

# 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





## Master Thesis Assignment Form

# UV weathering of fire fighter clothing

*Name and surname:* **Hikmat Marahatta, B.Sc.**  
*Identification number:* T17000365  
*Study programme:* N3106 Textile Engineering  
*Study branch:* Clothing and Textile Engineering  
*Assigning department:* Department of Clothing technologies  
*Academic year:* **2018/2019**

### 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.

*Scope of Graphic Work:* dle rozsahu dokumentace  
*Scope of Report:* cca 60 stran  
*Thesis Form:* printed  
*Thesis Language:* English



### **List of Specialised Literature:**

- A.L. Andradý,, S.H. Hamid X. Huc, A. Torikai, Effects of increased solar ultraviolet radiation on materials, *Journal of Photochemistry and Photobiology B: Biology* 46 (1998) 96-103
- Baljit Singh, , Nisha Sharma, 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
- A.L. Andradý,, S.H. Hamid X. Huc, A. Torikai, Effects of increased solar ultraviolet radiation on materials, *Journal of Photochemistry and Photobiology B: Biology* 46 (1998) 96-103

*Thesis Supervisors:* Ing. Adnan Ahmed Mazari, Ph.D.  
Department of Clothing technologies

*Date of Thesis Assignment:* December 14, 2018

*Date of Thesis Submission:* August 10, 2020

Ing. Jana Drašarová, Ph.D.  
Dean

L.S.

prof. Dr. Ing. Zdeněk Kůs  
Head of Department

Liberec December 14, 2018

## Declaration

I hereby certify, I, myself, have written my master thesis as an original and primary work using the literature listed below and consulting it with my thesis supervisor and my thesis counsellor.

I acknowledge that my bachelor master thesis is fully governed by Act No. 121/2000 Coll., the Copyright Act, in particular Article 60 – School Work.

I acknowledge that the Technical University of Liberec does not infringe my copyrights by using my master thesis for internal purposes of the Technical University of Liberec.

I am aware of my obligation to inform the Technical University of Liberec on having used or granted license to use the results of my master thesis; in such a case the Technical University of Liberec may require reimbursement of the costs incurred for creating the result up to their actual amount.

At the same time, I honestly declare that the text of the printed version of my master thesis is identical with the text of the electronic version uploaded into the IS/STAG.

I acknowledge that the Technical University of Liberec will make my master thesis public in accordance with paragraph 47b of Act No. 111/1998 Coll., on Higher Education Institutions and on Amendment to Other Acts (the Higher Education Act), as amended.

I am aware of the consequences which may under the Higher Education Act result from a breach of this declaration.

August 6, 2020

Hikmat Marahatta, B.Sc.

## **ACKNOWLEDGEMENT**

First and foremost, researchers would like to acknowledge Technical University of Liberec for providing this opportunity to carry out the research as a partial fulfillment for the requirement of Master Degree of Textile and Clothing Technologies.

Researcher would like to give warm gratitude towards doc. Ing. Antonin Havelka, of Department of Clothing Technologies, Technical University of Liberec for providing facility of laboratory for the experiment and data collection.

This work would have not been possible without the input and guidance of many professors.

My utmost gratitude to my supervisor, Ing. Adnan Ahmed Mazari, Ph.D for his patience, guidance and encouragement. I was always welcomed by my supervisor whenever I faced problem or had any question about my research or writing.

And last but not the least, my warm gratitude towards my family, my partner and colleagues for their support and encouragement during my study period and for preparing thesis. Also, specially thanks to my brother Jawad Naeen for his support during lab experiment.

## **ABSTRACT**

A **firefighter** are those persons who are special trained in firefighting mainly to destroy or eliminate the hazardous fires which may harm the animal life, property and environment and also to save them from that dangerous situation. Firefighting is a risky occupation, which lead to cause a chronic illness, such as cancer and heart disease, and in behavioral health issues that may end in suicide. According to National Fire Protection Association there are 310 fatalities in USA in between year 2015-2019. 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 be influenced by weather or other rapidly changing environmental conditions.

All the test were perform to identify whether the fabric will reach the minimum requirement and standards for firefighter clothing or not. It helps to identify the change in climate from fabric to skin or skin to fabric.

Nomex and proban, two different fabric were used for evaluating the impact of Ultraviolet weathering on tensile properties, bending properties, air permeability and radiation heat transmission. **Atlas weathering machine UV340** was used for the degradation of fabric. Ten samples of Nomex and ten samples of Proban were used for the ultraviolet exposure and the second part of experiment was performed on those sample. The TestoMetric (tensile test), Radiation Heat transmission equipment (Calorimeter), Air permeability Test equipment (FX3300 Textest instruments, Flexibility testing instrument (TH-4, Tuhomer) were used to evaluate.

The finding of study reveal that the performance of Nomex is better in each experiment.

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

## **ABSTRAKT**

Hasiči jsou osoby, které jsou trénovány nejen v boji s ohněm za účelem eliminace nebezpečných požárů, které ohrožují životy lidí a zvířat, majetek a životní prostředí, ale také za účelem jejich ochrany v různých nebezpečných situacích. Profese hasiče je riskantní, vede ke vzniku chronických nemocí, jako je rakovina či nemoci srdce, a také k rozvinutí psychických problémů, které mohou vést až k sebevraždě. Podle americké Národní asociace ochrany před požárem (NFPA) zemřelo v USA v letech 2015-2019 celkem 310 hasičů. Hasiči jsou vystaveni různým situacím, které se mohou rychle změnit a mohou být ovlivněny počasím nebo jinými měnícími se podmínkami prostředí.

Cíl práce je zaměřen na testování textilií, zda textilie splňují minimální požadavky a standardy kladené na oblečení pro hasiče. Zvláštní důraz je kladen na komfort oděvu. V rámci experimentu byl sledován vliv povětrnostních podmínek (UV záření) na vybrané vlastnosti textilií. Na přístroji Atlas UV 340 byly textilie vystaveny simulovaným povětrnostním podmínkám, kdy bylo provedeno testování dvou druhů textilií Nomex a Proban. U těchto textilií byla sledována změna vlastností před a po expozici v Atlas UV 340. Byla sledována změna těchto vlastností: pevnost a tažnost (na trhačce Testometric), přenos tepla sáláním (pomocí Kalorimetru), prodyšnost (na zařízení FX 3300 Textest) a tuhost v ohybu (na TH-4). Výsledky měření byly zpracovány a vyhodnoceny. Z výsledků je patrné, že Nomex měl lepší výše uvedené vlastnosti než Proban.

