TECHNICAL UNIVERSITY OF LIBEREC
Faculty of Textile Engineering

UV weathering of fire fighter clothing

Master Thesis

Study programme: N3106 Textile Engineering
Study branch: Clothing and Textile Engineering

Author: **Hikmat Marahatta, B.Sc.**
Thesis Supervisors: Ing. Adnan Ahmed Mazari, Ph.D.
Department of Clothing technologies

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Master Thesis Assignment Form

UV weathering of fire fighter clothing

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Rules for Elaboration:

1. Perform a research on the properties of firefighting clothing. Measure the tensile properties of the outer layer of various commercially available firefighting garments.
2. Expose the outer layers of firefighting clothing to UV radiation in accordance with applicable standards.
3. Analyze the effect of UV radiation by comparing the mechanical properties, air permeability, bending rigidity of the samples of firefighting layers before and after exposure to artificial UV radiation.
4. Test the radiatiation resistance of the firefighting suit before and after exposure to man-made weather conditions.
5. Analyze the experimental results and evaluate the effect of UV radiation on firefighters' suits.

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- ANDRADY, A.L., HAMID S.H., HUC, X., TORIKAI, A. Effects of increased solar ultraviolet radiation on materials, Journal of Photochemistry and Photobiology B: Biology 46, 1998, 96-103.
- SINGH, B., SHARMA, N. Mechanistic implications of plastic degradation, Polymer Degradation and Stability, 2008.
- RIVATON, B., MAILHOT, J., SOULESTIN, H., VARGHESE, J.L. Gardette, Comparison of the photochemical and thermal degradation of bisphenol-A polycarbonate and trimethylcyclohexane-polycarbonate, Polymer Degradation and Stability, 2002.

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Abstract

Firefighting is a risky occupation, with damage rate that has been assessed at multiple times that of different specialists. Although the firefighting is the single job but have to go through a lot of work inside it. They experience these and other threats to their safety and health in situations that can change quickly or is influenced by weather or other rapidly changing environmental conditions.

In this research, we studied about the impact of ultraviolet radiation on thermal protective performance and comfort properties of firefighter clothing. Nomex and Proban, which are commonly used for protective clothing, and these two fabrics are used for evaluating the impact and performance of Ultraviolet weathering on tensile properties, bending properties, water vapor permeability air permeability and radiation heat transmission. **Atlas weathering machine UV340** will be used for before and after weathering on the fabric. It helps to identify the change in climate from fabric to skin or skin to fabric. Ten samples from Nomex and ten samples of Proban will be used for the ultraviolet exposure and the second part of experiment will be performed on those sample. The machines like Water vapor transmission rate tester (fx3180 cup master), Testo Metric (tensile test), Radiation Heat transmission equipment (Calorimeter), Air permeability Test equipment (FX3300 Textest instruments, Flexibility testing instrument (TH-4, Tuhomer).

All the test will be performed to identify whether the fabric will reach the minimum requirement and standards for firefighter clothing or not.

Keywords: firefighter, protective clothing, weathering, radiant head flux density index, momentum, thermal protective performance.

Abstrakt

Hasičství je riskantní povolání s mírou poškození, která byla několikrát hodnocena u různých specialistů. I když je hašení požáru jediným úkolem, musí v něm projít spoustou jiných činností. Tyto a další hrozby pro jejich bezpečnost a zdraví zažívají v situacích, které se mohou rychle změnit nebo na ně má vliv počasí nebo jiné rychle měnící se podmínky prostředí.

Tento výzkum se zabývá vlivem ultrafialového záření na tepelnou ochranu a komfort hasičského oděvu. Nomex a Proban, které se běžně používají pro ochranné oděvy, tyto dvě látky se používají k hodnocení dopadu a výkonnosti ultrafialového záření na tahové vlastnosti, vlastnosti v ohybu, propustnost par, propustnost vzduchu a prostup tepla sáláním. Měřič UV záření **Atlas UV340** je použit pro měření před a po povětrnostních podmínkách na textilii. Pomáhá identifikovat změnu klimatu od textilie k pokožce nebo od pokožky k textilii. K ultrafialové expozici je použito deset vzorků Nomex a deset vzorků Proban a na těchto vzorcích je provedena i druhá část experimentu. Jsou použity stroje jako tester rychlosti přenosu vodní páry (fx3180 cup master), Testo Metric (zkouška tahem), zařízení pro přenos záření (kalorimetr), zařízení pro testování propustnosti vzduchu (přístroje FX3300 Textest), nástroj pro testování flexibility (TH-4, Tuhomer).

Celé testování je provedeno za účelem zjištění, zda textilie splňuje minimální požadavky a normy pro hasičské oděvy či nikoli.

Klíčová slova: hasič, ochranný oděv, vliv počasí, index hustoty toku sálavého tepla, hybnost, tepelná ochrana.

Aims and objectives

- Artificial weathering of outer layer of firefighter protective clothing under ultraviolet rays.
- To identify and explore the limit of firefighter protective clothing when exposed in UV rays.
- Analysis of thermal protective performance in terms of transmitted heat flux density is done before and after UV exposure of fabric.
- To compare the air permeability, bending moment and tensile strength of fabric before and after UV exposure.
- To compare the better performance level of the given different sample of fabric.

Purpose of study

The main purpose of the study is to identify the condition of fabric or to know if the fabric is suitable or not for protective use before it effects or harms the human body. The study will help the firefighter units to maintain its inventory and always be ready with the fully protective clothing for the job.

The study will have the significant implications in the academia by elaborating on the testing possibilities, whether the material is appropriate or there is further scope of research.

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CHAPTER 1: INTRODUCTION

1.1 Introduction

Firefighting is a risky occupation, with damage rate that has been assessed at multiple times that of different specialists. Despite the fact that there are different work settings where firemen are in danger of damage remembering for travel and even in the firehouse itself the fire-ground speaks to a particularly dangerous condition for firemen. Other than their conspicuous introduction to fire and blast hazards, firefighters routinely convey substantial hardware, chip away at elusive and lopsided surfaces, are presented to an assortment of fall perils and basic breakdown, work in conditions with poor perceivability, and take part in exercises that require cumbersome stances or tedious movement. Also, they experience these and different dangers to their well-being and well-being in circumstances that can change rapidly or be affected by climate or other quickly changing natural conditions. [1, 23]

Data about damage experience is basic for controlling mediation endeavors, and damage observation assumes a significant job in measuring wounds and recognizing circumstances that add to damage by gathering information on sort of damage, timing of damage event, damage occurrence subtleties, etc the fundamental "who, what, when, where, why, and how" components of damage occasions that can assist with recognizing damage designs. By considering patterns and damage conditions, it is conceivable to more readily recognize hazard factors for which anticipation measures can be created and executed. [1, 6]

Although the firefighting is the single job but has to go through a lot of work inside it. There are lots of other works to do by firefighter before they actually start the job, in between the job and after they finish the job. Besides their clear exposure to fire and explosion and chemicals, carrying heavy equipment during the work, slippery and uneven surfaces, fall and collapses of hazards, poor visibility, and engage in activities that require awkward postures or repetitive motion are the actions by which we can clearly identify that there is a lot of risks in this occupation. Moreover, they experience these and other threats to their safety and health in situations that can change quickly or be influenced by weather or other rapidly changing environmental conditions [3]**.** All the way in this job the clothing of fire fighter plays an important role for their safety and protection. The clothing should made in such a way that it protects the fire fighter and should be more comfortable during the job and should have high functional properties.

Fig 1: firefighter [4]

1.2 Firefighter clothing

Firefighting is a hazardous occupation, with an injury rate that has been estimated at four times that of other workers. Although there are multiple work settings in which freighters are at risk of injury including in transit and even in the firehouse itself the fire ground represents an especially perilous environment for firefighters. Besides their obvious exposure to fire and explosion hazards, freighters routinely carry heavy equipment, work on slippery and uneven surfaces, are exposed to a variety of fall hazards and structural collapses, work in conditions with poor visibility, and engage in activities that require awkward postures or repetitive motion. Moreover, they experience these and other threats to their safety and health in situations that can change quickly or be influenced by weather or other rapidly changing environmental conditions. [1]

During fire extinguishing and emergency rescue, firefighters may encounter multiple hazards, including thermal, chemical, biological, radiation, hot liquid, steam, and physical hazards. Firefighters' protective clothing (FPC) is essential to protect their health and safety. NFPA 1971 Standard (2007) provides numerous performance requirements for a new piece of protective ensemble. During the lifetime, the thermal protective clothing, especially the outer layer fabric, will be exposed to these hazards intermittently. The hazardous exposures can provide sufficient energy for chain scission of polymers and escape of volatile degradation products, which are rarely considered, though these might lead to decrease of protection performance and potential hazard to the users. However, the loss in performance may not always be easily detected unless it has reached an extreme level. Therefore, it was important to know how environmental conditions affect the fabric performance over time. FPA 1851 Standard (2008) gives many indicators to identify the deterioration but fails in providing quantitation of the degradation. How to determine the continuing use of protective ensemble is a critical issue for not only economic factor but also the assurance of firefighters' security. [6]

Firefighters are usually exposed to high levels of thermal strain which negatively affect their micro climate near the skin. This may lead to severe burns, or even death. It is therefore of crucial importance to assess if the inclusion of a PCM layer in a firefighting protective clothing (FFPC) ensemble, augments its thermal performance by storing, as latent heat, part of the energy coming from the external source. [8]

Structural firefighter protective clothing is designed to shield the firefighter from environmental hazards, such as heat, abrasive surfaces, and some chemicals. The turnout gear (jacket and pants only) is typically a three-layer system consisting of an outer shell (OS), moisture barrier (MB), and thermal liner (TL). The inner-most layer often is the TL, which primarily provides thermal protection. This layer typically consists of a facecloth, which slides easily along the skin to reduce the work required to move, and a spun-laced non woven insulating fabric. The air in the woven fabric provides thermal protection; therefore, the thicker the non woven fabric the better the thermal protection. However, a thicker TL is heavier and less breathable, and therefore, less comfortable. [1, 2]

The middle layer is typically the MB, which often is a Poly (tetrafluoroethylene) permeable film barrier laminated to a thin Polyaramid woven or non woven backing substrate. The membrane limits the transport of some chemicals, pathogens, and water from the environment to the firefighter. The transport of any liquids across the MB toward the firefighter is a severe concern as it adds significant mass to the garment and deteriorates the TL performance, both of which can lead to severe injury and death from thermal exposure and heat stress. The backing substrate increases the durability of the TL. The non woven backing is less durable than the woven, but provides additional thermal protection.

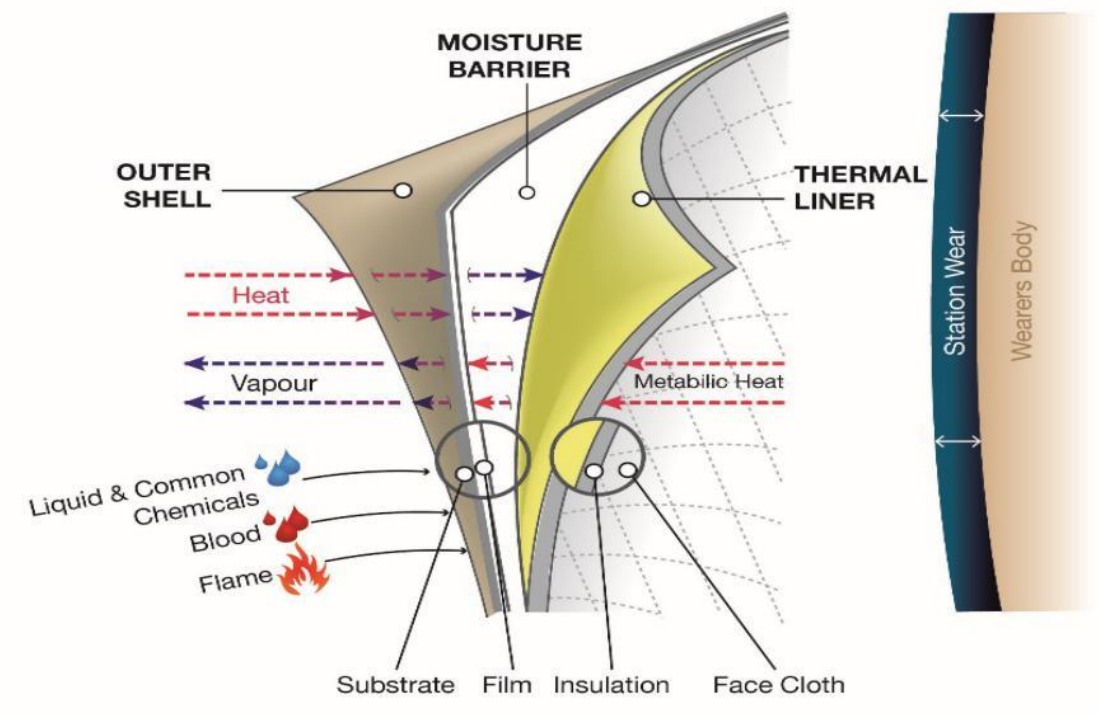

fig 2: Layers of firefighter clothing-1 [5]

The OS is the outermost layer and is the first line of defence against the abrasive and sharp physical hazards common to a fire scene. However, the OS also provides 25 % to 30 % of the turnout gear's thermal protection and serves to reduce water absorption. The OS is typically a woven fabric with a rip-stop construction being preferred as it prevents tear propagation. Similar to the TL, the OS is commonly constructed of Polyacrylamide, Polybenzimidazole, and/or poly(melamine-formaldehyde) fibers [1] Firefighter protective clothing (FFPC) is constructed of high performance fiber-containing fabrics capable of protecting against a wide range of potentially extreme exposure conditions (e.g. climate, nature and frequency of fires, firefighter's physiology, and cleaning frequency). Depending on the position of a firefighter in relation to the fire front line and type of activity in which the firefighter is involved, the firefighters' turnout gear is exposed to different conditions. The type of activity defines the thermal exposure conditions, exposure to ultraviolet (UV) radiation, level of usage, and frequency of cleaning of a turnout gear over its lifetime. The useful lifetime of turnout gear for firefighters is therefore difficult to estimate. Generally, after 10 years, the FFPC is removed from service as it no longer complies with the qualitative performance metrics defined in National Fire Protection

Association (NFPA) 1851 Standard on Selection, Care, and Maintenance of Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting. [1]

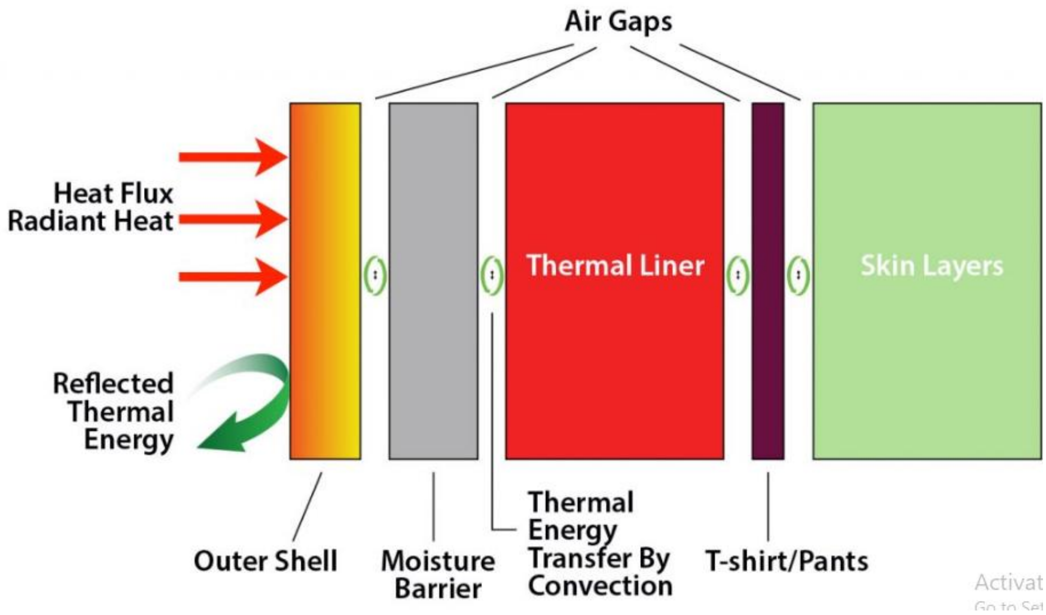

Fig 3: layers of firefighter clothing-2 [7]

The NFPA 1851 standard on selection, care, and maintenance of protective ensembles recommends retirement of the protective ensemble based on simple visual inspection and economic analysis. However, some form of degradation might not be visually detectable, for example, loss in tear strength or thermal protective performance of the ensemble due to prolonged usage and/or storage. Moreover, firefighter turnout gear is very expensive and disposal of such garments based solely on qualitative visual judgments could put undue financial burden on fire departments. It is therefore important to develop improved guidelines for the retirement of firefighters turnout gear that are based on performance metrics. [10]

The firefighter protective clothing should fulfil the following major requirements.:

a. Should protect firefighter from radiant heat.

b. Should minimize the burn injuries risk

c. Should minimize the chance of heat exhaustion.

d. Should be light and easy wear.

e. Should maintain the heat comfort during various climatic conditions and duration of work

f. Should dissipate metabolic heat.

g. Does not burn or melt.

h. Should provide the escape time.

Fig 4: firefighter clothing [11]

CHAPTER 2: LITERATURE REVIEW

2.1 Weathering

Weathering is the unfavourable reaction of a material or item to atmosphere, frequently causing undesirable and untimely item disappointments. Shoppers burn through billions of dollars for each year to keep up items that definitely debase and to supplant items that come up short. Materials that flop because of introduction to open air situations represent a huge segment of this absolute expense.

Most materials are liable to enduring. The world's outside layer is corrupted by substance and physical procedures because of presentation to the components. The pace of decay relies upon the idea of the material; for the hardest stone the time scale stretches to a great many years though for some natural polymers significant changes can be initiated by exposures of not many days.

Manufactured polymers offer an amazing scope of appealing properties and in a significant number of their applications they are presented to the outside condition. For instance; polymers and composites are generally utilized remotely just as inside in airplane, in vessel development and in the structure business plastics, composites and manufactured filaments are uprooting progressively ordinary materials.

Whatever the application; there is regularly a characteristic concern with respect to the sturdiness of polymeric materials somewhat in view of their relative novelty yet additionally as a result of the helpful lifetime of these materials can be anticipated their support and substitution can be arranged. [12, 13]

2.2 Factors affecting Weathering

The three principle variables of weathering are sunlight-based radiation (light), temperature, and water (Moisture). Yet, it isn't simply "how much" of every one of these variables at last makes degradation to the materials, in light of the fact that various sorts of solar radiation, various periods of weathering, and temperature cycling significantly affect materials on presentation. Airborne contaminates, natural wonders, and polluted rain, are the other factor which may act together to cause "weathering." [13, 15]

2.2.1 Solar Radiation

Radiant energy that originates from the sun is comprised of photons that comes through space as waves. Their vitality (E) is relative to their recurrence (ν) agreeing to the accompanying condition, where (h) is Planck's steady, (c) is the speed of light in a vacuum, and (λ) is wavelength.

