the field of textile [50-54].

With the development of high-tech multi-functional garments of fire pursuit, the fire insulation class clothing gradually developed into a multi-layer composite structure, in order to achieve efficient, intelligent, multi-functional protection. Such as the U.S. fire suits typically designed as a three-layer structure respectively, i.e. the outer and the inner casing layer, a vapor barrier layer or insulation layer in the middle. Our fire class clothing usually has a four-layer structure: the outer layer, waterproof, breathable layer, insulation layer and comfortable layer. The outer layer is used to resist flames and heat; close to the outer fabric, breathable waterproof layer serve to prevent moisture and harmful chemicals through, ensure good ventilation; the insulation layer acupuncture fabric or non-woven, play prevent heat conduction; and comfortable layer is the innermost layer, so that the wearer is more comfortable to wear, it is usually sewn insulation lining.

CONCLUSION

- During last few years, there is a considerable development in composition of fire resistant fabric such as Nomex, Kevlar, PBI, FR Rayon, Kermel, P84, and pre-oxidized PAN based fibers, among others, as well as better FR finishes for cotton and new blends of fibers have made possible far more effective garments. Many of these fibers were developed as asbestos substitutes for high heat areas. The thermal protection is a starting point for development of many of the new high temperature fibers; new research is still going in progress for more improvement.
- Despite the existence of the standardized bench top tests for evaluating fabrics for thermal protective clothing for flash fire and other high heat flux exposure there are still many questions about the thermal response of these then fibrous materials under high heat flux condition. While others have developed analytical and numerical methods of these materials, these models are difficult to use and have not been overly successful predicting fibers.

- Protective cloth can be evaluated using test which simulate possible accidents. The evaluation of the protective qualities can be done by a variety of method such as predicting the skin burns that person wearing various fabrics or garment in such accidents will receive
- Additionally, a lot of progression has been observed in the maturity of materials used as moisture barrier and as thermal liner.
- A point should be made here about the dynamics of constructing protective clothing. Tests concerning the effectiveness of fibers or fabrics are only relative guidelines as to how one fabric may perform compared to another. Such tests should be considered as starting points. Many things may affect test results including moisture, thickness, airspace, etc. The insulation value of a fabric or garment changes dramatically when the body bends, twists, sweats, and does work. The use of and results of the manikin test in bum evaluations is a case in point. Even so, the test is a static one and disagreement exists on the procedures and validity of testing.
- With the expansion of scientific routes and upgrading of the technologies in this field the hazards associated to flames can be diminished considerably. In this review efforts have been made to have a look of the research activities taking place in the field during very last few years.

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