Klíčová slova: hasič, ochranný oděv, povětrnostní podmínky, přenos tepla, snížení komfortu.

## Table of content

<b>Acknowledgement</b> .....	<b>I</b>
<b>Abstract</b> .....	<b>II</b>
<b>Abstrakt</b> .....	<b>III</b>
<b>List Of Figure</b> .....	<b>VII</b>
<b>List Of Table</b> .....	<b>VIII</b>
<b>Chapter I: Introduction</b> .....	<b>1</b>
1.1 Introduction.....	1
1.1.1 Firefighter Clothing .....	2
<b>Chapter II: Literature Review</b> .....	<b>7</b>
2.1 Weathering .....	7
2.2 Factors Affecting Weathering.....	7
2.2.1 Solar Radiation.....	8
2.2.2 Temperature .....	8
2.2.3 Moisture .....	9
2.2.4 Irradiance .....	9
2.2.5 Secondary Effects .....	10
2.3 Types Of Weathering .....	10
2.3.1 Natural Weathering: .....	10
2.3.2 Artificial Weathering. ....	10
2.4 Effects .....	11
2.4.1 Effect Of Ultraviolet Radiation On Fabric: .....	11
2.4.2 Heat Stress And Skin Burn.....	12
2.5 Relation .....	12
2.5.1 Human-Clothing-Environment System.....	12
2.6 Measurement.....	13
2.6.1 Thermal Comfort .....	13
2.6.2 Transport Properties .....	13
2.6.3 Moisture Management Properties.....	14
2.6.4 Mechanical Properties .....	14
<b>Chapter III: Materials</b> .....	<b>15</b>



3.1	Fabric .....	15
3.1.1	Nomex Fabric: .....	15
3.1.2	Proban .....	18
<b>Chapter IV: Equipment .....</b>		<b>19</b>
4.1.	Artificial Weathering Chambers.....	19
4.1.1.	Atlas Weathering Machine Uv 340.....	19
4.2.	Transmission Of Radiant Heat Flux Density .....	20
4.2.1.	Iso 6942.....	21
4.3.	Air Permeability Test.....	23
4.3.1.	Csn En Iso 9237 .....	24
4.4.	Flexibility/Bending Performance .....	24
4.4.1.	Csn 800858 .....	24
4.5.	Tensile Strength Measurement .....	25
4.5.1.	En Iso 13934: .....	28
<b>Chapter V: Research Methodology .....</b>		<b>29</b>
5.1	Test Method .....	29
5.2	Artificial Exposure: .....	30
5.3.	Specification of Fabric.....	30
5.4.	Tensile strength of Fabric.....	30
5.4.1	Physical Properties Of Tasted Sample For Tensile. ....	31
5.5	Transmission Of Radiant Heat .....	32
5.6	Bending Moment Properties: .....	39
5.7	Air Permeability Of Fabric.....	41
<b>Result And Discussion .....</b>		<b>44</b>
<b>Conclusion .....</b>		<b>45</b>
<b>Future Work.....</b>		<b>46</b>
<b>Refrences.....</b>		<b>47</b>
<b>Appendix.....</b>		<b>50</b>
Appendix 1: Air Permeability Of Proban .....		50
Appendix 3: Tensile Strength O Nomex Before Uv .....		52
Appendix 4: Tensile Strength Of Nomex After Uv .....		55
Appendix 5: Bending Properties Of Proban .....		58
Appendix 6: Bending Properties Of Nomex .....		58

Appendix 7: Transmission Of Radiant Heat For Nomex.....	59
Appendix 8: Transmission Of Radiant Heat For Proban.....	62

## List of Figure

<b>Figure 1: Firefighter [4].....</b>	<b>2</b>
<b>Figure 2: Layers of firefighter clothing [5].....</b>	<b>4</b>
<b>Figure 3: Layers of firefighter clothing[7].....</b>	<b>5</b>
<b>Figure 4: Firefighter clothing .....</b>	<b>6</b>
<b>Figure 5 : Types of rays of light emitted by sun. [15] .....</b>	<b>8</b>
<b>Figure 6: Proban treated fabric. [25] .....</b>	<b>18</b>
<b>Figure 7: Atlas weathering machine [13].....</b>	<b>20</b>
<b>Figure 8: Radiant heat transmission machine.....</b>	<b>22</b>
<b>Figure 9: Fabric ready for exposure .....</b>	<b>22</b>
<b>Figure 10: Air permeability tester (FX3300).....</b>	<b>24</b>
<b>Figure 11: Flexibility testing machine.....</b>	<b>25</b>
<b>Figure 12: Tensile strength tester (Testometric).....</b>	<b>26</b>
<b>Figure 13: Stress strain curve of a fabric [37] .....</b>	<b>27</b>
<b>Figure 14: Breaking strength of firefighter specimen .....</b>	<b>31</b>
<b>Figure 15: Comparison time vs temperature .....</b>	<b>34</b>
<b>Figure 16: Comparison time vs temperature .....</b>	<b>34</b>
<b>Figure 17: Showing transmitted heat flux density.....</b>	<b>36</b>
<b>Figure 18: Qc comparison for nomex and proban after UV.....</b>	<b>36</b>
<b>Figure 19:Showing RHTI 24 before exposure.....</b>	<b>37</b>
<b>Figure 20: Showing the RHTI 24 after exposure .....</b>	<b>37</b>
<b>Figure 21: Comparison between the Meta and proban for RHTI 24 .....</b>	<b>38</b>
<b>Figure 22: Showing the bending property of nomex and proban before UV.....</b>	<b>39</b>
<b>Figure 23: Bending property of nomex and proban after UV.....</b>	<b>40</b>
<b>Figure 24: comparison of bending moment.....</b>	<b>40</b>
<b>Figure 25: Air permeability before UV.....</b>	<b>42</b>
<b>Figure 26: Air permeability after UV exposure.....</b>	<b>42</b>
<b>Figure 27: Comparison of air permeability before and after UV .....</b>	<b>43</b>

## **List of Table**

Table 1:Specification of fabric.....	30
Table 2: Result by heat transmission machine.....	33

# CHAPTER I: INTRODUCTION

## 1.1 INTRODUCTION

Firefighting is a risky occupation, with damage rate that has been assessed at multiple times that of different specialists. according to national firefighter protection association there has been 310 fatalities since 2015 till 2019. Even though 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 prceivability, 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, 24]

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 have to go through a lots of work inside it. There are lots of other work 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 the their safety and protection. The clothing should made in such away that it protects the fire fighter and should be more comfortable during the job And should have high functional properties.