$E=hC/\lambda$ (9)

- Ultraviolet (UV)- 295 – 400 nm, 6.8% of Total Solar
- Visible (VIS)- 400 – 800 nm-55.4% of Total Solar
- Infrared (IR) 800 – 2450 nm-37.8% of Total Solar. [13]

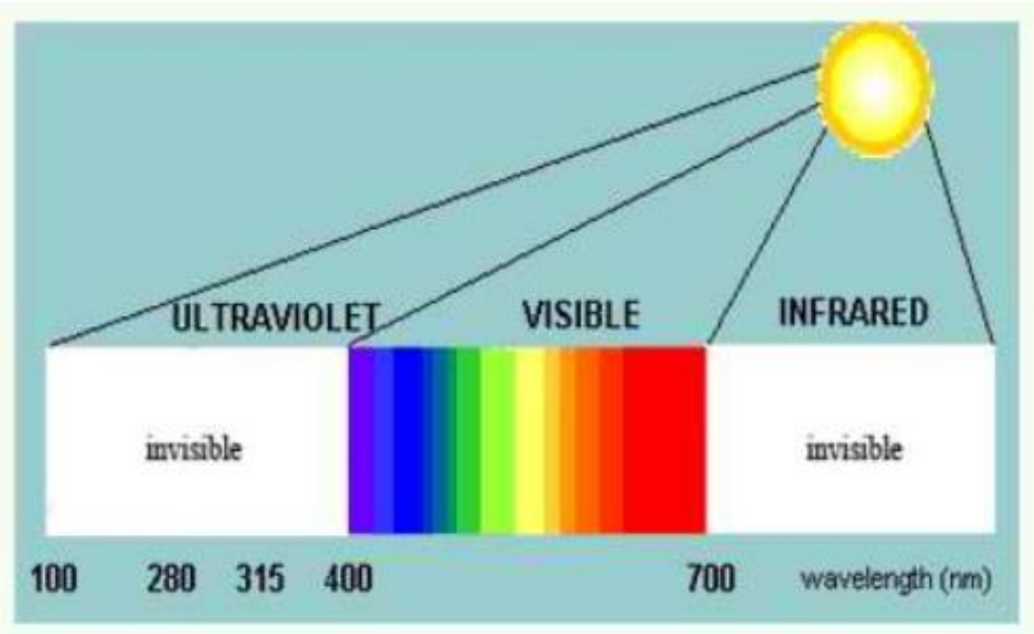

Fig 5: Types of rays of light emitted by sun. [15]

2.2.2 Temperature

The temperature of exposed fabric to solar radiation has an impact on the effect of the radiation. With the rise in temperature photo chemical reactions are usually accelerated. Also, the temperature decides the rate of subsequent reaction. A general rule of thumb assumes that with 10ºC the rate for reaction doubles the temperature on the fabric. But, while measuring the appearance or physical changes this cannot be observed. Also, thermo chemical reactions which may occur in higher temperature but may not occur at lower temperature.

The temperatures for exposed material to the sunlight are decided by various factors. The surface temperature of sample is because of thermal absorptivity, irradiance from solar, surface temperature. Therefore, with the exposed-on sunlight the surface temperature an object is mostly higher than the air temperature. [14]

2.2.3 Moisture

Water, which is everywhere in the form of humidity, rain, snow etc, the materials which are common outdoor use are exposed on these influences. The surface of fabric absorbs the moisture and volume es expanded and the stress is occur in dry surface. The absorbed moisture by fabric cause the expansion and stress of fabric and this cause peeling, cracking and flaking on coating of fabric. [14]

2.2.4 Irradiance

Irradiance is the radiant flux incident occurrence per unit area on the given surface, unit of irradiance is W/m2. It is important to signify the phantom range from where the readings were taken to determine the quality of irradiance the light rays from 295-3000 nm is complete sun-based UV. For the weathering experiment, the plan of display of radiant, in which the time is required for irradiance, which is expressed in J/m2. Best exposures are determined in either kJ/m2 or MJ/m2. The level of, direct, reflected and diffuse radiation striking a fabric is examined.

The radiation from sun that arrives the surface of the earth comprises of wavelength between the range of 295 and 3000 nanometers. A nanometer is one billionth (1×10^{-9}) of a meter. This daylight is divided into three primary wavelength ranges: bright (UV), obvious (VIS), and infrared (IR). Wavelengths which are viewed and bright (UV) are from the range of 295 and 400 nm which provides between 4–7% of the absolute radiation. Ozone layer in atmosphere filters the UV rays lower than 295 nm. Most sensitive equipment which are more reactive to light can identify the radiation which are below 295 nm, though some scientist called this sum of light are minor. [13, 14]

2.2.5 Secondary effects

Pollution and Gases may cause degradation on fabric in the form of acid rains and cause the fabric and materials to cause degradation faster than regular. Acid rain is the prime elements for weathering process which effect many materials. Climate, Dust and dirt are the other elements for the degradation. [14]

2.3 Types of Weathering

There are two types of weathering

2.3.1 Natural weathering

It is the direct weathering in which the materials are exposed to the outdoor or to the direct sunlight and other natural elements for weathering. The weathering is performed whenever the fabric is exposed in sunlight or natural environment which is responsible for weathering. When the clothing is in daily use then those are exposed to the natural environment which slowly effect the protecting properties of the clothing. Sunlight rays are the most important element which helps the protective clothing to lose its protective performance. [13]

2.3.1.1 Sunlight

The sunlight electromagnetic energy is regularly separated into visible rays, infrared energy and ultraviolet rays. Infrared light (not appeared) having of wavelengths longer than the obvious red wavelengths starts above around 760 nanometers (nm). visible rays is characterized as radiation between the range of 400 and 760 nm. Ultraviolet rays have radiation below 400 nm. [13]

2.3.2 Artificial weathering.

The weathering process which takes place in artificial medium or in self-made medium is called artificial weathering. This type of weathering is mainly done for experimental purpose. The fluorescent lamps are used as the source for the light inside the weathering machine for the exposure of fabric. Though the natural weathering has different rays and wavelength of light but the rays from artificial weathering have the same wavelength. [13]

2.4. Effects

2.4.1 Effect of Ultraviolet radiation on fabric

UV radiation is one of the main causes for the degradation of fabric. When the UV hit the fabric surface, UV is absorbed, reflected or transmitted through the fabric. The amount of that radiation depends upon the many factors such as fiber type, surface of fabric, cover factor of fabric and amount of fiber delustrants UV absorbers and dyes added in the fabric.

UV radiation which passes through fabric are unchanged waves which passes through the gap of fabrics. The part of rays that passes through the fabric and get to the skin of human is referred as transmission component.

UV radiation is the significant reasons for degradation of textile materials, which is because of excitation in certain pieces of the polymer particle and a continuous loss of honesty, and relies upon the fibers nature. On account of the huge surface volume proportion, textile materials are defenceless to impacts from light and other natural components. The entrance of UVR in nylon brings photo oxidation and results in decline in flexibility, rigidity and a slight increment in the level of crystalline. Without UV channels, the misfortune in elasticity seems, there will be higher loss in tensile strength on account of nylon (100% misfortune), trailed by polyester (44%), cotton (34%) and fleece (23%) following 30 days of presentation. Some of the fabric in presence of sunlight may cause photo oxidization which may later decrease in tensile strength, flexibility, air permeability or radiant heat transfer. [15]

2.4.2 Heat stress and skin burn.

The inner temperature helps to know the human physiological behaviour for the heat stress. The temperature which is maintained within 37.0 ± 1.0 °C, for the safety 38.0 °C is considered for the public, and the injury would occur with inner temperature above 40 °C. The maximum limit of temperature was 40 °C which is used here in the experiment. Burn occurs in human body when it is heated over the higher or limits temperature. The burn depends upon the temperature rise and the time of exposure of skin to. The second degree and third degree burn of body is more major and complicated than first degree burn. [16]

2.5 Relation

2.5.1 Human-clothing-environment system.

Clothing is the integral part of the human life. The primary role of clothing is to provide a layer of barriers that protect the body against unsuitable environments as shown in table.

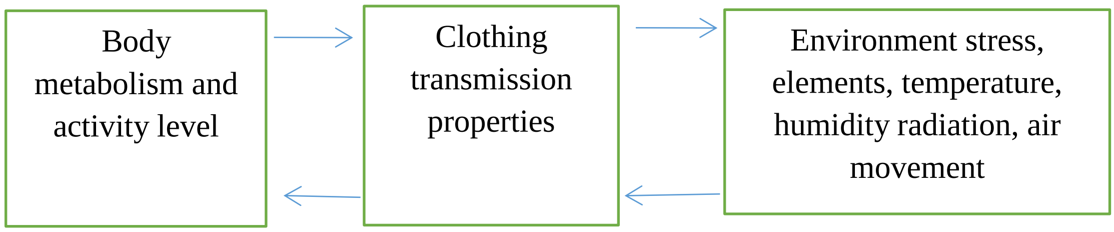

Table 1: role of clothing in protecting the body and maintaining the thermal balance between body and environment.

The environmental factors, such as temperature and air movement, can have drastic effect on the perceived temperature of the exposed skin, thereby strongly affecting the cooling or heating sensation.

Clothing provides a micro climate between the nude body and the external environment. The body responds to this micro climate, and the thermoregulatory responses of the body and the transfer and vapor permeation properties of the clothing determine the micro climate. For a continuously heated body (by metabolic heat production), a dynamic equilibrium is maintained where, generally the Body temperature> Skin temperature> Clothing surface temperature> Ambient temperature. That temperature of clothing is higher than the ambient temperature emphasizes that the environment also provides insulation by the boundary or air layer The properties of this layer are very important to heat exchange and can be affected by the external environment.

In the garment the heat is transferred in the form of convection, conduction, radiation and latent heat by moisture transport. Convection, conduction and radiation are influenced by the temperature difference between environment and skin. Whereas the latent heat is achieved by the transmission of moisture which is related to water vapor pressure between the environment and the skin surface. [17]

CHAPTER 3: MATERIALS

3.1 Fabric

The fabric used for firefighting clothing must be flame retardant. The properties is achieved by the following:

a. Flame retardant by chemical treatment: for improving the fire-resistant properties then the clothes are treated with some chemical on its surface which is called as chemically treated fire-resistant fabric. For e.g.: Proban

b. Flame retardant by flame resistant fibers: By using the inherently fire resistant we can make flame retardant textile product. For e.g., Polyamide, glass, kyrol, Polyoxazole etc. Or by fibers that have flame retardant chemicals in the solutions and spun through the spinner for fire retardant chemical structure. Eg: flame retardant Poly amide, flame retardant wool etc.

c. Flame retardant by suitable structural engineering: flat yarn will reflect more heat due to more surface area. The hollow fiber and hollow yarn will insulate the body from influence of outer heat. [18]

3.1.1 Aramid fabric

These are the first organic fiber which has highest tensile strength. These are inherently flame-retardant fabric. These fibers have 5% to 10% higher mechanical properties than the other known synthetic fibers. These fibers are taking the place of metal wires and inorganic fibers from the market for the high-performance activities like various composites like in air craft's, marine, automobile, bullet proof clothing, ropes and industrial uses. These fibers not only have better mechanical properties but also maintain the properties at high temperature because Aramid polymers are excellent in heat and flame resistant. Due to these properties of this fabric, they have various uses in protective clothing where heat, radiation and chemicals are present.

Aramid are the manufactured fibers in which the fiber forming Poly amide is the long chain of fibers. In non-aromatic ring, 85% of Aramid chains are directly attached. Kevlar, Nomex, Technora, Teijinocnex, Twaron etc are the fibers in Armid family. Aramid fabric are manufactured in two stages, among them the First is, carbon based organic substances are reacting together to form a liquid for a basic polymer. In the second stage, the solution is spun which results the solid fibers, that can weave to for a fabric or can be transform into sheet form.

The chemical structure of the chain molecules is such that the bonds are aligned along the fiber axis, giving them outstanding strength, flexibility, and abrasion tolerance. Because of the bounding of very short molecules the fiber is stronger.

Aramid fibers fibers are poor resistant to Ultraviolet light and when exposed it, the fabric changes its color and also changes in mechanical properties, thermal properties, comfort properties etc. Aramid fibers have low flammability and more heat resistance and also high resistance to organic solvents. At around 500°C Aramid fibers start to degrade. The “inert” aspects of Aramid fiber offer excellent versatility for a wide range of applications. But the Aramid fabrics are more reactive to the Ultraviolet light, acids and some salts.

Aramid fibers are more commonly used for protective clothing like body armor, military helmets, protective gloves and firefighter clothing, bullet proof jackets etc. Due to the presence of hydrogen bonds in Aramid fabric, it is polar in nature.

This property enhances the wet ability of Aramid fibers and makes them chemically more active. On the other hand, this is also responsible for the hydrolytic degradation of Aramid fibers in the presence of high temperature and humidity conditions it causes loss in mechanical properties and thermal stability in the fabric. The presence of water also breaks the inter molecular hydrogen bonds inside the Aramid fibers. Kevlar, Zylon or PBO fibers, and M5 fibers are commonly used fibers as the high-performance Aramid fibers for reinforcement. [19, 20]

The common characteristics of the Aramid fibers are:

a. Sensitive and degredate when exposed to UV radiation.

b. Chemical resistant but is sensitive to some acid and base.

c. Cannot be break or cut easily.

d. Maximum weight strength and high tenacity.

e. Degraded under high temperature and humidity.

f. Resistant to organic solvent.

g. Non conductive.

h. It has no melting point and the degradation starts from 500°C.

[15]

Nomex

a. Nomex I the brand name manufactured by DuPont chemical company.

b. The chemical name for Nomex is poly (m-phenylenediamine isophthalamide).

c. Special type of staple filament yarn having characteristics of fire resistant.

d. Nomex is inherently flame resistant; it has high temperature resistance property and will not melt, drip or doesn't support combustion in air.

e. Nomex is used for various applications but is well known for component for protective clothing. [21, 22]

3.1.2 Proban

It is the fabric first developed in 1950's. It is the cellulose fabric in which the chemical is applied to provide flame retardancy for the fabric. Proban is named after the chemical additive is applied on the fabric. The additive decomposes with the effect of flame and form the insulating char which stays in place, Proban treated fabric do not smolder, have no afterglow and do not flow or spread outside the charred area and the fabric do not melt away or nor form a hot sticky residue which can affect the skin of fighter, these properties of Proban protect the firefighter form heat and chemical during the job. It has high breath-ability and thermal resistance. It does not allow water vapor to transfer from body to external environment. It is the result of controlled during the finishing stage of cellulose fabric and cellulose blended fabric during manufacturing. The formation of polymer is irreversible and completely insoluble that is embedded in the fibers to form cellulose Proban fabric. [23, 24]

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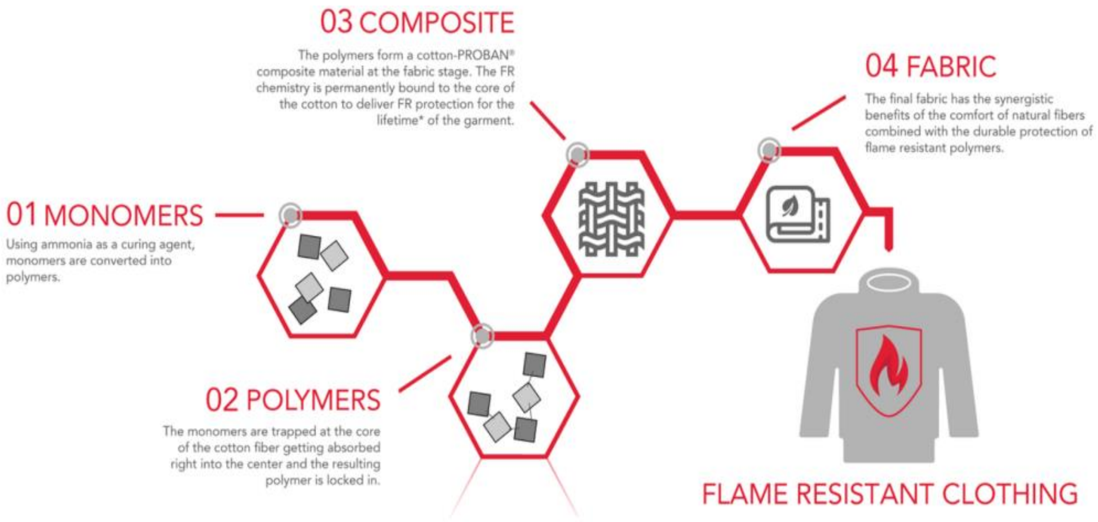


Fig 6: Proban treated fabric. [25]

Proban treated fabric are safer and also don’t give skin irritation for the wearer. It doesn’t affect the natural properties of the cotton fabric. Proban sometimes may pass flame test up to 100to 150 washes.

CHAPTER 4: MEASUREMENT

4.1 Thermal comfort

In ISO standard 7730, thermal comfort is defined as the 'condition of mind which expresses the satisfaction of thermal environment'. The most important properties to identify is firefighter clothing is thermal properties. Various factors such as body reaction, transportation properties of clothing, external surroundings can affect the thermal properties of fabric. The transport properties of the clothing are the essential parameters for affecting the thermal comfort properties. With the compromise of physiological comfort high level of protection can be achieved for the fire fighter. For the reduction of heat stress the following methods can be done: (a) we can design special protective with less thermal effect, (b) by controlling on exposure level or time, and (c) on control of environment which is comparatively less possible. [17]

4.2 Moisture management properties

The firefighter sometimes could go through risk of burn because of condensation of evaporated moisture of skin. The use of moisture barrier in the garment help the sweat to be soaked from the garment to make the fighter keep dry. The moisture barrier has some micro porous structure which prevents water to move back towards the skin. It helps the water vapor to escape to the environment and reduce the burns and heat for the fighter.

4.3 Transport properties

The transport properties are closely related to the comfort performance which is considered by thermal resistance, air permeability and water vapor permeability. Heat, air and water vapor release through firefighter protective clothing is one of the difficult process which are linked with sorption and desorption of moisture, evaporation and condensation. Air permeability allows more air to pass through the protective clothing and makes able to loss heat from the protective clothing. The flow of air and heat both effect the comfort of the clothing. The water vapor permeability of such fabric should be as high as possible to allow to escape the water vapor released from the body. High water vapor permeability is to some extent incomplete with high resistance to air flow and to protection from rain and art of designing clothing for extreme conditions lies in finding a satisfactory compromise.

4.4 Mechanical properties

Elongation, elasticity or flexibility abrasion resistance, modulus of elasticity, strength comes under the mechanical properties of the fibers. The fiber is said to be strong if it can resist the external damage which determine the lifespan of the textile product. absolute fiber strength is calculated with fibers under the increased load until it gets fractured with maximum load.

Tensile properties show how the fiber will react with the forces applied in tension and elasticity or flexibility properties means the behaviour which is shown by the material when it is bend. Importance of flexibility is when we wear cloth. [26]

CHAPTER 5: INSTRUMENT AND THEIR WORKING PRINCIPLE

5.1 Artificial weathering chambers.

These chambers are made for laboratory purpose. These provide the UV rays with the help of fluorescent tube. Most of the experiment fore protective clothing which are to be exposed in UV are performed in these chambers. [12]

5.1.1 Atlas weathering machine UV 340

It is the instrument for exposing the materials to artificial ultraviolet irradiation. In this instrument the fluorescent lamp is concentrated below the 350 nm wavelength region. The rectangular samples of the fabric are cut with size of 20cm*5cm in warp and weft direction. There are 19 frames to place the sample and those frames are kept inside the chambers. The samples are to be kept inside the chambers according to our planned days and hours for the exposure. After the exposure again, the same experiments are repeated which are done with unexposed fabric. Then those sample are exposed in high artificial U.V irradiation in a weather-o-meter(ci-400). In this machine the fabric is accelerated exposures to high intensity. [12]

The equipment consists of three sections:

1. Top section: contains control cabinet, control panel, fluorescent lamp ballasts, expander fuels, optional chart recorder, and water purity meter.
2. Middle section: UV fluorescent lamps, specimen racks, water heater, air heater, air circulation fan, water inlet float value and drain.
3. Base section: convenient storage area for spare U.V storage lamp and also house for optional aquanizer.