Figure 1: Firefighter [4]

### **1.1.1 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 firefighters 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, firefighters 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. NFPA 1851 Standard (2008) gives many indicators to identify the deterioration but fails in providing quantification 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 microclimate 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.

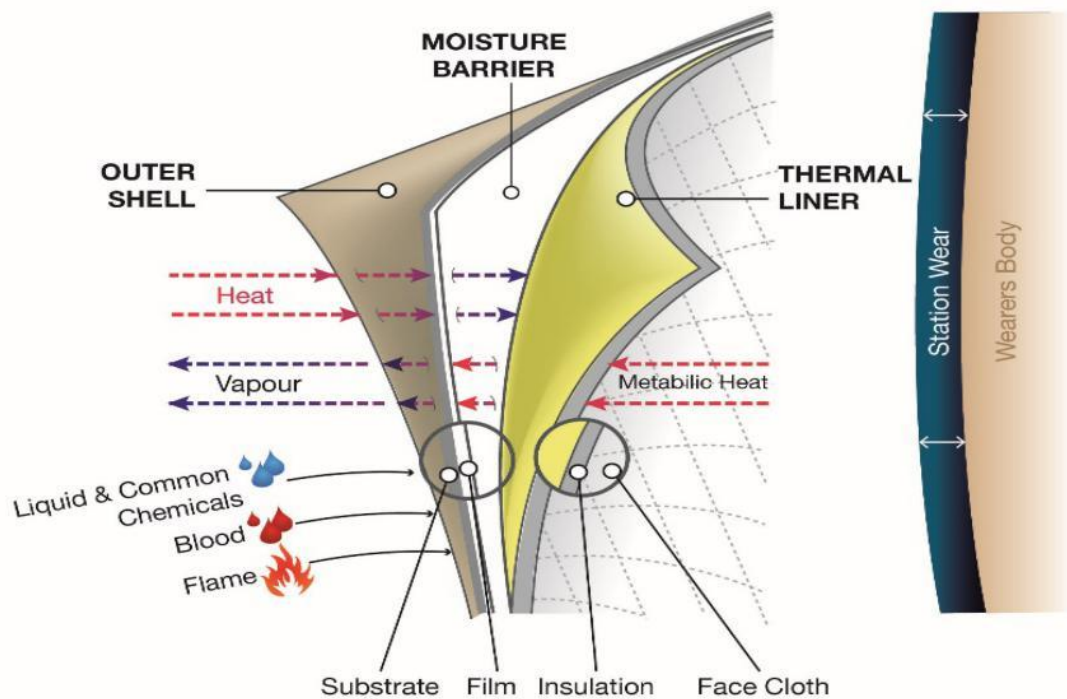


Figure 2: Layers of firefighter clothing [5]

The OS is the outermost layer and is the first line of defense 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 polyaramid, polybenzimidazole, and/or poly(melamine-formaldehyde) fibers. 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]

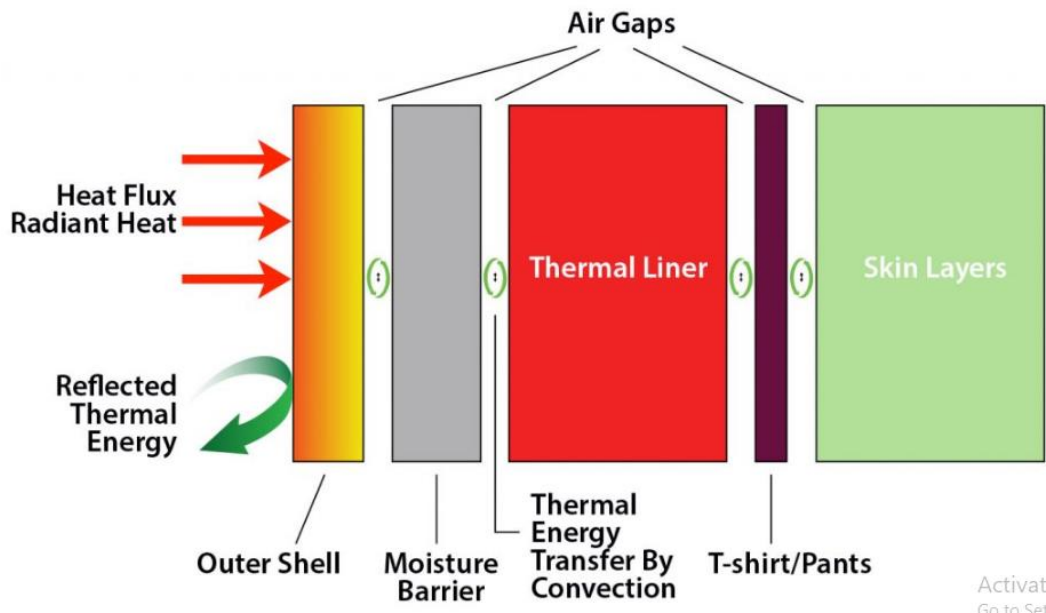


Figure 3: Layers of firefighter clothing [7]

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 firefighter's turnout gear that are based on performance metrics. [10]

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

- i. Should protect firefighter from radiant heat.
- ii. Should minimize the burn injuries risk
- iii. Should minimize the chance of heat exhaustion.
- iv. Should be light and easy wear.
- v. Should maintain the heat comfort during various climatic conditions and duration of work
- vi. Should decapitate metabolic heat.
- vii. Does not burn or melt.
- viii. should provide the escape time.



Figure 4: Firefighter clothing

## **CHAPTER II: LITERATURE REVIEW**

### **2.1 WEATHERING**

Weathering is the unfavorable 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. [13,14]

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. [13]

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. [13, 14]

### **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."  
[14, 16]

### 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 (v) agreeing to the accompanying condition, where (h) is Planck's steady, (c) is the speed of light in a vacuum, and ( $\lambda$ ) is wavelength.

$$E=hC/\lambda \text{ (9)}$$

- 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. [14]

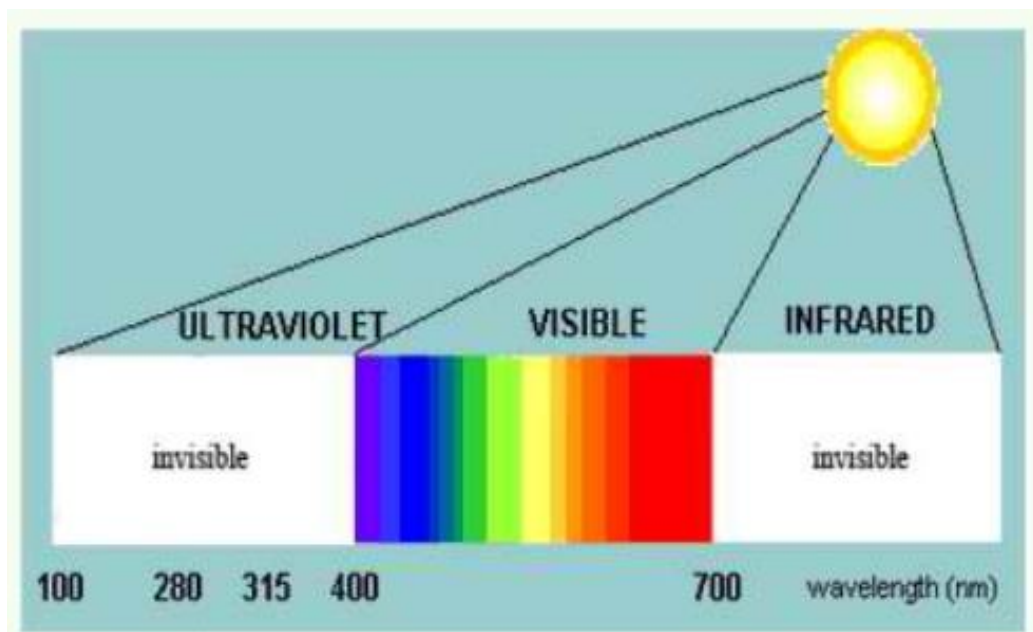


Figure 5 : Types of rays of light emitted by sun. [15]

### 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 photochemical reactions are usually accelerated. Also, the temperature decides the rate of subsequent reaction. A general rule of thumb assumes that with 10°C the rate for reaction doubles the temperature on the fabric. But while measuring the appearance or physical changes this cannot be observed. Also, thermochemical reactions which may occur in higher temperature but may not occur at lower temperature. [15]

The temperature for exposed material to the sunlight are decided by various factors. The surface temperature of sample is because of thermal absorption, irradiance from solar, surface temperature. Therefore with the exposed on sunlight the surface temperature an object is mostly higher than the air temperature. [15]

### **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 the stress is occurred 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. [15]

### **2.2.4 Irradiance**

Irradiance is the radiant flux incident occurrence per unit area on the given surface, unit of irradiance is W/m<sup>2</sup>. 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/m<sup>2</sup>. Best exposures are determined in either kJ/m<sup>2</sup> or MJ/m<sup>2</sup>. 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 nanometer. A nanometer is one billionth ( $1 \times 10^{-9}$ ) 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. [14,15]

### **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. [15]

## **2.3 TYPES OF WEATHERING**

There are two types of weathering:

### **2.3.1 Natural weathering:**

It is the direct weathering in which the material is 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 is the most important element which helps the protective clothing to lose its protective performance. [14]

#### **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 and starts above around 760 chronometers (nm). visible rays are characterized as radiation between the range of 400 and 760 nm. Ultraviolet rays have radiation below 400 nm. [14]

### **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 lamp is used as the source for the light inside the weathering machine for the exposure of fabric. Though the natural weathering have different rays and wavelength of light but the rays from artificial weathering have the same wavelength. [14]

## **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 either be absorbed, reflected or transmitted through the fabric. the amount of those radiation depends upon the many factors such as fiber type, surface of fabric, cover factor of fabric and amount of fiber delustrants UV absorbent 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 refereed as transmission component. [16]

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 fiber's nature. On account of the huge surface volume proportion, textile materials are defenseless 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 crystallization. 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. [16]

## 2.4.2 Heat stress and skin burn.

The inner temperature helps to know the human physiological behavior for the heat stress. The temperature which is maintained within  $37.0 \pm 1.0$  °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 limit 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. [17]

## 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 Figure.

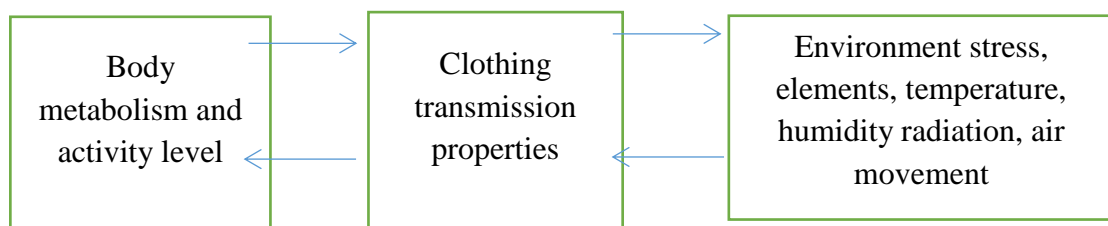


Table: role of clothing in protecting the body and maintaining the thermal balance between body and environment.

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 microclimate between the nude body and the external environment. The body responds to this microclimate, and the thermoregulatory responses of the



body and the transfer and vapour permeation properties of the clothing determine the microclimate. 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 vapour pressure between the environment and the skin surface. [18]

## **2.6 MEASUREMENT**

### **2.6.1 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 in 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. [18]

### **2.6.2 Transport properties**

The transport properties are closely related to the comfort performance which is considered by thermal resistance, air permeability and water vapour permeability. Heat, air and water vapour 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 he comforts of the clothing. The water vapour permeability of such fabric should be as high as possible to allow to escape the water vapour released from the body. High water vapour 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. [27]

### **2.6.3 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 have some micro-porous structure which prevents water to move back towards the skin. It helps the water vapour to escape to the environment and reduce the burns and heat for the fighter. [27]

### **2.6.4 Mechanical properties**

Elongation, elasticity or flexibility abrasion resistance, modulus of elasticity, strength is coming 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 felicity or flexibility properties means the behaviour which is shown by the material when it is bend. Importance of flexibility is when we wear cloth. [27]

## CHAPTER III: 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. E.g. Proban
- b. Flame retardant by flame resistant fibers: By using the inherently fire resistant we can make flame retardant textile product. Eg. polyimide, glass, Kevlar, 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 polyimide, 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. [19]

#### 3.1.1 Nomex fabric:

These are the first organic fiber which have 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 crafts, 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 is 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. [21]

Aramid are the manufactured fibers in which the fiber forming polyimide 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 aramid family. Aramids 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. [20,21]