Temperature control:

Temperature control circuit board and digital panel meter are used to control and display the test chamber (black panel) temperature. Two thumb wheel switches are connected with circuit board and those switches are calibrated in degree Celsius. It determines test temperature during U.V cycle exposure and condensate cycle exposure. [12]

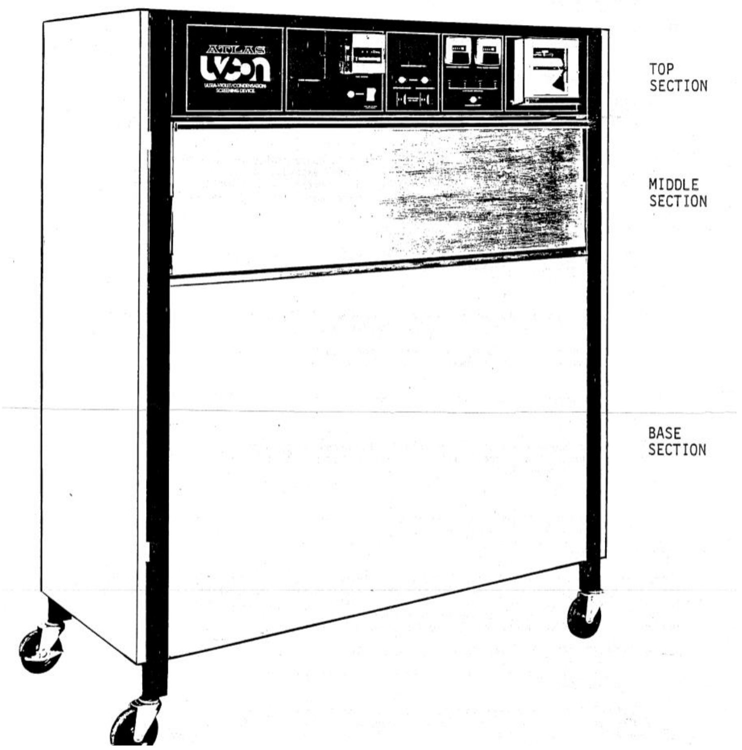


Fig 7: Atlas weathering machine [12]

5.2 Transmission of radiant heat flux density

The instrument comprises of a radiation heat source, which can create heat flux thickness up to 80 kW/m2 alongside a Calorie meter to calculate the warmth transition of thickness. ISO 6942 was utilized to calculate the transport of heat from a single layer and multiplayer fabric. The instrument is equipped with slightly bended copper plate calorie meter put on a non-burnable surface. The front of the calorie meter was layered with a slim and fine film of dark paint. The heating instrument consists of six heating rods, a movable frame which is constantly cooled by moving water through the pipe in the frame which helps to maintain the temperature of the frame. First, the position of calorie meter should be adjusted correctly. We should identify the exact distance between the rods and calorie meter and the given rate of heat flow. We maintain the exact distance between the heating rods and heating source for 40kw/m2. It is very important to maintain the correct distance to get the correct value. The calorie meter is then exposed to the heating rods and the movable frame is taken to the original position when the temperature reached 30°C and the incident heat flux density Q_o is measured. Then we use our sample on this following the same procedure. The sample is fixed to one side and is made contact with Calorie meter tightly so that all the surface of fabric touches the calorie meter with applying the load of 200gm. The time t12 is for the temperature rise of 12.0±0.2 °C and the time t24 is for the temperature rise of 24±0.2 °C in the Calorie meter, indicated in seconds, determined to the closest 0.1 s. At least three samples are tested to get the average value of the given sample. The result of the experimentation prompted two limit times, one is radiant heat transfer index (RHTI12 and RHTI24), the other is transmitted heat flux density (Qc) and percentage heat transmission factor %TF (Qo). Before the experiment, all the sample are preconditioned for 24 hours at the temperature of 20ºC and have relative humidity 65%. the sample size is 230mm*80mm. Experiment was performed in the fabric before and after U.V degradation in 5 sample each. [27, 33, 38]

5.2.1 ISO 6942

Minimum three samples are to be tested from the given materials. As per the standard of test the fabric are exposed to 20-40 kw/mm² ± 5%. The Calorie meter which is in contact to fabric is used to measure the heat that passes through the sample.

When indicator reaches 24°C the radiation will be stopped. Time is expressed in seconds to measure the produced temperature increase in Calorie meter. The given time is the length of time where the heat is passed due to increase in temperature in which the wearer feels pain due to the burn in second degree. [28, 38]

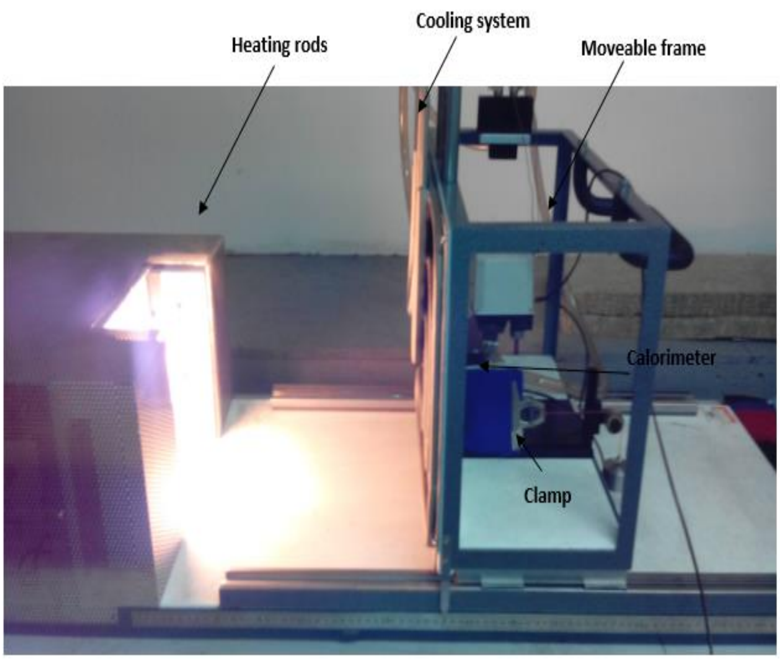


Fig 8: Radiant heat transmission machine.

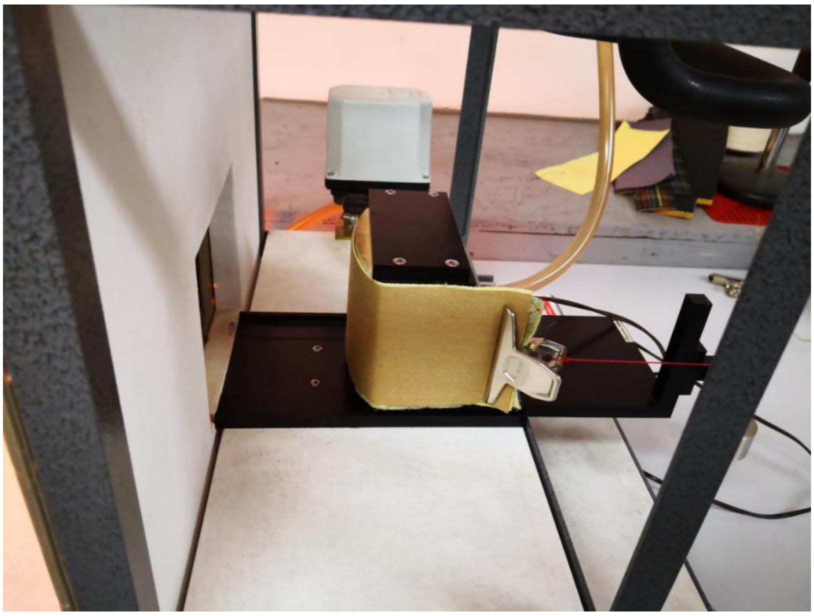


Fig 9: fabric ready for exposure

5.3 Air permeability test

This test determines the rate of air flow from the fabric. The firefighter clothing has very low air permeability as the main job of the clothing is to protect the body from heat, radiation, conduction and convection. If the air permeability value is high in such clothing, it will decrease the capacity for thermal performance, as it will allow more air to pass through the sample which results the temperature increase in human body in very short period of time. [30, 32]

An air permeability analyzer FX3300 Lab tester III (Textest Instruments) was used to measures air penetrability in accordance with the CSN EN ISO 9237 standard. The pressure was tested on 200 Pa on the region of 20 cm2 (l/m2/s). Ten estimations were done before and after the U.V degradation for each example as indicated by the standard. [31]

The equation for average of readings of air permeability: $R = \bar{q}_v / A * 167$

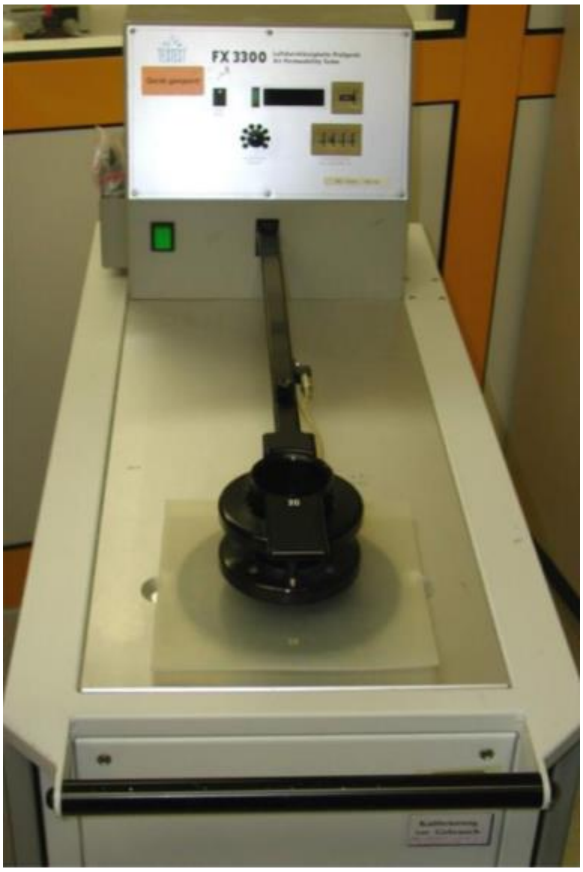


Fig 10: Air permeability tester (FX3300)

5.3.1 CSN EN ISO 9237

This standard tells us about the process to measure the air permeability. It measures the rate of air flow that passes perpendicularly through that given area of the textile fabric. Area, time period and pressure are given at the time of test. It can be applied in various types of fabrics like non woven, protective, technical, industrial fabrics and etc. [29]

5.4 Flexibility/Bending performance

Tuhomer TH-4 was used to identify the bending moment of the given sample of the fabric. This machine measures the bending moment of the protective textile with CSN 800858 and the size of the sample is 5cm*2.5cm. It measures the sample before the UV exposure and after the UV exposure.

Bending property is the ability of any materials to overcome the deformation when the force is applied on that material. The give instrument measures the force that is required to bend the given sample by 60 degree.

It can be written as the following equation:

Mo=F*K

Where,

Mo is the bending moment [mN.cm]

F is force applied in mN

K is constant and the value is 0.52

5.4.1 CSN 800858

This standard measures the force applied in the fabric or given sample to bend it by 60 degree.

Fig 11: Flexibility testing machine

5.5 Tensile strength measurement

The experiment is done on the instrument named testometric. The instrument follow ISO 13934 standards. The instrument determines the maximum force and elongation at maximum force of textile fabrics in equilibrium with standard atmosphere for testing and test sample in the wet site using strip methods. The size of sample for fabric is usually 5cm*30cm.

During the experiment, the sample are placed on the jaws on the machine and the two points of sample between the clamping points before the moving of machine is known as initial length and the distance between the two effective clamping points is known as the gauge length. Then, the moment of the clamp should be in constant rate, one clamp should be in stationary position and the other should be in motion with the constant speed. The force which is applied in the beginning is called pretension. After the force is applied there is the certain increase in the length, which is known as extension. Then the sample is extended and is elongated with maximum force till the damage of fabric. [37]

The maximum force on the sample is recorded when the sample is taken to the rapture under the specified conditions. The tensile test was measured for the outer layer fabric for the given samples before and after U.V exposure. [2, 36]

Stress (σ): It is the force per unit area. It is measured in Pascal i.e. Newton/m^2. [36]

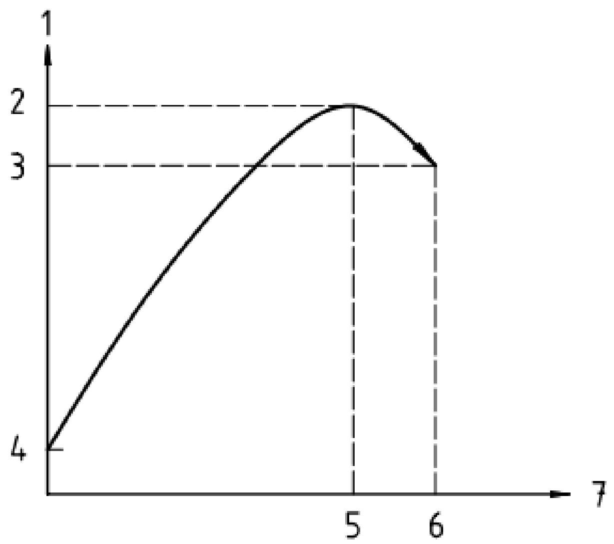
Therefore,

$\sigma = F/A$

Tensile strength: It is the maximum strength of the fabric while stretched before the breakage. [35]

Strain: It is the calculation of the object that how much material is stretched during stress. At the maximum point of strain, the deformation is seen. [36]

Fig 12: Tensile strength tester (testometric)



1. Force
2. Maximum force
3. Force at rupture
4. Pretension
5. Elongation at max. force
6. Elongation at rupture
7. Elongation

Fig13: Stress strain curve of a fabric [36]

The stress strain graph is one of the most dependable and main source for the examination of mechanical properties of the fiber. The stress strain curve or graph is created by plotting the applied weight on the fiber axis where the elongation delivered due it. The stress strain curve or graph of a sample fiber is appeared the screen. Various kinds of fiber produce various stress strain graph or curve. The nature of the single curve or graph significantly impacted by the structure of the fiber.

The tenacity of fiber and stretching at break are the two significant properties that can be gained from the stress strain graph. The differences in the fiber tenacity can for the most part be ascribed to a few factors: the level of polymerization, the quality of holding between neighboring polymer chains, their level of direction toward fiber hub and the degree of crystallinity. Filaments that have higher crystallinity, higher chain direction and solid inter chain holding will by and large display lower estimations of lengthening at break. [2, 36]

5.5.1 EN ISO 13934

The standard is used to determine the maximum force and the elongation of fabric at maximum force. In this standard the constant rate for extension of fabric is used. This standard is prepared with several test process for the identification of mechanical properties using tensile testing machine. The result which is gained or obtained by one method or process should not be compared to the result obtained from other methods. [36]

5.6 Water vapor permeability

Water vapor permeability is the important factor for determining the breath ability of clothing. It is the ability of clothing to allow the water vapor to move or to pass through the body to the external environment.

5.6.1 Textest FX 3180 cup master

Cup method test is useful to find out the loss in weight of fabric using the evaporation time (24h) of water in a cup covered by cover ring. The sample fabric during this method is kept on the top of the cup and is air tight. The reference fabric is also placed a similar air tight in another cup. Sample fabric and reference fabrics are placed in the cups as above to perform the experiment in duplicate. ISO11092:1993 testing standard are followed for the testing.

5.6.2 Experiment method

The water vapor permeability of the sample fabric is studied by using the cup method according to the given test standard. It is the non-destructive method. This method is easy to perform and determines the loss of weight, with evaporation time 24 hour of water stored in the cup, the top of the cup is concealed by the covering ring and the fabric is kept under air tight condition. Each cup contains the reference fabric with same air tight condition and the experiment is carried in out in duplicate, so that the cups with the sample fabric and two cups with the reference fabric can be checked. The size of the cup provides 10mm deep layer of air in between the bottom of sample and surface of water. This technique compares the rate of transfer of mass of water through fabric from the cup. The difference in water loss between the cup covered by both normal fabric and test fabric makes possible to study the relative humidity movements' through the test fabric so that the humidity vapor permeability of the test specimen can be calculated.

CHAPTER 6: RESEARCH METHODOLOGY

6.1. Test method

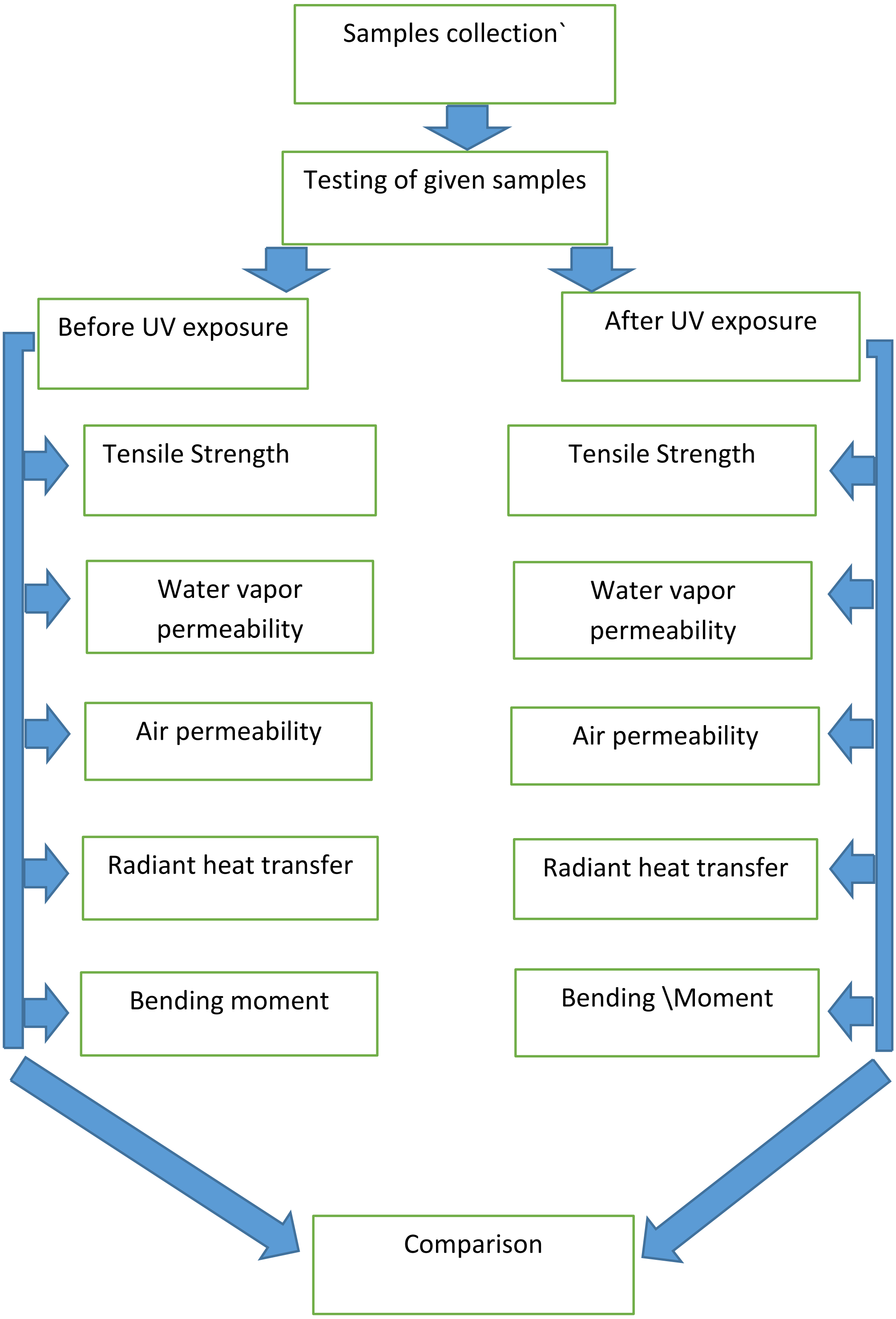


Table 2: work flow process

6.2. Artificial exposure:

All the given samples were preconditioned in a climate chamber with constant temperature 40°C for 12 days to accelerate the thermal aging of flame-resistant fabric. The time for exposure is determined by the outer layer of the protective clothing as per the standards. After the exposure, the materials which are exposed are taken and kept it till next days. Then, the fabric with after and before exposure are taken to the different types of testing measurement. The wavelength is usually shorter than the wavelength present in the natural sunlight. With the wavelength longer than 360nm it has little radiation. Then, the results were in the mean values of the sample and also the standard deviation from the values was determined. Again, to determine the significant exposure related changes the statistical analysis is carried out. The process for degradation in laboratory may be different from the natural test because of large number of short wavelengths of UV and less amount of long wavelength of UV and visible radiation. Test using the fluorescent lamp are commonly practiced. The test with the instrument is useful for the comparisons between the materials or given samples under the given conditions.