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. [22]

Aramid fibers fibers are poor resistant to Ultraviolet light and when exposed it, the fabric changes its colour 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 fabric are more reactive to the Ultraviolet light, acids and some salts. [21]

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. [20]

This property enhances the wettability 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 intramolecular 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. [20, 21]

Nomex I the brand name manufactured by Dupont chemical company. The chemical name for nomax is poly (m-phenylenediamine isophthalamide). It is the special type of staple filament yarn. It is manmade strong fiber. It has the special characteristics of fire resistant. The fabric burns when it is kept on the flame and stops burning when the fabric is removed from the flame. It takes time for heat to travel through the nomex because it is poor conductor of heat. The fabric does not melt or drip when exposed on

heat or chemical environment, this special feature makes fabric applicable in firefighter clothing. This fabric is known for the fire and heat barrier. It has high breathability and low water vapour resistance because of which it is used as outer layer fabric in firefighter clothing. Nomex mainly have three kinds. It can be 100% nomex, blended with Kevlar (60%), or blended with Kevlar and some anti-static fibers which is known as, Nomex III.

Nomex is inherently flame resistant, it has high temperature resistance property and will not melt, drip or does not support combustion in air. Nomex can be found in fabric, paper, felt and fiber form. Nomex is used for various applications but is well known for component for protective clothing.

The ability of nomex to carbonize and get thicken when exposed to the extreme heat is the main reason for the protection provided by the nomex. this reaction increases the barrier between the source of heat and decrease the injury or burn.[22,23]

The common characteristics of the Nomex fibers are: [16]

- a. Sensitive and degradate 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. Degradate 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.

### 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 retardation 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 breathability and thermal resistance. It does not allow water vapour to transfer from body to external environment. It is the result of controlled during the finishing stage of cellulose fabric or 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. [24, 25]

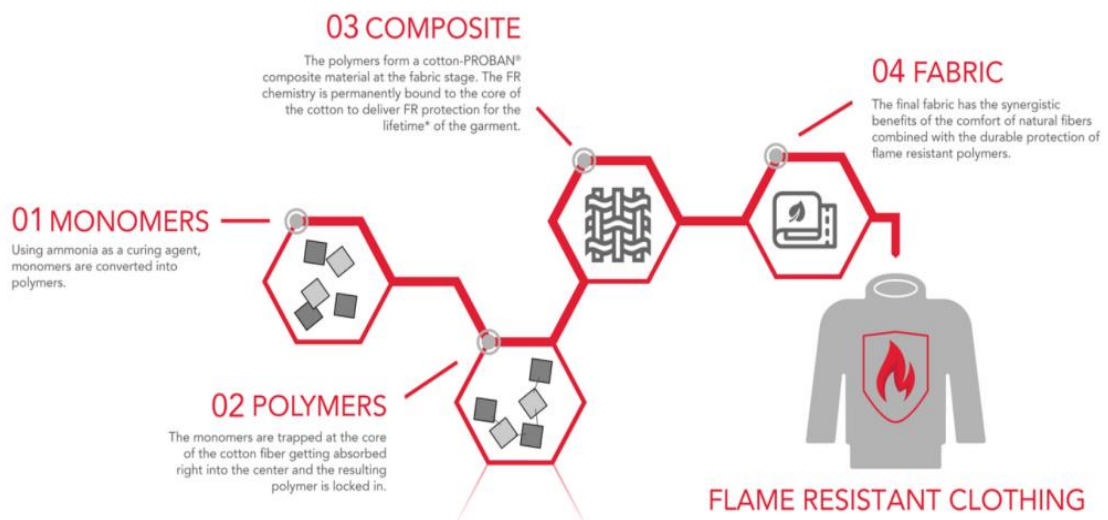


Figure 6: Proban treated fabric. [25]

Proban treated fabric are safer and also do not give skin irritation for the wearer. It does not effect the natural properties of the cotton fabric. Proban sometimes may pass flame test up to 100to 150 washes.

## **CHAPTER IV: EQUIPMENT**

### **4.1. Artificial weathering chambers.**

These chambers are made for laboratory purpose. These provides 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 this chamber. [13]

#### **4.1.1. 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 sample 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 sample are to be kept inside the chambers according to our planned days and hours for the exposure. After the exposure again, this same experiment is 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 exposure to high intensity. [13]

The equipment consists of three sections:

1. Top section: contains control cabinet, control panel, fluorescent lamp ballasts, expander fuels, optional chart recorder, water purity meter.
2. Middle section: UV fluorescent lamps, specimen racks, water heater, air heater, air circulation fan, water inlet float valve 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 determine test temperature during U.V cycle exposure and condensate cycle exposure. [13]



Figure 7: Atlas weathering machine [13]

#### 4.2. Transmission of radiant heat flux density

The instrument comprises of a radiation heat source, which can create heat flux thickness of up to  $80 \text{ kW/m}^2$  alongside a calorimeter to calculate the warmth transition thickness. ISO 6942 was utilized to calculate the transport of heat from a single layer and multilayer fabric. The instrument is equipped with slightly bended copper plate calorimeter put on a non-burnable surface. The front of the calorimeter was layered with a slim and fine film of dark paint. The heating instrument is consisting 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 calorimeter should be adjusted correctly. We should identify the exact



distance between the rods and calorimeter and the given rate of heat flow. We maintain the exact distance between the heating rods and heating source for  $40\text{kw}/\text{m}^2$ . 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  $30^\circ\text{C}$  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  $t_{12}$  is for the temperature rise of  $12.0\pm 0.2^\circ\text{C}$  and the time  $t_{24}$  is for the temperature rise of  $24\pm 0.2^\circ\text{C}$  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 ( $Q_c$ ) and percentage heat transmission factor %TF ( $Q_o$ ). Before the experiment, all the sample are pre-conditioned for 24 hours at the temperature of  $20^\circ\text{C}$  and have relative humidity 65%. the sample size is  $230\text{mm}\times 80\text{mm}$ . Experiment was performed in the fabric before and after U.V degradation in 5 sample each. [28,34, 39]

#### **4.2.1. ISO 6942**

Minimum three samples are to be tested from the given materials. As per the standard of test the fabric are exposed to  $20\text{-}40\text{ kw}/\text{mm}^2 \pm 5\%$ . The calorimeter which is in contact to fabric is used to measure the heat that passes through the sample.

When indicator reaches  $24^\circ\text{C}$  the radiation will be stopped. Time is expressed in seconds to measure the produced temperature increase in calorimeter. The given time is the length of time where the heat is passed due to increase in temperature in which the wearer feel pain due to the burn in second degree. [29,39]

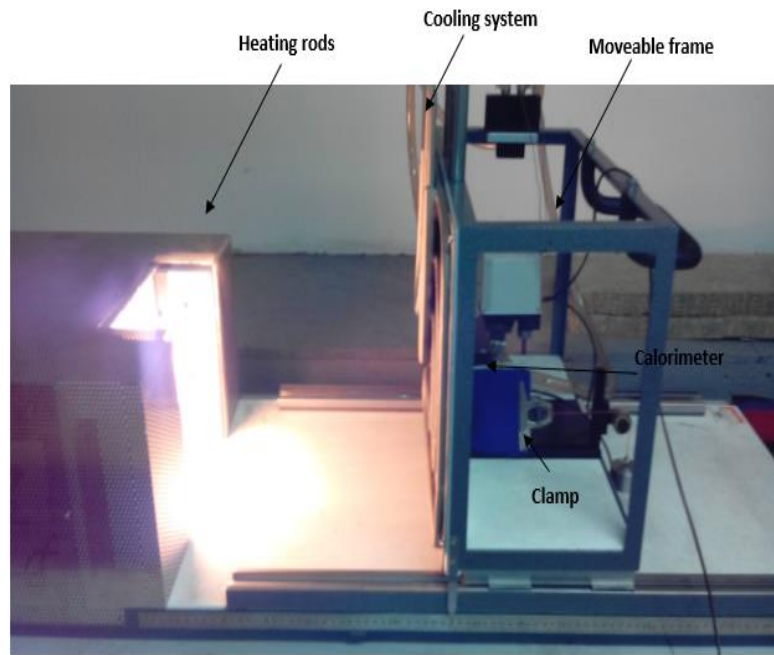


Figure 8: Radiant heat transmission machine.

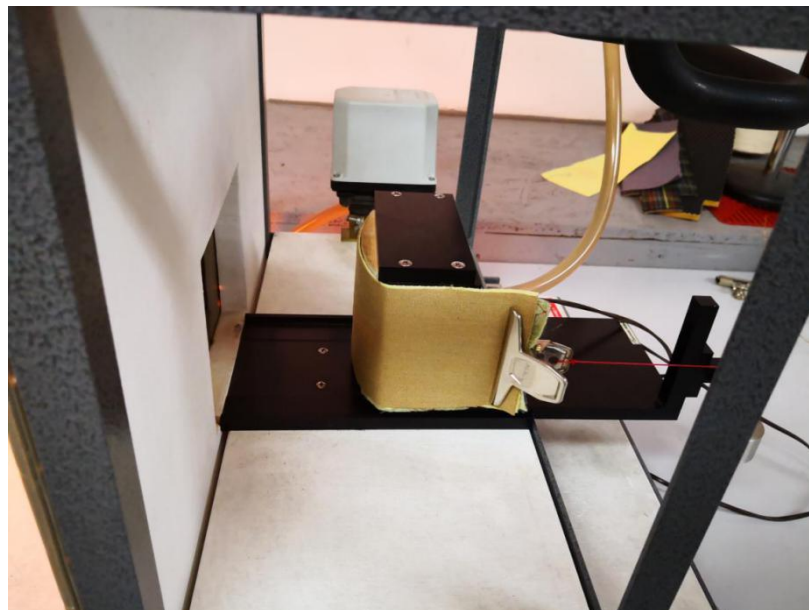


Figure 9: Fabric ready for exposure

### 4.3. 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. [31, 33]

An air permeability analyzer FX3300 Labotester III (Textest Instruments) was used to measure air penetrability in accordance with the CSN EN ISO 9237 standard. The pressure was tested on 200 Pa on the region of 20 cm<sup>2</sup> (l/m<sup>2</sup>/s). Ten estimations were done before and after the U.V degradation for each example as indicated by the standard. [32]

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

Where,  $q_v$  is rate of flow of air litre per minute,

A in cm<sup>2</sup> is area.

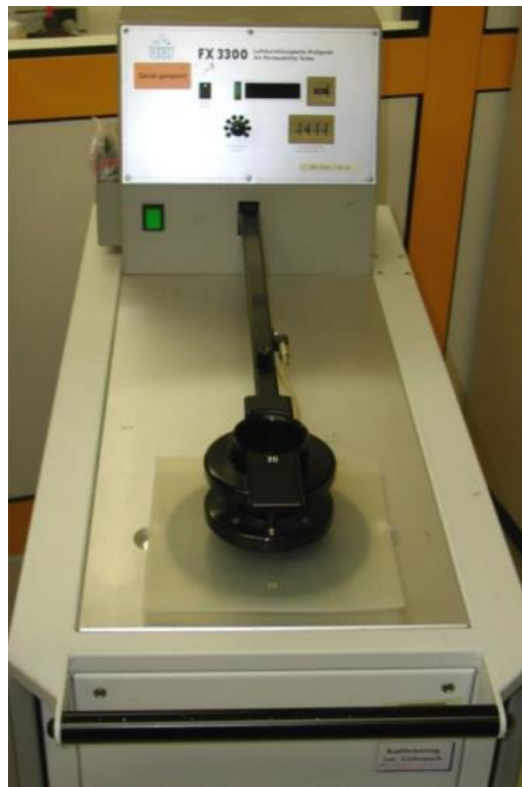


Figure 10: Air permeability tester (FX3300)

#### **4.3.1. 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. [30]

#### **4.4. Flexibility/Bending performance**

Tuhome 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:

$$M_o = F * K$$

Where,

$M_o$  is the bending moment [mN.cm]

F is force applied in mN

K is constant and the value is 0.52

#### **4.4.1. CSN 800858**

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



Figure 11: Flexibility testing machine

#### 4.5. Tensile strength measurement

The experiment is done on the instrument named testometric. The instrument follows 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 state using strip methods. The size of sample for fabric is usually 5cm\*30cm.