6.2.1 Specification of fabric

SR NO.	Sample name	code	Fabric specification	Weave design	GSM (g/m2)
1	NOMEX	O1	70% Conex, 23 % Lenzing FR, 5% Twaron, 2 % Beltron	Rip stop weave	225
2	PROBAN	02	79% Proban, 20 % polyester and 1 percent antistatic	Twill Weave	260

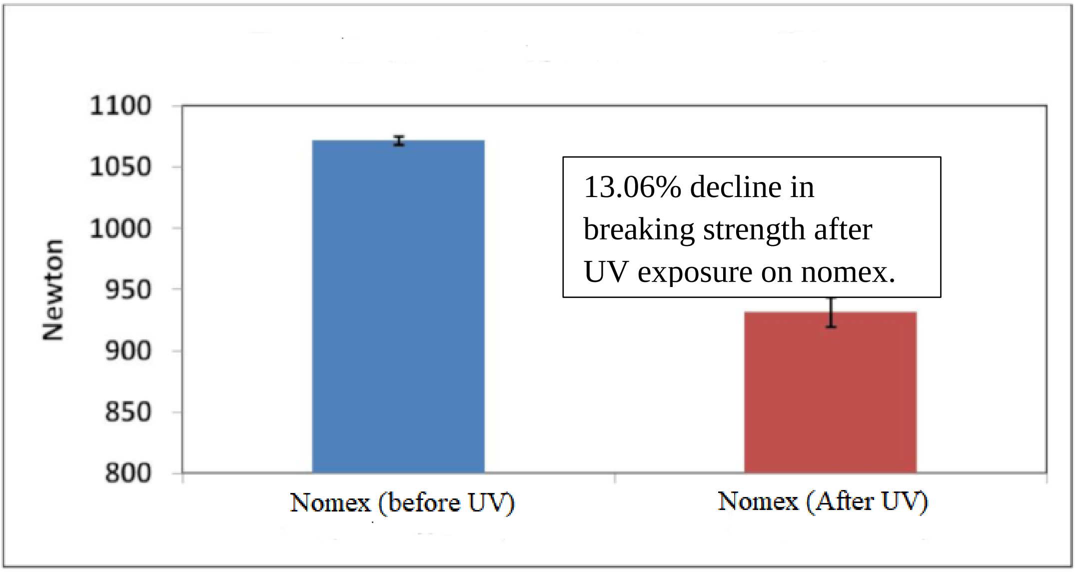
Table 3: Specification of fabric

6.3 Tensile strength tester

After and before UV exposure, the tensile strength of the outer layer firefighter protective fabric was measured using a Testometric M350-5CT test machine in accordance to the ISO 13934-1 strip method. The chuck distance is 100 mm and the tensile speed is 100 mm/min. [36]

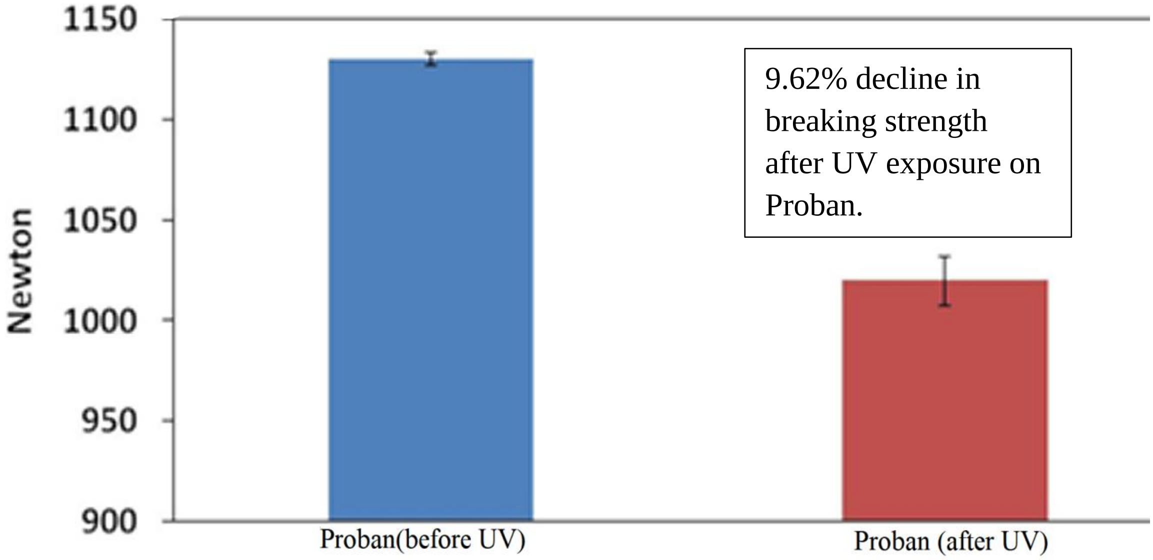
6.3.1 Physical properties of tasted sample for tensile.

The tensile strength of two different flame-resistant fabrics after radiation exposure is compared. For all scenarios, the fabric Nomex (O1) had the highest tensile strength, before and after the exposure though the tensile strength of the fabric has some decrease after the exposure. Proban had the lowest tensile strength and is more decreased in strength after the exposure. As it was clear that, the tensile strength of the fabric is decreased after the exposure. Both fabrics showed the similar change but with different decreasing level. After the UV there was 13.06% of decline in the tensile strength of the Nomex. The tensile strength was decline from 1075 N to 925N. From the experiment we get to know that the longer the exposure the decrease in tensile value increases. [2, 36]



Graph 1: Showing the breaking strength of Nomex

Tensile strength of outer layer Proban



Graph 2: showing the breaking strength.

In the graph, the tensile strength of Nomex was more before UV exposure but after exposure to UV radiation the strength is decreasing which might be due to decline in breaking strength of fibers and the result there was 13.06% decline in tensile strength after UV radiation exposure.

The similar trend is followed by Proban. It also had more tensile strength before UV exposure but after the exposure to UV radiation the tensile strength decreases 9.67%

6.3.2 Discussion

In this experiment, the tensile strength of the firefighter protective fabric was experimented, where we found that the strength varies after the exposure. In all radiation exposure of flame protective clothing the tensile strength goes lower than its acceptance level or fails to fulfil the minimum requirements of standards for firefighter clothing. All the samples of the Nomex loose its tensile properties. There is the decline of 13.06% in the tensile strength of Nomex after UV exposure and 9.62% decline in tensile strength of Proban after exposure. The decrease in tensile strength depends upon the time of exposure of fabric on the UV radiation and frequency of the wavelength. The more days we expose on UV the more we lose the tensile strength.

6.4. Transmission of Radiant Heat

SR NO.	Sample name	code	Fabric specification	Weave design	GSM (g/m2)
1	NOMEX	O1	70% Conex, 23 % Lenzing FR, 5% Twaron, 2 % Beltron	Rip stop weave	225
2	PROBAN	02	79% Proban, 20 % polyester and 1 percent antistatic	Twill Weave	260
3	Moisture barrier	MB	Face fabric, 50% kermel 50% viscose FR, PTFE membrane	Non woven	120
4	Thermal barrier	TB	Thermo: Para Aramid Inner fatter: 50% Meta Aramid, 50% viscose.	Non woven	200

Table 4: fabric and specification used in Transmission heat radiant.

6.4.1 Experiment method

The experiment of thermal resistance of single layer and three-layer protective clothing was done with the help of radiant heat transmission machine. Radiant heat flux density transmission through firefighter protective clothing was carried as per ISO 6942 standard. After and before UV exposure, the thermal resistance the outer layer firefighter protective fabric was measured. The size of the sample is 230mm*80mm. The sample is placed in the calorie meter with the face side in front. The specific level of radiant heat and in the calorimeter will be found out for the temperature of 12°C and 24°C. The results are mentioned in radiant heat transmission index (RHTI 12 and RHTI 24) and (% TF Qo) is the percentage heat transmission factor. The sample is exposed on 40kw/m2 with the distance between is 16.9cm from heating rods to heating plate.

The surrounding temperature was about 28°C. The rise of temperature was determined by the calorimeter in two threshold times i.e. RHTI 12 and RHTI 24, Qc and percentage heat transmission factor (% TF Qo).

We maintain the exact distance between the heating rods and heating source for 40kw/m2. It is very important to maintain the correct distance to get the correct value. The calorie meter is then exposed to the heating rods and the movable frame is taken to the original position when the temperature reached 30°C and the incident heat flux density Q_o is measured. Then we use our sample on this following the same procedure. The sample is fixed to one side and is made contact with calorimeter tightly so that all the surface of fabric touches the calorimeter with applying the load of 200gm. The time t12 is for the temperature rise of 12.0±0.2 °C and the time t24 is for the temperature rise of 24±0.2 °C in the calorimeter, indicated in seconds, determined to the closest 0.1 s. At least three samples are tested to get the average value of the given sample. The result of the experimentation prompted two limit times, one is radiant heat transfer index (RHTI12 and RHTI24), the other is transmitted heat flux density (Qc) and percentage heat transmission factor %TF (Qo). Before the experiment, all the sample are preconditioned for 24 hours at the temperature of (20±2) °C and have relative humidity (65±2) %. the sample size is 230mm*80mm. Experiment was performed in the fabric before and after U.V degradation in 3 sample each.

On the basis of determined dependence T = f(t), the following parameters describing the thermal protection properties of heat protective clothing, were calculated according to EN ISO 6942:

1. Transmitted Heat Flux Density (THFD) – heat flux density transmitted through sample exposed to heat radiation.

2. Heat Transmission Factor (HTF) - ratio of the transmitted heat flux density through the sample to the incident heat flux density,

3. Radiant Heat Transfer Index (RHTI) - time to achieve a temperature rise of 24°C in calorimeter when testing the sample with a specified incident heat flux density (this temperature rise indicates that the user experienced second degree burns).

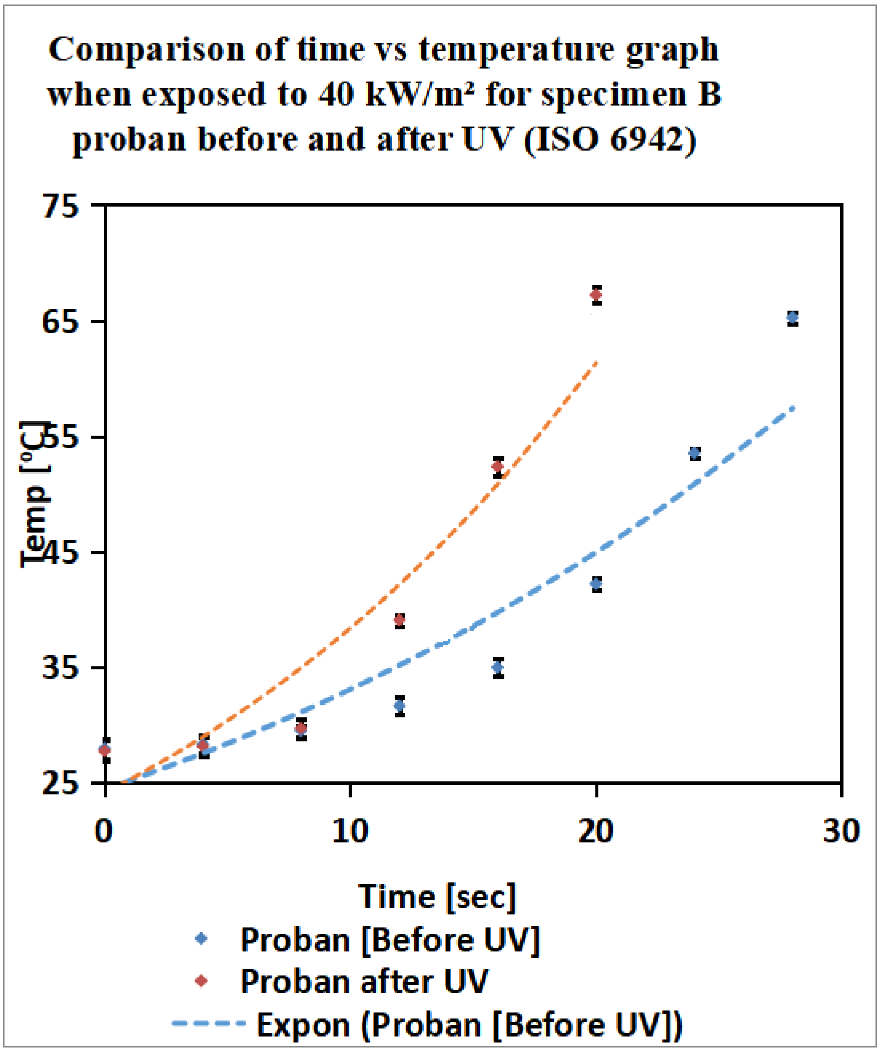
The temperature on surface of sample when exposed to incident heat flux density of 40 kW/m2.

Sr	Name of material	transmission factor (Qo) [kW/m²]		RHTI12 [sec]	RHTI24 [sec]	RHTI24 – RHTI12 [sec]	transmitted heat flux density (Qc) [kW/m2]	Percentage TF Qo
1	A	40	Before UV	17.4	24.31	6.9	9.71	24
2	B	40		19.15	23.4	4.25	15.67	39
1	A	40	After UV	17.0	23.6	6.6	**10.089**	**25**
2	B	40		16.3	19.9	3.6	**18.48**	**46.2**

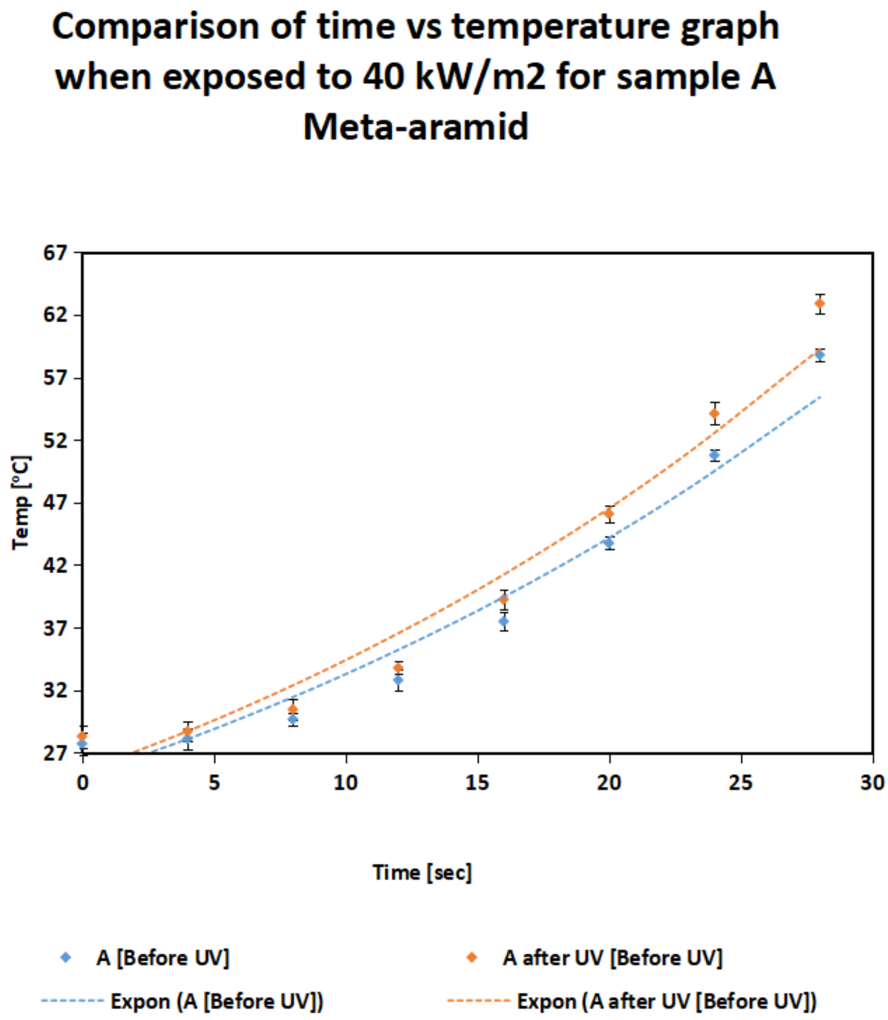
Table 5: Result by heat transmission machine.

In the above table it shows that the sample A has less transmitted heat flux density value than that of sample B. The lower the value of transmitted heat the better will be thermal protective performance of the fabric because as less amount of heat is transmitted towards calorimeter. It is also showing the greater values from the radiant heat transmission factor RHTI24, the rate of rise of 24 centigrade is greater for sample A than that of sample B.

Also, from the above table it shows that the values of transmitted heat flux density of both sample A and B respectively has increased after the after exposure to UV radiation. This might be due to deterioration of constitution fibers present in the fabric layer.



Graph 3: Comparison time vs temperature



Graph 4: Comparison time vs temperature.

In the graph 4 and 5 it shows the result of Proban and Aramid fabric before and after the UV exposure. The test was performed in the three sample of the both Proban and meta Aramid fabric before and after UV exposure each. The distance between the source and sample is 16.9cm. The result of performed test is the average value of the three measurements we performed.

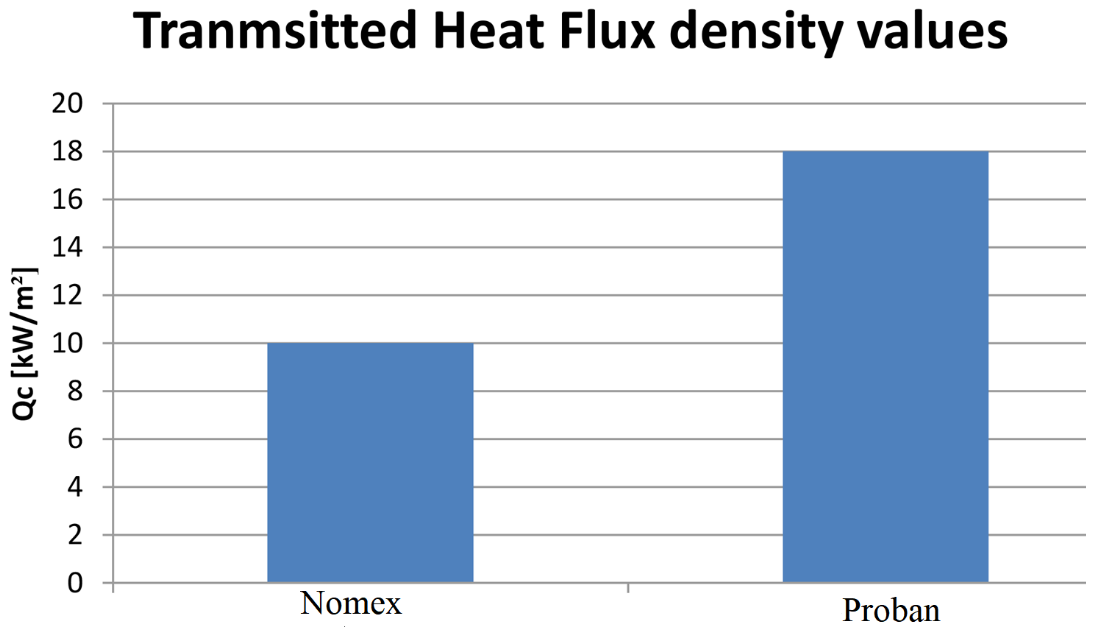
The study of percentage transmission factor (% TF Qo) and transmitted heat flux density Qc that least values of transmitted flux density Qc (kW/m2) were examined for the given sample.

If the value of transmitted heat flux density is lower, the amount of radiant heat transmitted through the fabric provides more time for wearer to perform their work more continuously and safely without no more injuries.

If more the difference between RHTI 12 and RHTI 24, the value of transmitted flux density Qc [kW/m2] will be lower, that means the sample can resist the heat flux for longer time which can increase the time for firefighters to do their job.

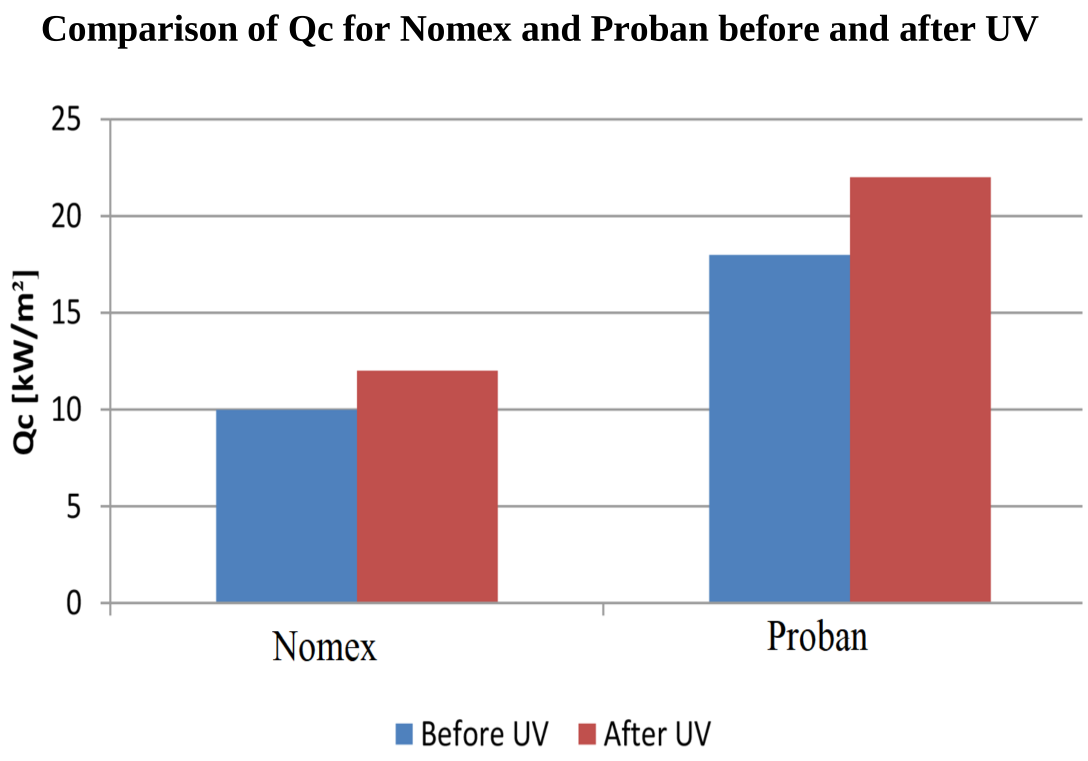
From the above graph, it shows that before exposure to UV radiation for Nomex and Proban, the structure of curve was flat but after the exposure to UV the flatness of curve is slightly decreased. Which clearly shows the decline in thermal protective performance of fabric after it is exposed to UV radiation, and the lower value of RHTI 24 is obtained. Till two or three seconds for both Proban and Nomex sample, both curves lies to each other but then the curve of sample B which is after exposure starts to become more flat and the gap between curve A and B goes increasing till the end of the experiment. This clearly shows that there is decrease in thermal protective performance after UV exposure. The flat curve means that the, temperature rises of sample takes place in slow rate and also means there is less damage in the fabric.

If the curve is more pointed it means that the rate of rises in temperature speed is high with the time. And also result th faster transmission of heat exchange and more damage on fabric.



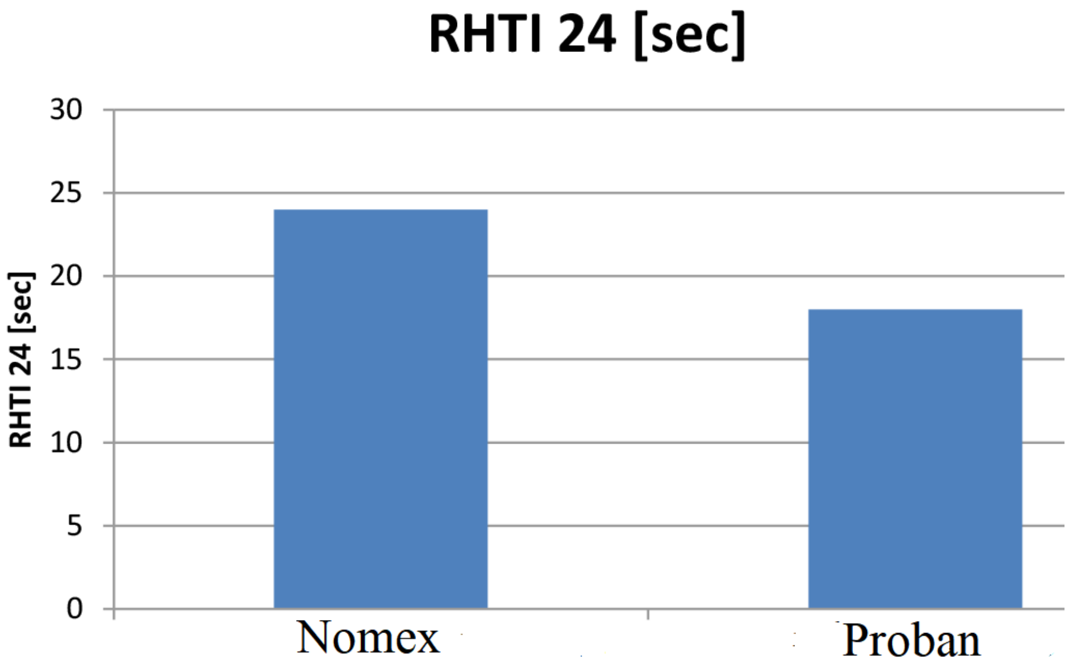
Graph 5: showing transmitted heat flux density values.

In the given graph the value of transited heat flux density of Aramid fabric Nomex has low value before UV exposure and the Proban has higher than Nomex. Even though both are fire resistant fabric Nomex provide the fighter to perform his job for more time without any injuries.



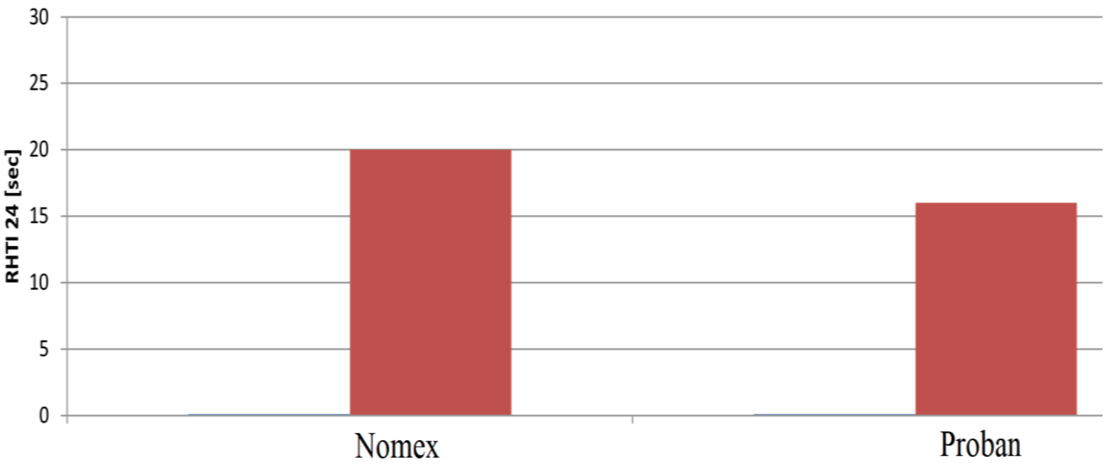
Graph 6: Qc comparison for Nomex and Proban after UV.

In the given graph the value of transmitted heat flux density of Aramid fabric Nomex and Proban has been compared before and after UV. In the figure given A is the value of Nomex and B is the value of Proban. The flux density of Nomex is lower before UV and it increases after the UV. This means that the Nomex the performing rate of Nomex will decrease after exposure. In the other case Proban has low value before UV exposure though the value is larger than Nomex of same condition. Both fabric fails to meet the minimum requirements as protective clothing after the exposure.



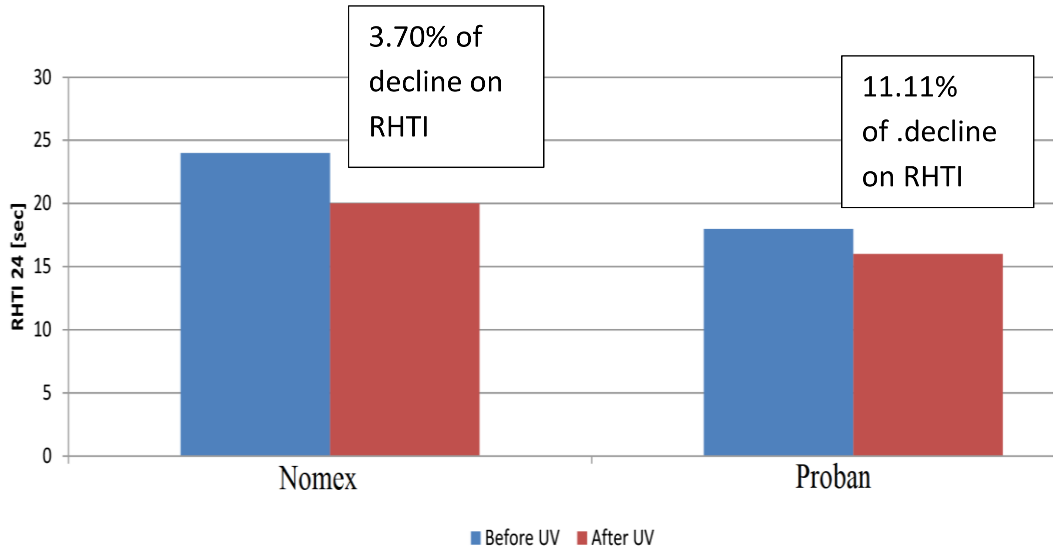
Graph 7: Showing RHTI 24 before exposure

Before the UV the time to rise for 24 degree Celsius was 24.3 second and 18 second for both Nomex and Proban respectively. It means that the Nomex need more time to rise in the temperature which allows firefighter to work in fire for longer time and in the case of Proban the raise in temperature in short time which brings damage in the clothing in lesser time and allows firefighter to work for less period of time.



Graph 8: Showing the RHTI 24 after exposure

After the UV the time to rise for 24 degree Celsius was 23.4 second and 16 second for both Nomex and Proban respectively. It means that the fabric declines its RHTI value. Nomex and Proban after exposure on UV need less time to rise in the temperature which allows firefighter to work in fire for shorter time period for both fabrics. The raise in temperature in short time brings damage in the clothing cannot meet minimum standards for protective clothing.

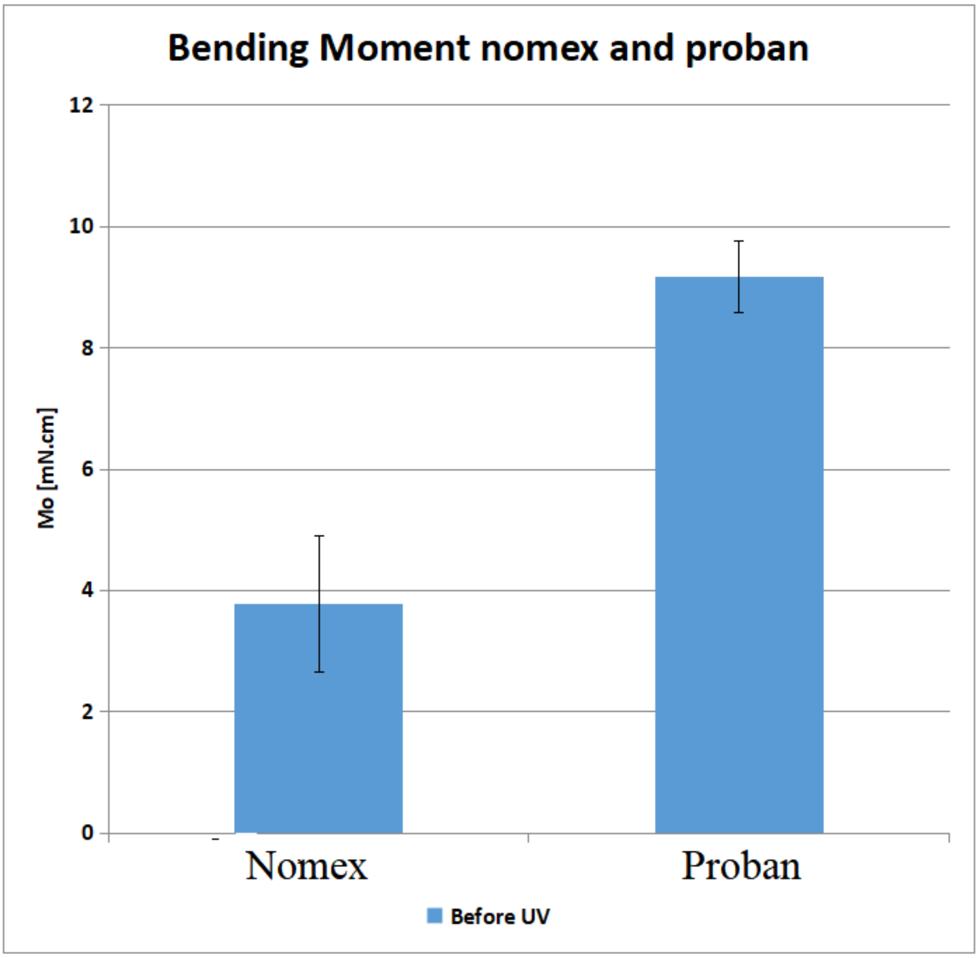


Graph 9: comparison between the Meta and proban for RHTI 24

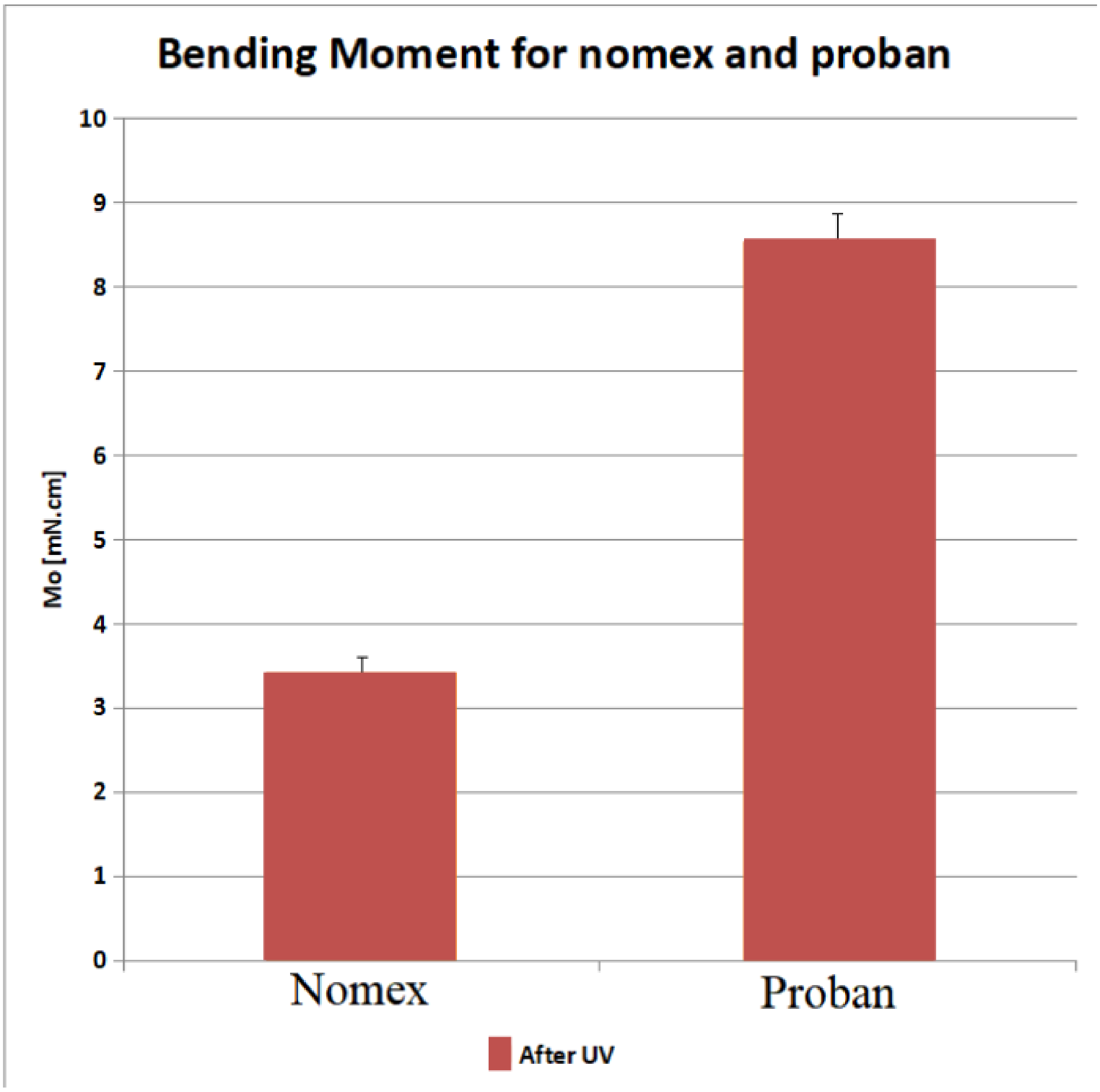
In the graph the comparison of RHTI 24 is shown. The RHTI 24 value of both fabrics decreases after the exposure in UV. The RHTI of Meta is declined by 3.70% after UV and the RHTI of proban is declined by 11.11% after the exposure. After the exposure the protective performance of both fabrics declines in terms of RHTI. Which means the both fabrics cannot meet the minimum requirements after as protective clothing after the exposure.