During the experiment, the sample is 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 movement 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 a 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. [38]

The maximum force on the sample is recorded when the sample is taking 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, 37]

Stress ( $\sigma$ ): It is the force per unit area. It is measured in pascal ie Newton/m<sup>2</sup>. [37]

Therefore,

$$\sigma = F/A$$

Tensile strength: It is the maximum strength of the fabric while stretched before the breakage. [36]

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. [37]

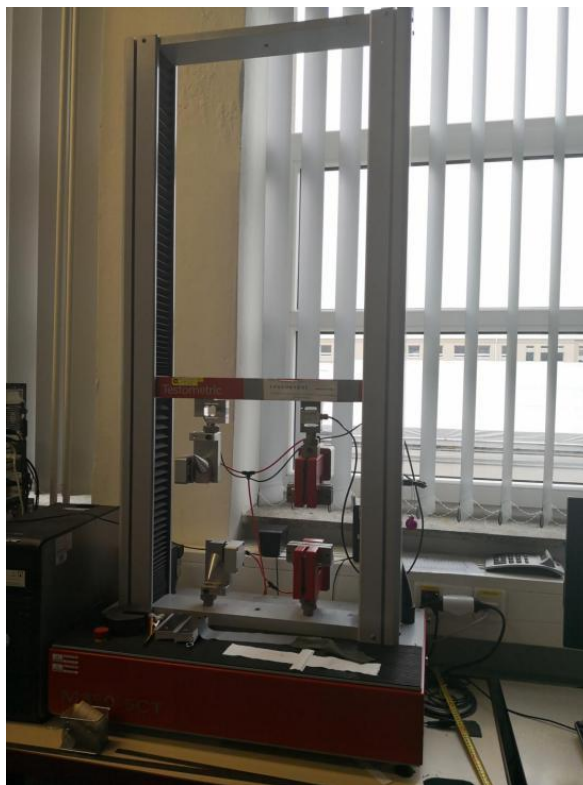


Figure 12: Tensile strength tester (Testometric)

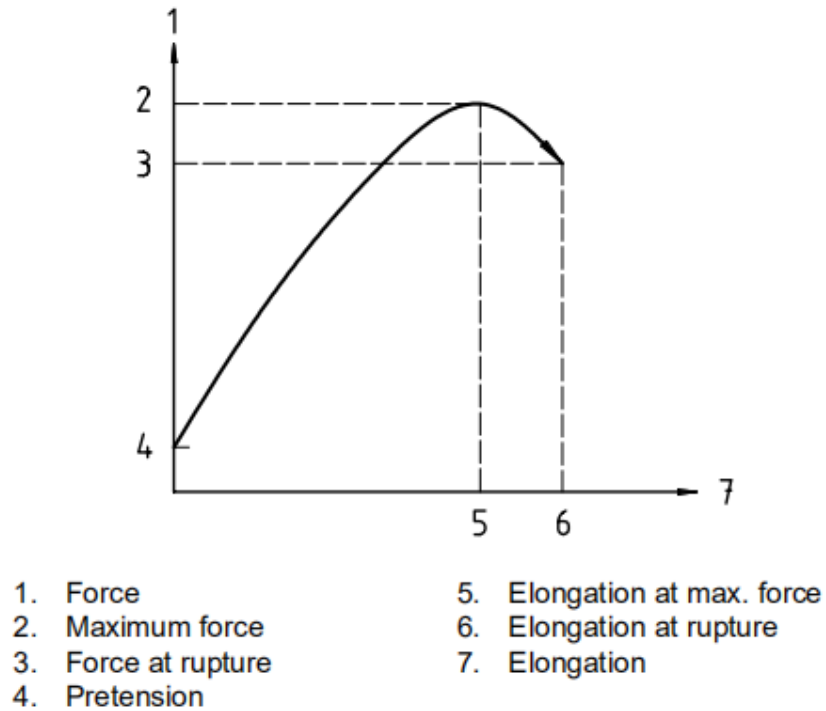


Figure 13: Stress strain curve of a fabric [37]

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 fibre 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.

[2,37]

#### **4.5.1. EN ISO 13934:**

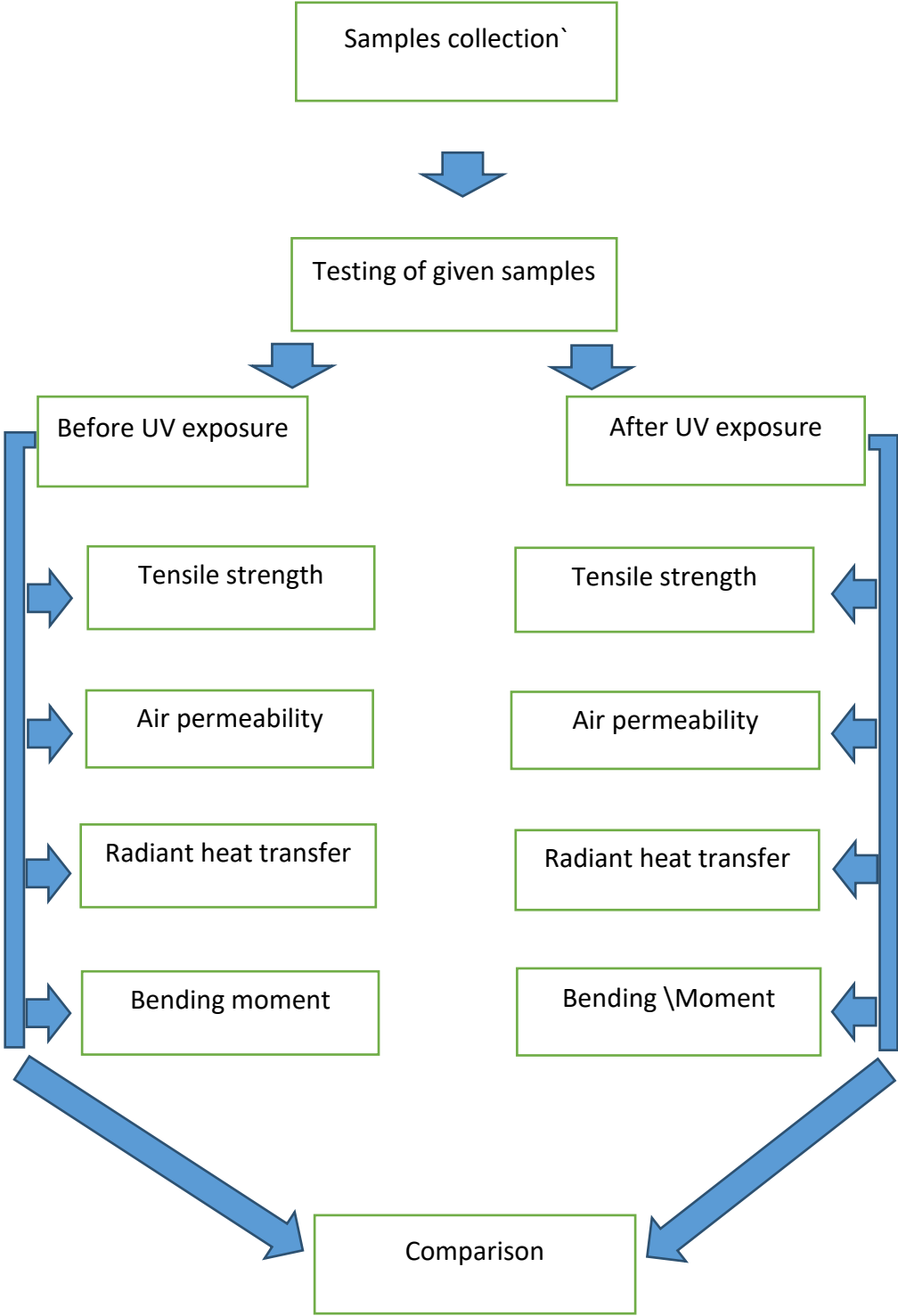
The standard is used to determine the maximum force and the elongation of fabric at maximum force. In this standard the constant rate for extension of fabric is used. This standard is prepared with several test process for the identification of mechanical properties using tensile testing machine. The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