6.5. Bending moment properties:

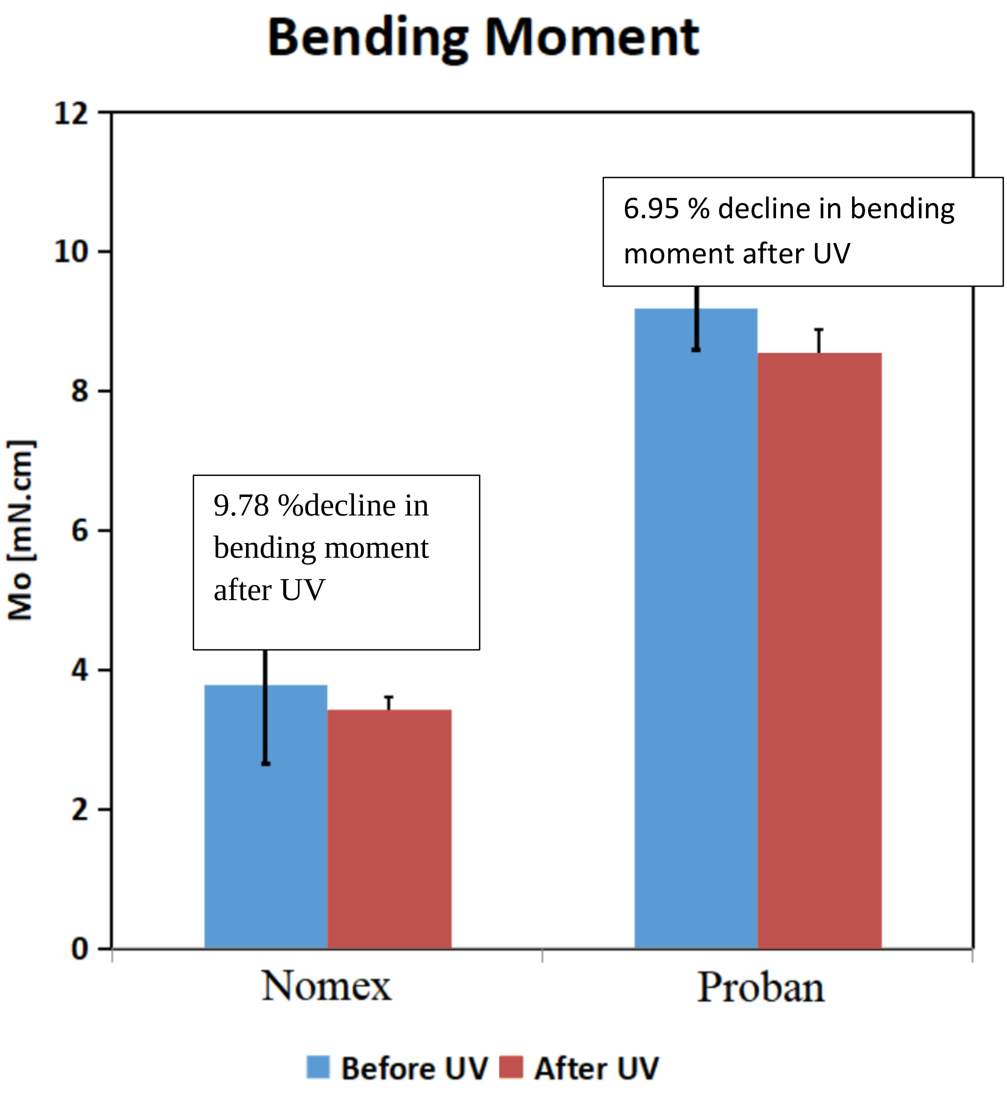
Bending property is the ability of any materials to overcome the deformation when the force is applied on that material. The give instrument measures the force that is required to bend the given sample by 60 degree. The experiment is performed in three sample of each fabric Nomex and Proban before and after UV exposure.



Graph 10: showing the bending property of Nomex and proban before UV.



Graph 11: bending property of Nomex and Proban after UV.



Graph 12: comparison of bending moment.

6.5.1 Discussion

From the graph above, we can see that, after exposure to UV radiation there was changes in bending moment. There was decline in bending moment values of both outer shell Nomex and outer shell Proban. Bending moment is related to flexibility of fibers. Before the UV exposure of Nomex fabric the 3.78N force can bend the given sample by 60 degree but after the exposure on UV same fabric need 3.41 N force to bend it by 60 degree. After the UV there was less bending moment force applied to the fabric. This means there is the decline of 9.78% in bending moment of the Nomex fabric.

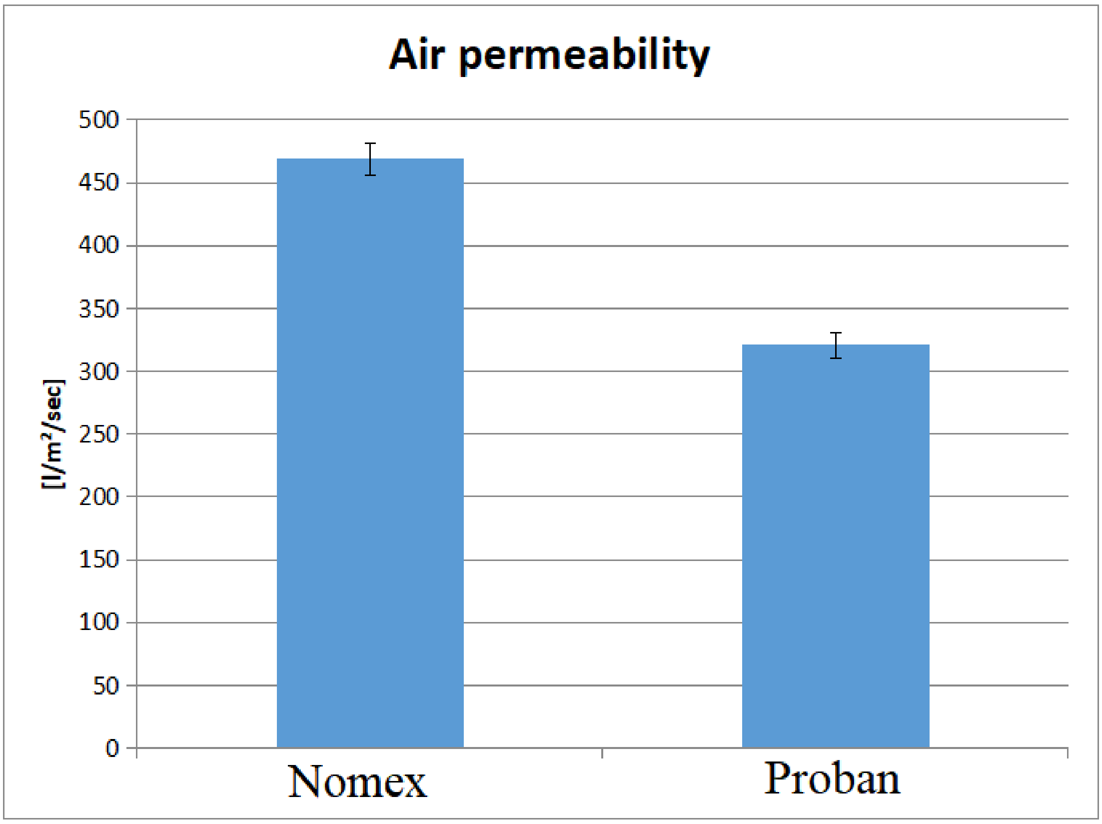
The bending moment force in Proban is more than the Nomex fabric. The bending moment force of Proban before UV exposure was 9.17N to bend the given sample by 60 degree but after the exposure on UV, less bending moment force was applied to bend the given sample by 60 degree which was 8.54N. It shows there is the decline of 6.95% in bending moment of Proban fabric.

Greater the bending moment value, greater will be the force required to bend the fabric. After the exposure to UV, there was decline in the strength of the both fabric because of which less amount of force also can bend the fibers. In case of Nomex there is 9.78 percentages and in case of Proban there is 6.95 percentage of decline in bending moment value after exposure.

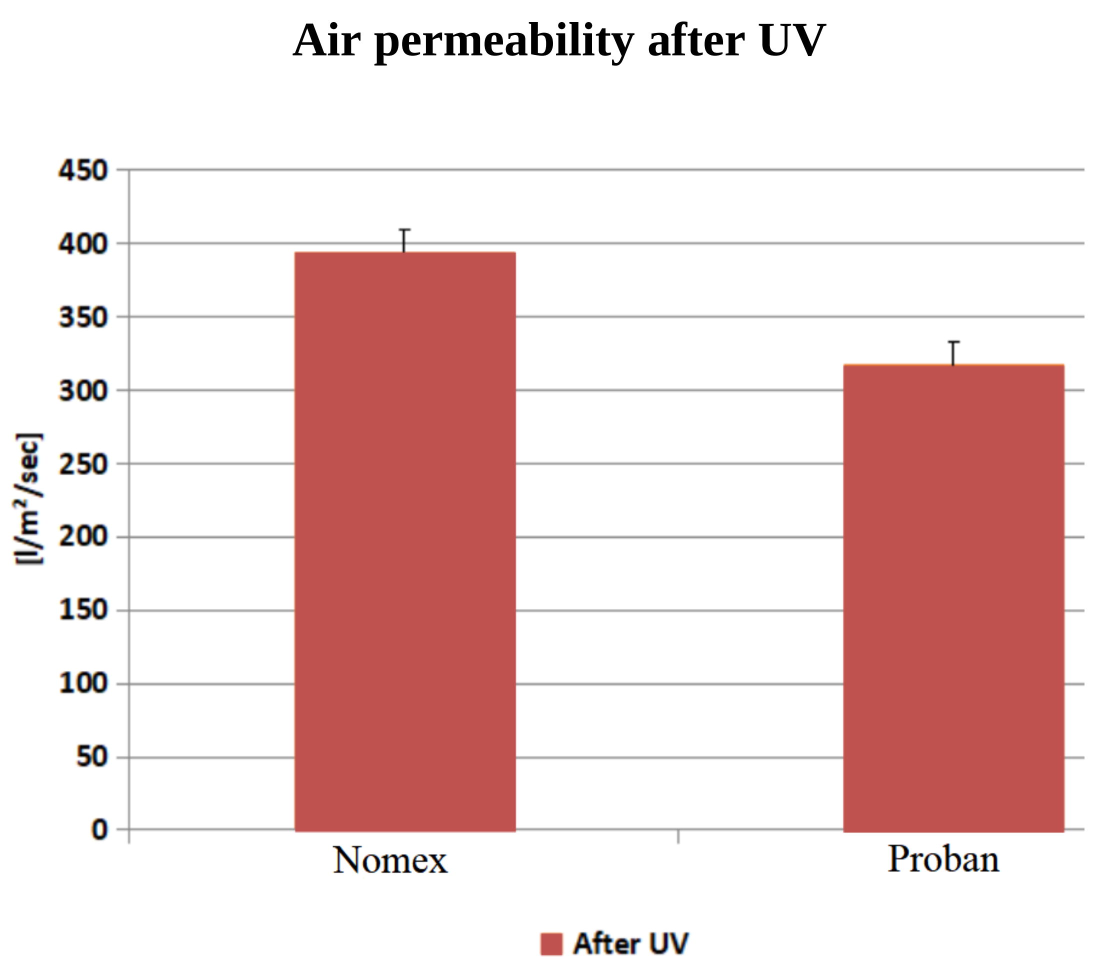
6.6. Air permeability of fabric.

Porosity of the fabric determines the air permeability. The tightness of weave in the fabric largely determines the porosity of the fabric. It is the rate of air flow from the fabric. It is the measure that how good the fabric allows the air to pass through it in the given condition of firefighter. It is the velocity of air flow passing perpendicularly through the sample under the given condition of test, area, pressure drop and time. The air permeability of Nomex and Proban was conducted before and after UV exposure. As the main job of the firefighter protective clothing is to protect from heat and high temperature therefore, the air permeability of firefighter clothing must be very low. The efficiency of firefighter clothing is inversely related to the air permeability of the protective clothing. If the fabric shows high air permeability then the fabric has low thermal protective performance as it provides the passage for air flow and increase the temperature of firefighter in very short time.

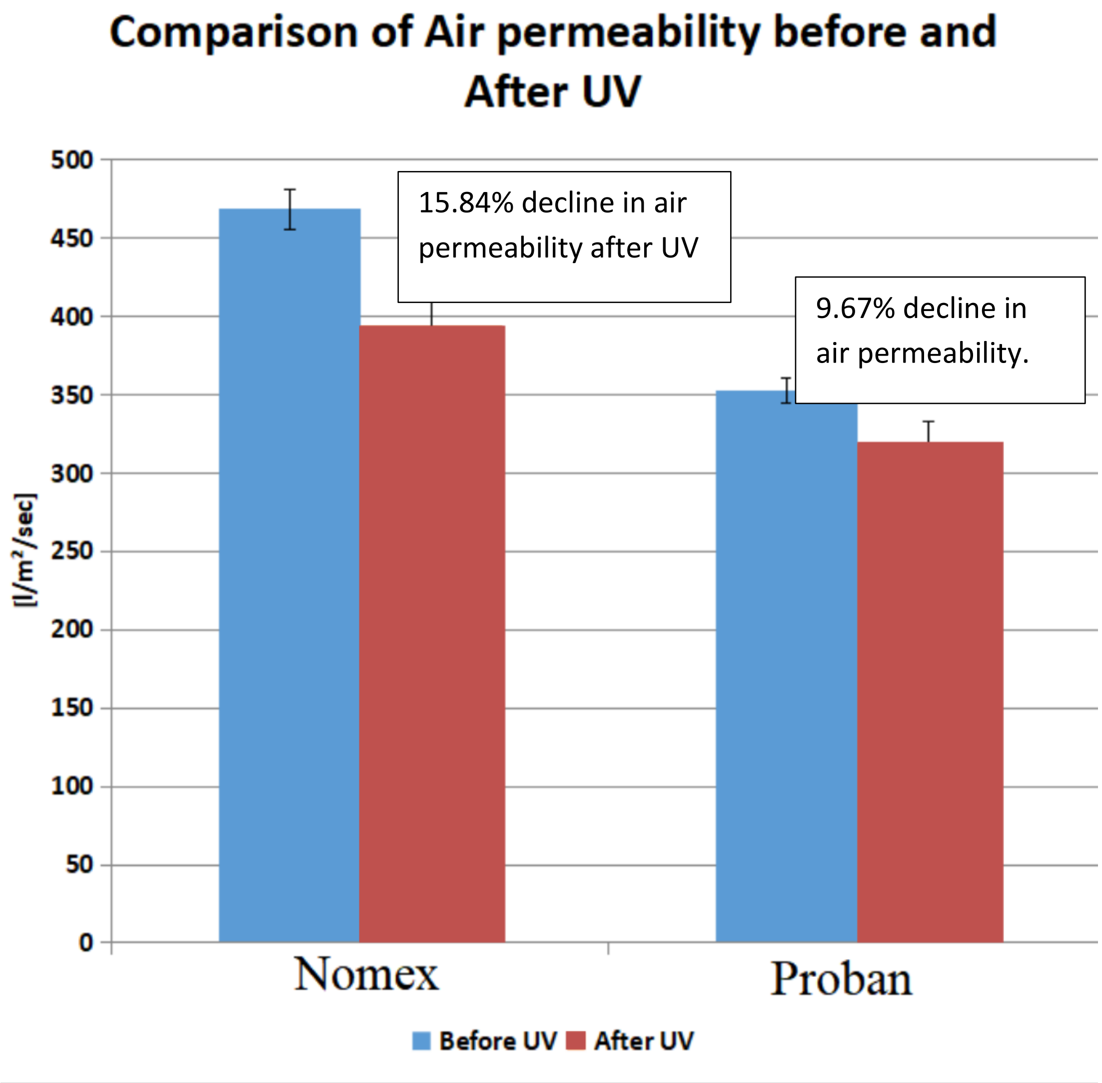
Ten readings from each fabric were used in both conditions, i.e before and after UV exposure. The experiment of air permeability of the sample fabric was done with the help of FX3300 Labotester III (Textest Instruments) in accordance with the CSN EN ISO 9237 standard machine. The experiment was performed after and before UV exposure. On 200 pa the pressure was tested at 20 cm2 (l/m2/s). Ten readings were done before and after the U.V degradation.



Graph 13: Air permeability before UV



Graph 14: Air permeability after UV exposure.



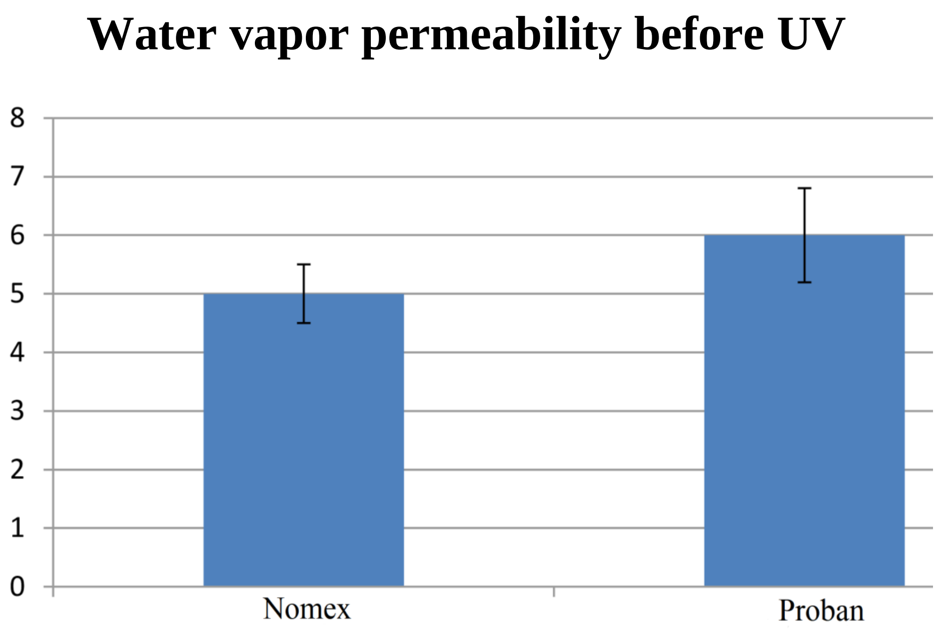
Graph 15: comparison of air permeability before and after UV

6.6.1. Discussion

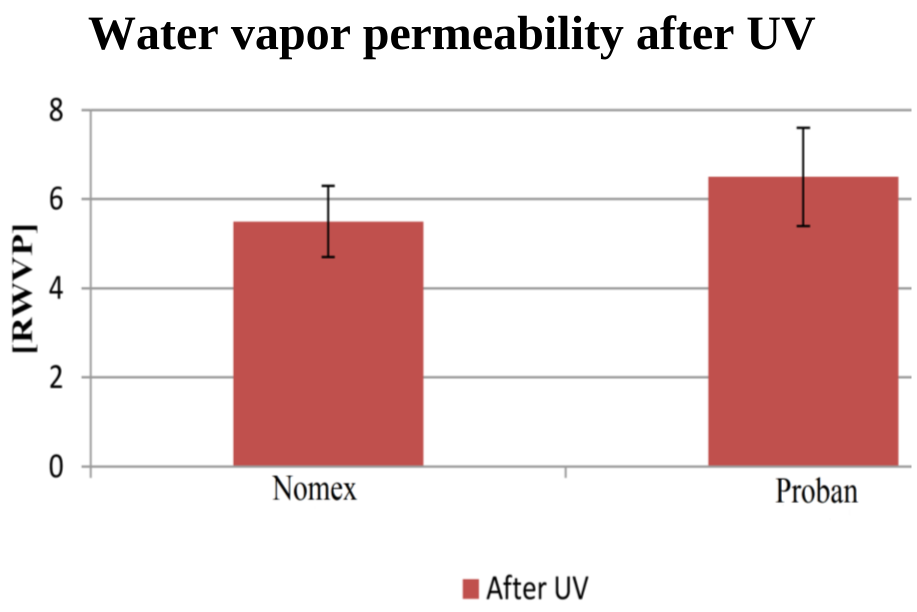
From the above graph, we can see that there is gradual decline in air permeability. There is the decline in the value of both samples. This is because the exposure on UV damages the fibers and may have closed the gaps between the fibers and allows less amount of air to pass through the both fabrics. The above graph also shows that the permeability value for Nomex is more than the Proban which may be due to the thickness of Proban fabric. The air permeability going higher in short period of time is not considered as good for protective clothing.

6.7 Water vapor permeability.

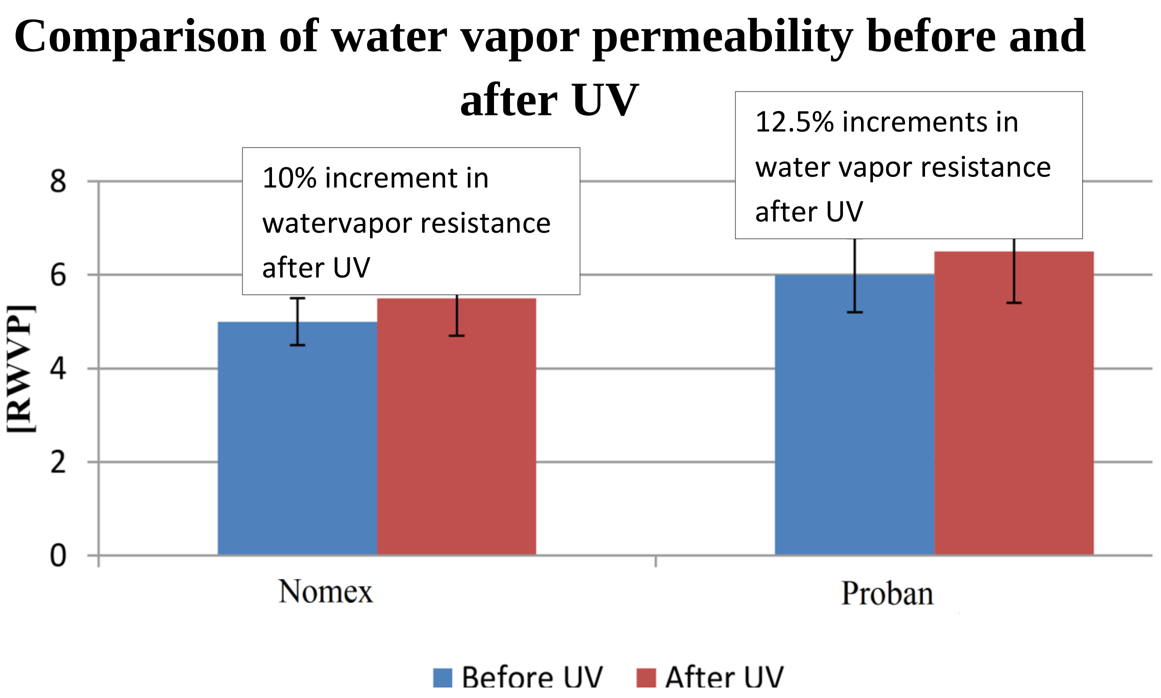
The breath-ability of textile surface is related to water vapor permeability of fabric. The more the water vapor permeability, the better will be the comfort property of the fabric. The release of water vapor is one of the important aspects of textile surface. The higher water vapor permeability means the lesser water vapor resistance values. The wearer may feel uncomfortable during his work if the permeation of water vapor is not good in the fabric.



Graph 16: Water vapor permeability before UV



Graph 17: Water vapor permeability after UV



Graph 18: Comparison of water vapor permeability before and after UV

From the above graph, the water vapor resistance of both outer shell fabric are increased after UV radiation. This may be due to the degradation of fibers which can able to block the water vapor through the fabric which are exposed to UV radiation. There is 10 percent increase in water vapor resistance in Nomex after exposure and for Proban there is 12.5 percent increment in water vapor resistance value after UV exposure.

7. CONCLUSION

Firefighting is the job that could have exposure to many types of thermal and other hazards while performing the job. in this job the amount of heat and mass transfer may rises from the source or hazards to the fighters clothing which can pass through the fabrics and may cause burn to the body of firefighter.

The safety and minimizing the risks of firefighter to injured is effected by the protective performance of the firefighter protective clothing. The experiment was performed in the outer layer of the firefighter clothing and was performed in the two fabric types Nomex, which contain Meta Aramid and is inherently flame resistance and the other is Proban, which is the flame resistance coating specially in cotton fabric. These fabrics were performed experiment before and after UV exposure. The sample of Nomex in the experiment shows the better thermal resistance properties than the sample of Proban. The Nomex also shows the lower value of air permeability, and exposure time to heat at constant temperature was longer than Proban in both before and after exposure. The tensile strength of Nomex was better in both case before and after exposure than that of Nomex and the bending moment of Nomex was also better in both case before and after exposure. The tensile strength of Nomex was better than the Proban. The thermal barrier of Nomex was better than Proban in both before and after UV exposure. If the fighting time with surrounding temperature and of protective clothing is increased against radiant heat flux density then the firefighting job holders will be more secure and will have less risk in their job. Duration of exposure to UV radiation and frequency of UV radiation determines these properties of the protective clothing.

The result from the experiment tells us the outer layer of the protective clothing cannot meet the minimum requirement and gets damaged when it is exposed in UV radiation. It slowly decreases its thermal protective performance. The final result tells us that the protective clothing should be kept away from direct sunlight, and should be checked in some time intervals.

Though, natural weathering and artificial weathering have different wavelength, because of which the study may not be always accurate but it will provide some safe estimation about the minimum requirements of the protective clothing without harming the wearer.

FUTURE WORK

- Microscopic examination of fiber structure and their change after the exposure can be carried out in the future.
- To find out the total energy consumed by fabric during the time of exposure.
- Study can be done in variable wavelength with variable time zone for the same fabric in future.

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APPENDIX

APPENDIX 1: AIR PERMEABILITY OF PROBAN

SR.	PRESSURE (200 PA) (BEFORE UV)	PRESSURE (200 PA) (AFTER UV)
1	350 l/m²/s	310 l/m²/s
2	352 l/m²/s	316 l/m²/s
3	346 l/m²/s	317 l/m²/s
4	376 l/m²/s	305 l/m²/s
5	362 l/m²/s	312 l/m²/s
6	354 l/m²/s	310 l/m²/s
7	348 l/m²/s	311 l/m²/s
8	329 l/m²/s	308 l/m²/s
9	335 l/m²/s	292 l/m²/s
10	373 l/m²/s	306 l/m²/s

APPENDIX 2: AIR PERMEABILITY OF NOMEX

SR.	PREASSURE (200 PA) (BEFORE UV)	PREASSUER (200 PA) (AFTER UV)
1	481 l/m²/s	400 l/m²/s
2	485 l/m²/s	383 l/m²/s
3	474 l/m²/s	393 l/m²/s
4	477 l/m²/s	409 l/m²/s
5	473 l/m²/s	385 l/m²/s
6	442 l/m²/s	396 l/m²/s
7	455 l/m²/s	399 l/m²/s
8	465 l/m²/s	398 l/m²/s
9	473 l/m²/s	387 l/m²/s
10	463 l/m²/s	395 l/m²/s

APPENDIX 3: TENSILE STRENGTH O NOMEX BEFORE UV

Nazev zkousky : Plošné textilie tah (80 0812)

Druh zkousky : Tkanina

Datum zkousky : 17.12.2019 9:34

Rychlost zkousky : 100,000 mm/min

Predpeti : 2,000 N

Sirka : 100,000 mm

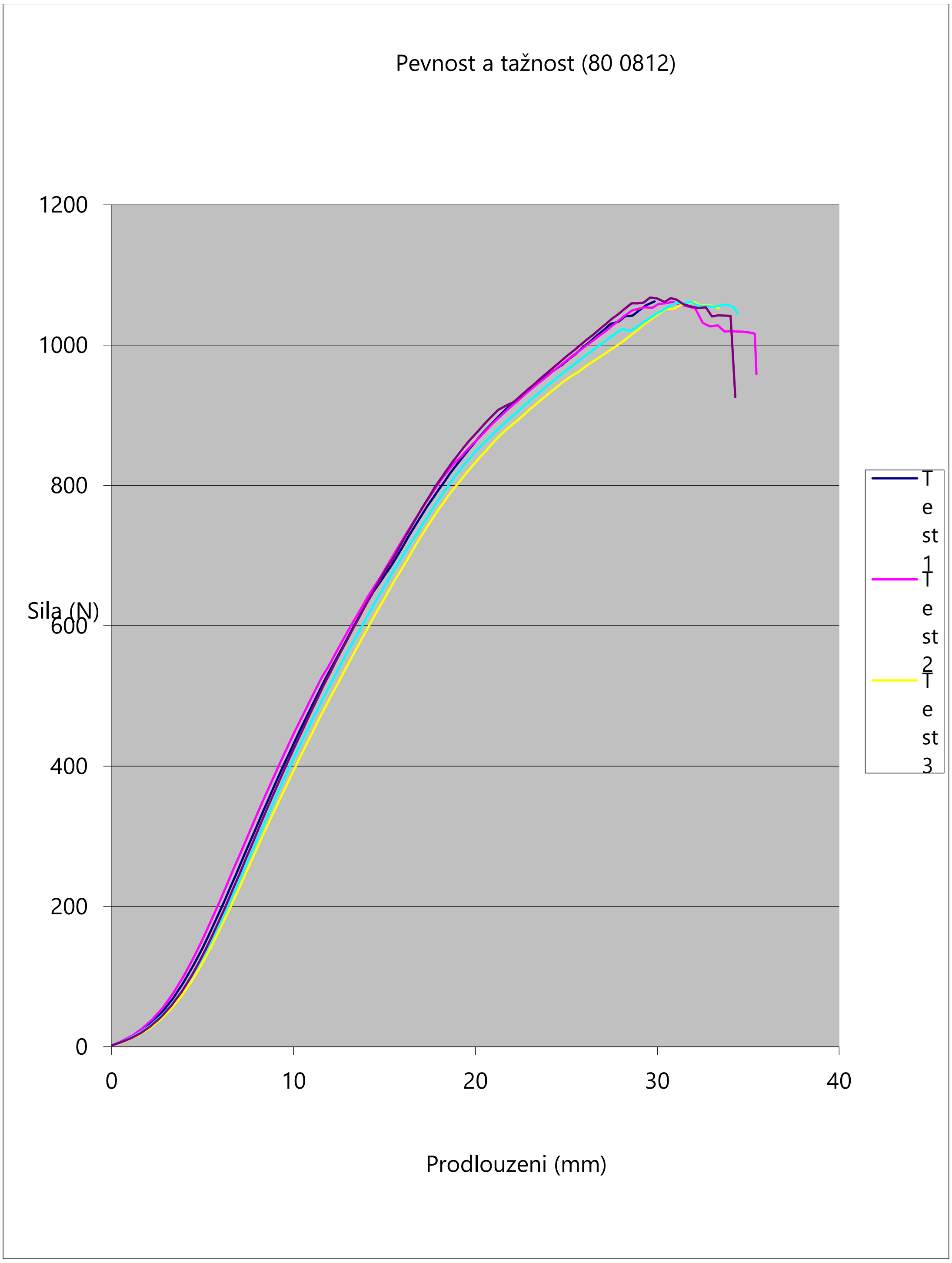
Tloustka : 0,810 mm

Delka vzorku : 150,000 mm

Poznamky:

Zkouska c.	Nejvyssi pevnost (N)	Prodlouzeni pri nejv. Pevnosti (mm)	Taznost pri nejvyssi pevnosti (%)
1	1066,200	29,910	19,916
2	1063,500	31,034	20,671
3	1063,500	32,236	21,463
4	1064,500	31,783	21,167
5	1071,800	29,830	19,861

Min	1063,500	29,830	19,861
AVERAGE	1065,900	30,959	20,616
Max	1071,800	32,236	21,463
S.O.	3,478	1,083	0,722
VK	0,326	3,498	3,502
D.H.D	1061,582	29,614	19,719
H.H.D.	1070,218	32,303	21,512


Pevnost a tažnost (80 0812)
Sila (N)
1200
1000
800
600
400
200
0
0
10
20
30
40
Prodlouzeni (mm)
Test 1
Test 2
Test 3

APPENDIX 4: TENSILE STRENGTH OF NOMEX AFTER UV

Nazev zkousky : Plošné textilie tah (80 0812)

Druh zkousky : Tkanina

Datum zkousky : 10.02.2020 11:41

Rychlost zkousky : 100,000 mm/min

Predpeti : 2,000 N

Sirka : 100,000 mm

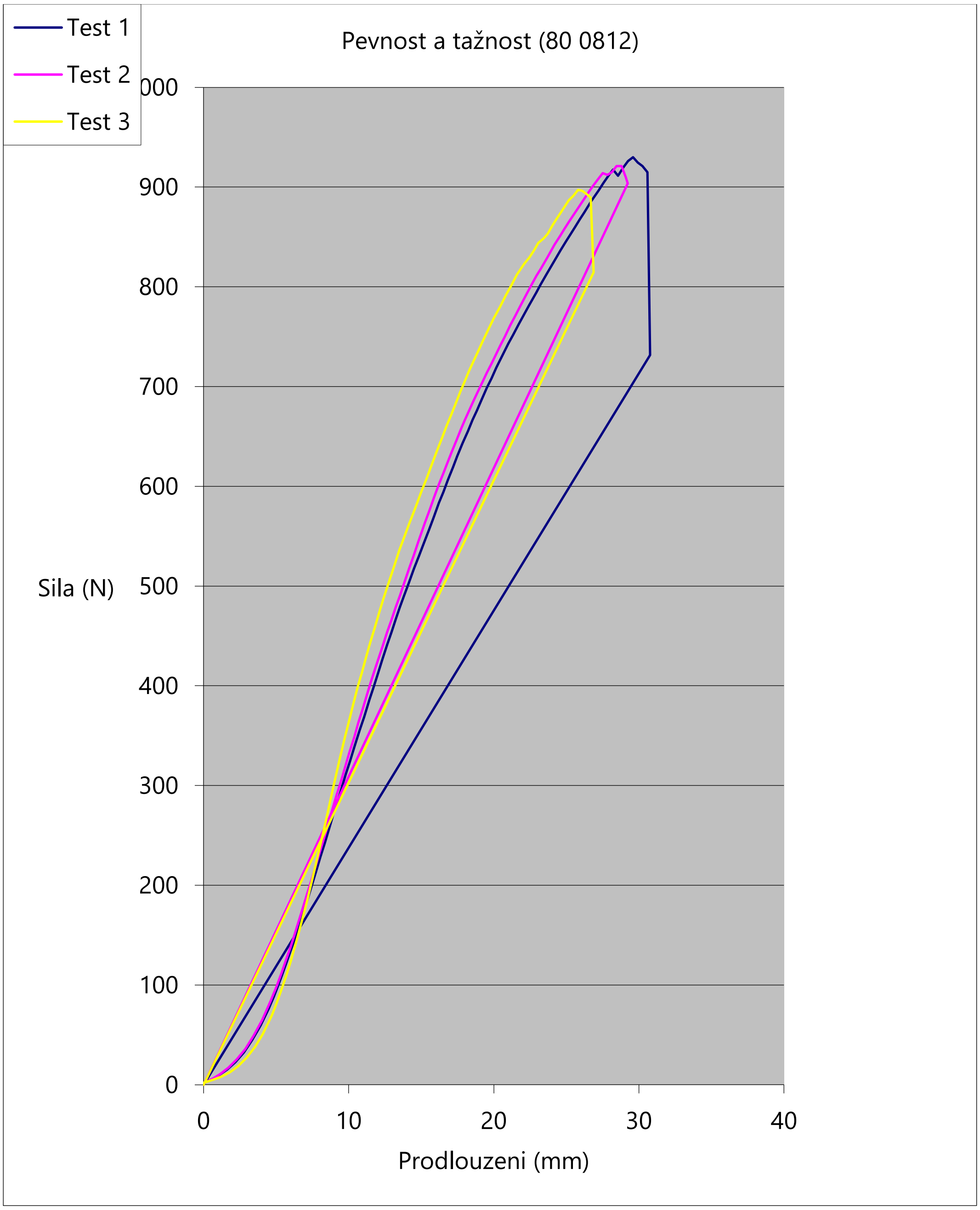
Tloustka : 0,810 mm

Delka vzorku : 150,000 mm

Poznamky :

Zkouska c.	Nejvyssi pevnost (N)	Prodlouzeni pri nejv. Pevnosti (mm)	Taznost pri nejvyssi pevnosti (%)
1	931,800	29,614	19,704
2	925,400	28,753	19,141
3	898,300	25,849	17,149
Min	898,300	25,849	17,149
Stred	918,500	28,072	18,665

Max	931,800	29,614	19,704
S.O.	17,784	1,973	1,342
VK	1,936	7,028	7,191
D.H.D	874,322	23,171	15,331
H.H.D.	962,678	32,973	21,999


Test 1
Test 2
Test 3
Pevnost a tažnost (80 0812)
000
900
800
700
600
500
400
300
200
100
0
Sila (N)
0
10
20
30
40
Prodlouzeni (mm)

APPENDIX 5: BENDING PROPERTIES OF PROBAN

SR.N	PROBAN (BEFORE UV) /M.N	PROBAN (AFTER UV) /M.N
1	16.7	15.8
2	17.1	17.1
3	17.5	16.4

APPENDIX 6: BENDING PROPERTIES OF NOMEX

SR.N	NOMEX (BEFORE UV) /M.N	NOMEX (AFTER UV) /M.N
1	10.4	6.4
2	6.1	7.0
3	5.6	6.3

APPENDIX 7: TRANSMISSION OF RADIANT HEAT FOR NOMEX

Before UV

Mode: Method B

System parameters

Heat flux Q0: 40.100 kW/m2

Mass M: 0.036 kg

Specific heat cp: 0.38500 kJ/kgK

Area A: 0.002500 m2

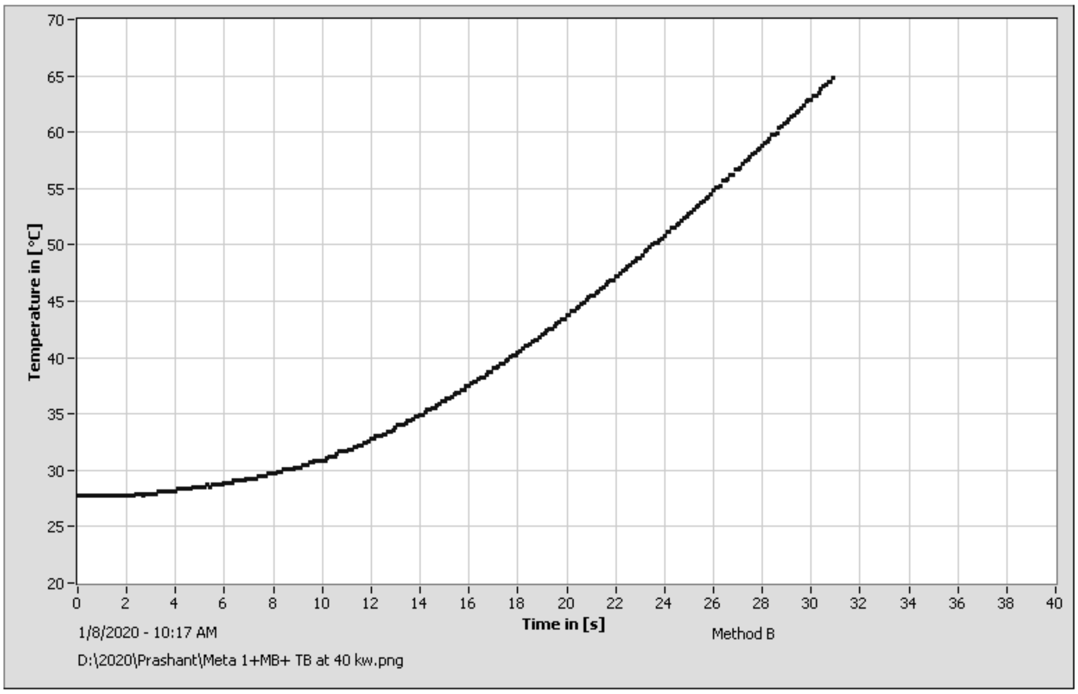
Absorption coefficient alpha: 0.90

Distance d: 16.9 cm

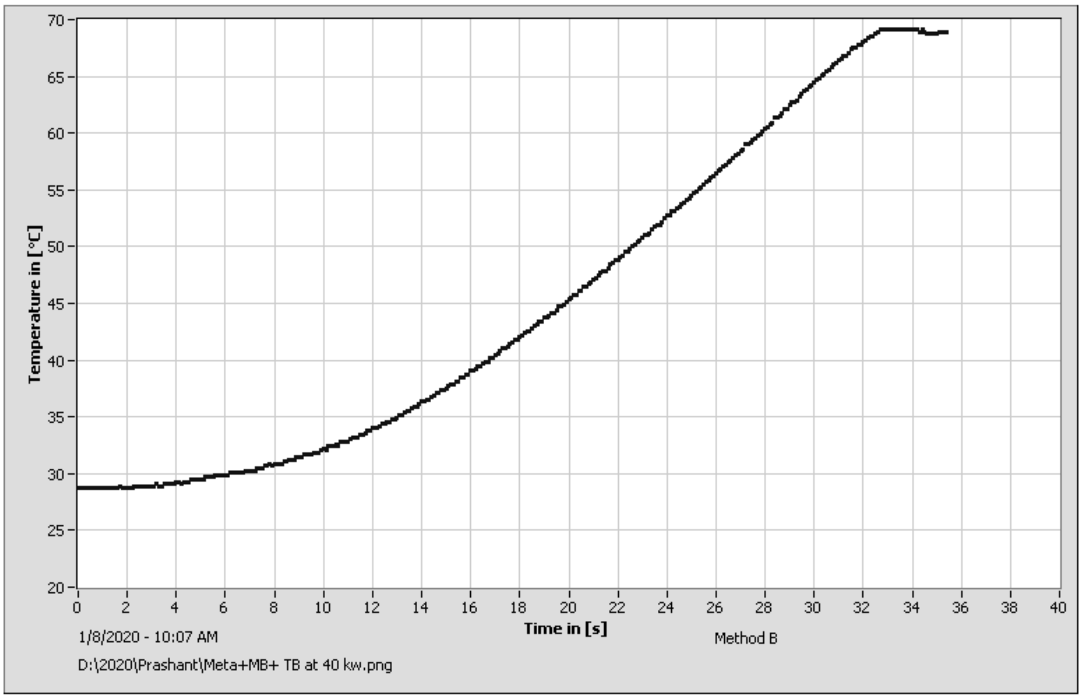
		Meta before UV		Meta after UV	
SR.N	Time [sec]	Meta	Meta1	Meta	Meta1
1	0	28.71	27.73	28.12	28.32
2	5	29.49	28.51	28.90	29.10
3	10	32.22	30.58	31.64	31.83
4	15	37.50	36.13	37.30	37.69
5	20	45.31	43.75	45.70	46.09
6	25	54.49	52.73	55.85	56.28
	Results	**t12: 17.2 s** **t24: 24.0 s** **Qc: 9.784 kW/m2** **TF: 0.244**	**t12: 17.6 s** **t24: 24.5 s** **Qc: 9.642 kW/m2** **TF: 0.240**	**t12: 16.9 s** **t24: 23.3 s** **Qc: 10.395 kW/m2** **TF: 0.260**	**t12: 16.8 s** **t24: 23.2 s** **Qc: 10.395 kW/m2** **TF: 0.260**

Meta aramid before UV

Meta1

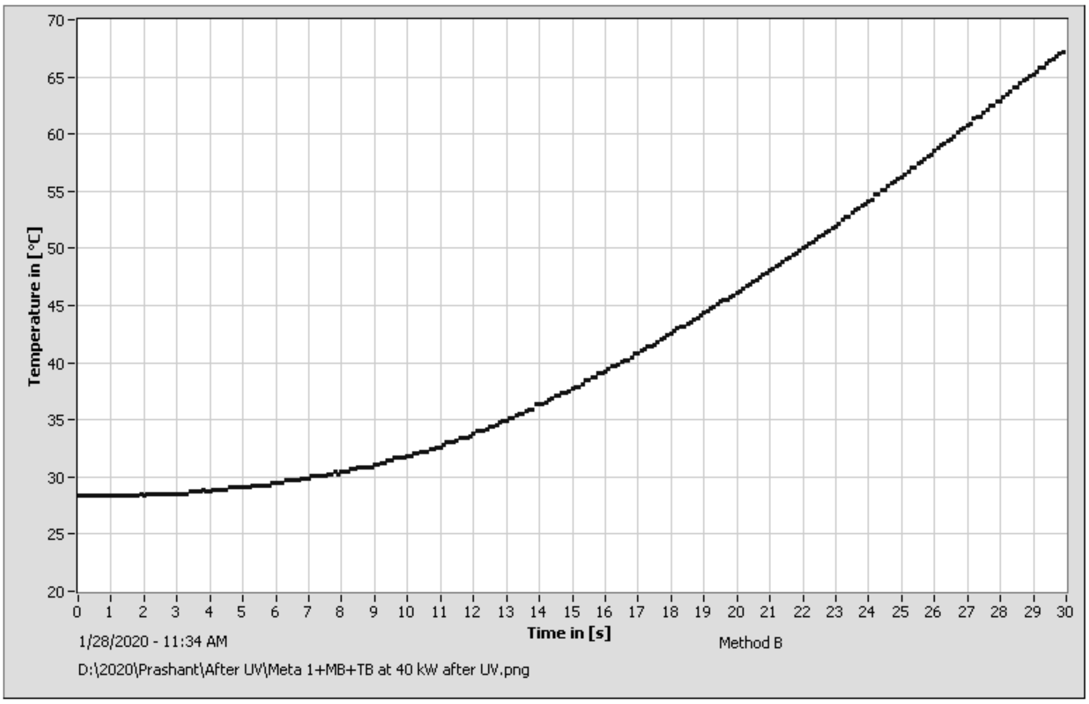


Meta

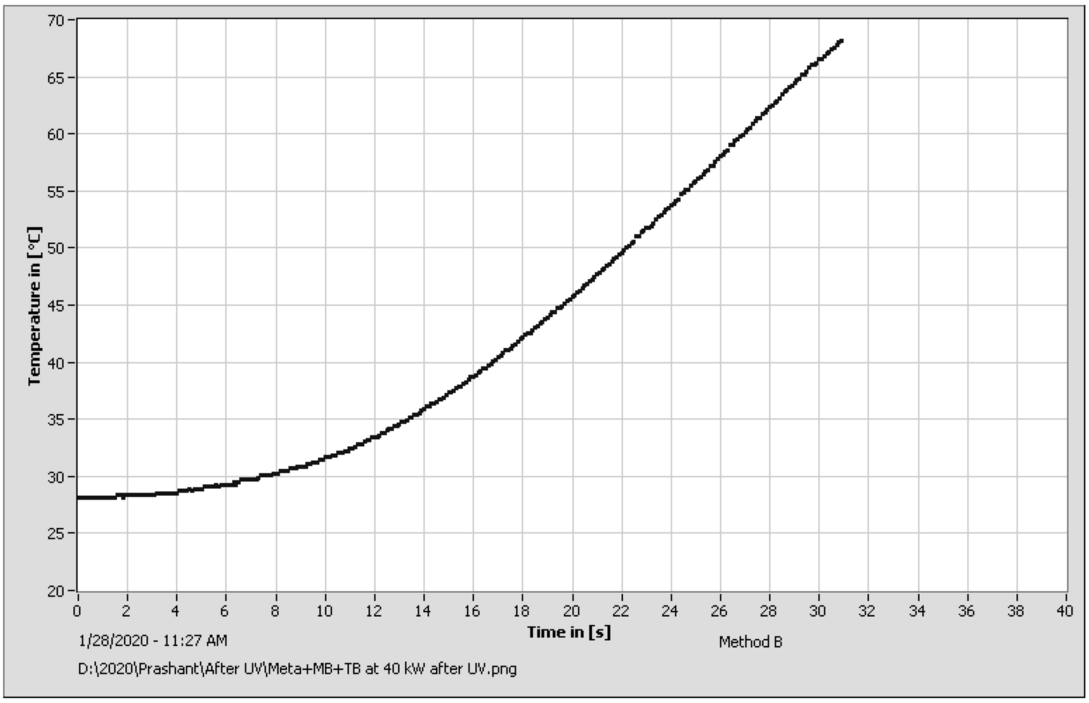


Meta Aramid after UV

Meta1



Meta



APPENDIX 8: TRANSMISSION OF RADIANT HEAT FOR PROBAN

After UV

Mode: Method B

System parameters

Heat flux Q0: 40.100 kW/m2

Mass M: 0.036 kg

Specific heat cp: 0.38500 kJ/kgK

Area A: 0.002500 m2

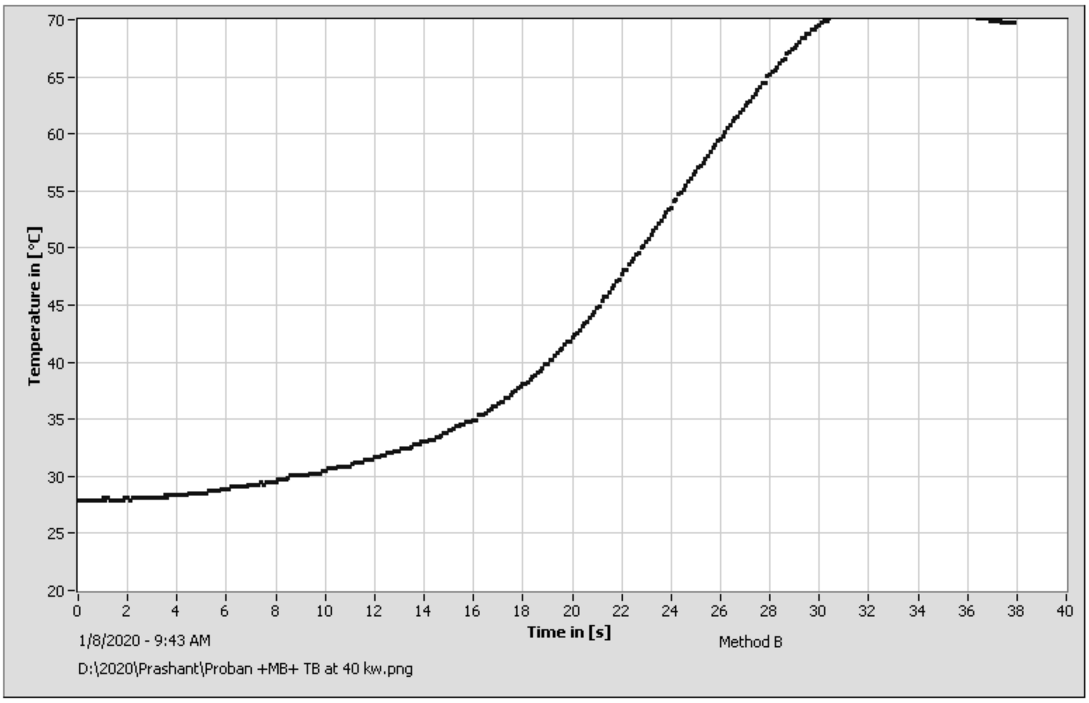
Absorption coefficient alpha: 0.90

Distance d: 16.9 cm

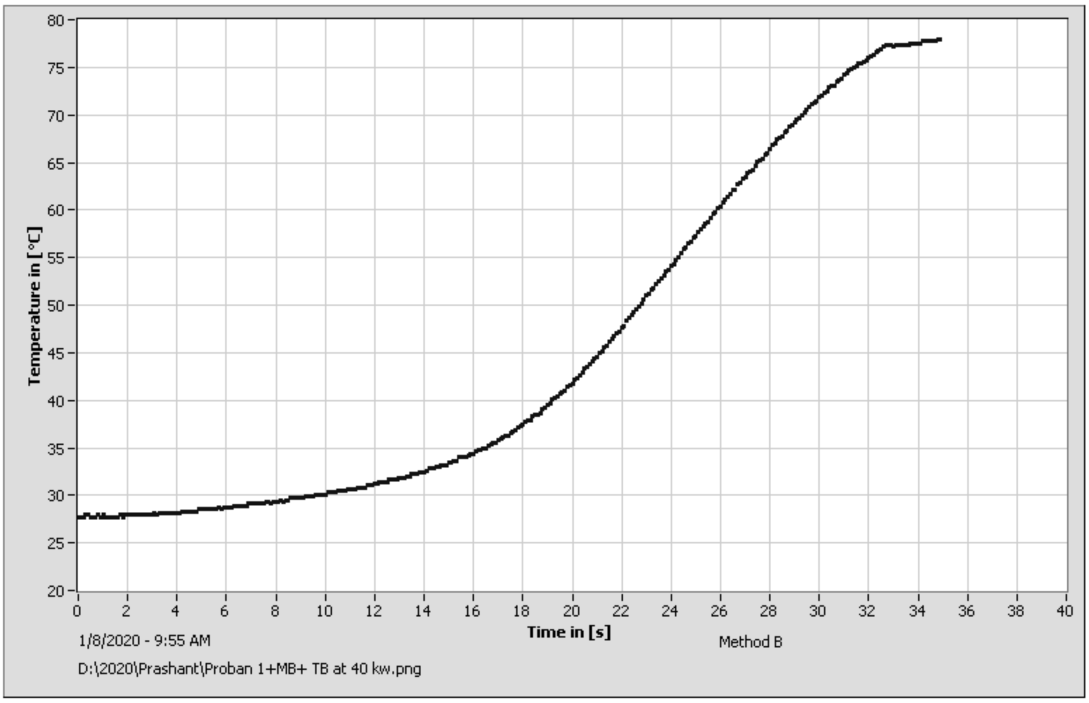
		Proban before UV		Proban after UV	
SR.N	Time [sec]	Proban	Proban1	Proban	Proban1
1	0	27.92	27.73	27.92	27.73
2	5	28.51	28.51	28.51	28.51
3	10	30.46	30.07	30.66	30.66
4	15	33.98	33.39	35.54	36.71
5	20	42.18	41.79	49.60	52.34
6	25	56.64	57.22		
	Results	**t12: 19.1 s** **t24: 23.5 s** **Qc: 15.120 kW/m2** **TF: 0.377**	**t12: 19.2 s** **t24: 23.3 s** **Qc:16.226 kW/m2** **TF: 0.405**	**t12: 17.1 s** **t24: 20.6 s** **Qc: 19.008 kW/m2** **TF: 0.475**	**t12: 16.3 s** **t24: 19.9 s** **Qc: 18.480 kW/m2** **TF: 0.462**

Graph: proban before UV

Proban

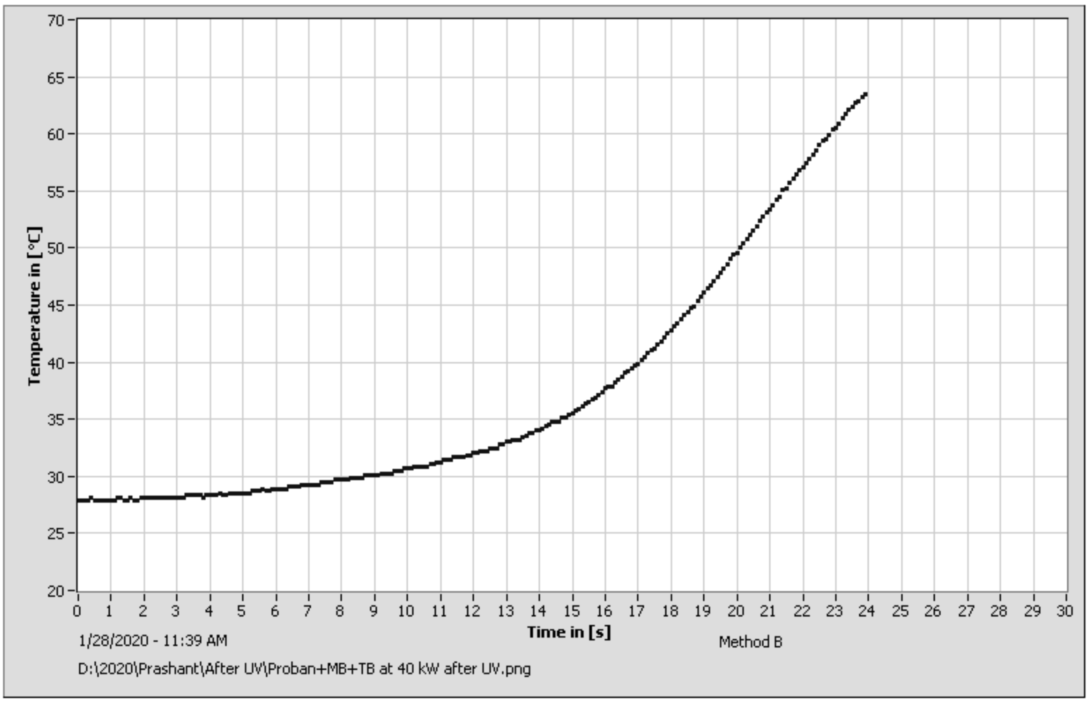


Proban1

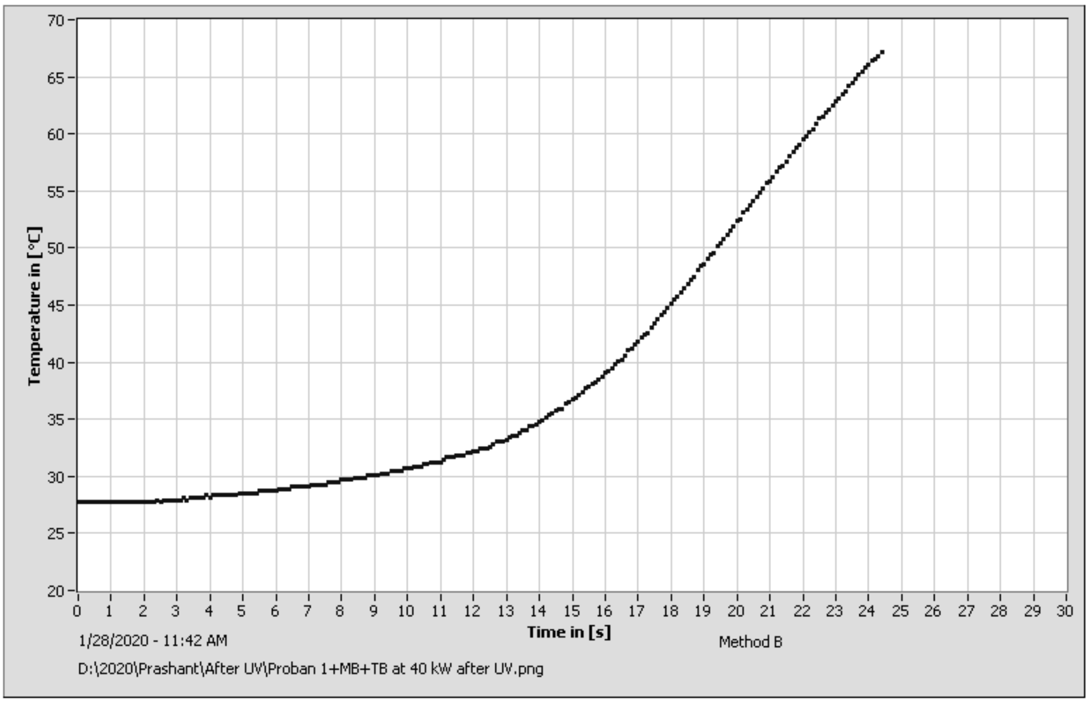


Graph: proban after UV

Proban


Temperature in [°C]
Time in [s]
1/28/2020 - 11:39 AM
Method B
D:\2020\Prashant\After UV\Proban+MB+TB at 40 kW after UV.png

Proban1


Temperature in [°C]
Time in [s]
1/28/2020 - 11:42 AM
Method B
D:\2020\Prashant\After UV\Proban 1+MB+TB at 40 kW after UV.png