[37]



# CHAPTER V: RESEARCH METHODOLOGY

## 5.1 Test method



## 5.2 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. 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 were determined. 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.

## 5.3 Specification of fabric

**Table 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 anti static	Twill Weave	260
3	Moisture brier	MB	Face fabric, 50% kermel 50% viscose FR, PTFE membrane	Non-woven	120
4	Thermal barrier	TB	Thermo: Para Aramid Inner futter: 50% Meta aramid, 50% viscose.	Non-woven	200

## 5.4 Tensile strength test

After and before UV exposure, the tensile strength of the outer layer firefighter protective fabric was measured using an 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. [37]

### 5.4.1 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 decrease 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. The tensile strength of fabric. From the experiment we get to know that the longer the exposure the decrease in tensile value increases. [2 ,37]

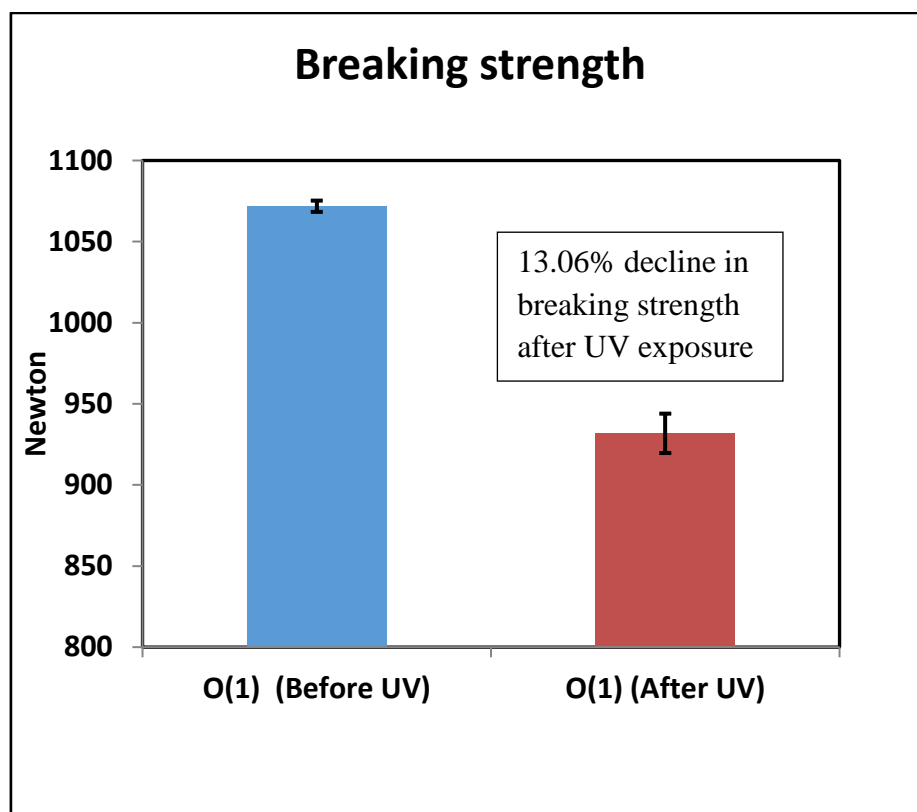


Figure 14: Breaking strength of firefighter specimen

The fabric was done tensile strength test before exposure and was able to bear load as high as 1075N which is its ultimate tensile strength and then the one sample of fabric breaks at 975N, which is its breaking stress or force during its break. In the figure above is shown the average strength of fabric before exposure.

The test which is performed after the UV exposure the tensile strength is decreased after the test and the one of the samples of the fabric can bear the load maximum capacity of 925N and starts to break at 725N the fabric has breaking stress or force during its break. In the figure above is shown the average strength of fabric after exposure.

In this experiment the tensile strength of the firefighter protective fabric was experimented, where we found that the 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 fulfill the minimum requirements of standards for firefighter clothing. All the samples of the nomex loose its tensile properties. There is seen the decline of 13.06% in the tensile strength of nomex after UV 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 loose the tensile strength.

## **5.5 Transmission of Radiant Heat**

The experiments of thermal protective performance of 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 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 Q<sub>o</sub>) is the percentage heat transmission factor. The sample is exposed on 40kw/m<sup>2</sup> 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, Q<sub>c</sub> and percentage

heat transmission factor (% TF Q<sub>o</sub>).

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)  $Q_c$  [ kW/m<sup>2</sup>] – heat flux density transmitted through sample exposed to heat radiation,
2. Heat Transmission Factor (HTF) %age TF Q<sub>o</sub>- 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/m<sup>2</sup>.

**Table 2: Result by heat transmission machine.**

Sr	Name of material	transmission factor (Q <sub>o</sub> ) [kW/m <sup>2</sup> ]		RHTI12 [sec]	RHTI24 [sec]	RHTI24 – RHTI12 [sec]	transmitted heat flux density(Q <sub>c</sub> ) [kW/m <sup>2</sup> ]	Percentage TF Q <sub>o</sub>
1	A	40	Before UV	17.4	24.31	6.9	9.71	24
1	A	40	After UV	17.0	23.6	6.6	<b>10.089</b>	<b>25</b>
2	B	40	UV	16.3	19.9	3.6	<b>18.48</b>	<b>46.2</b>

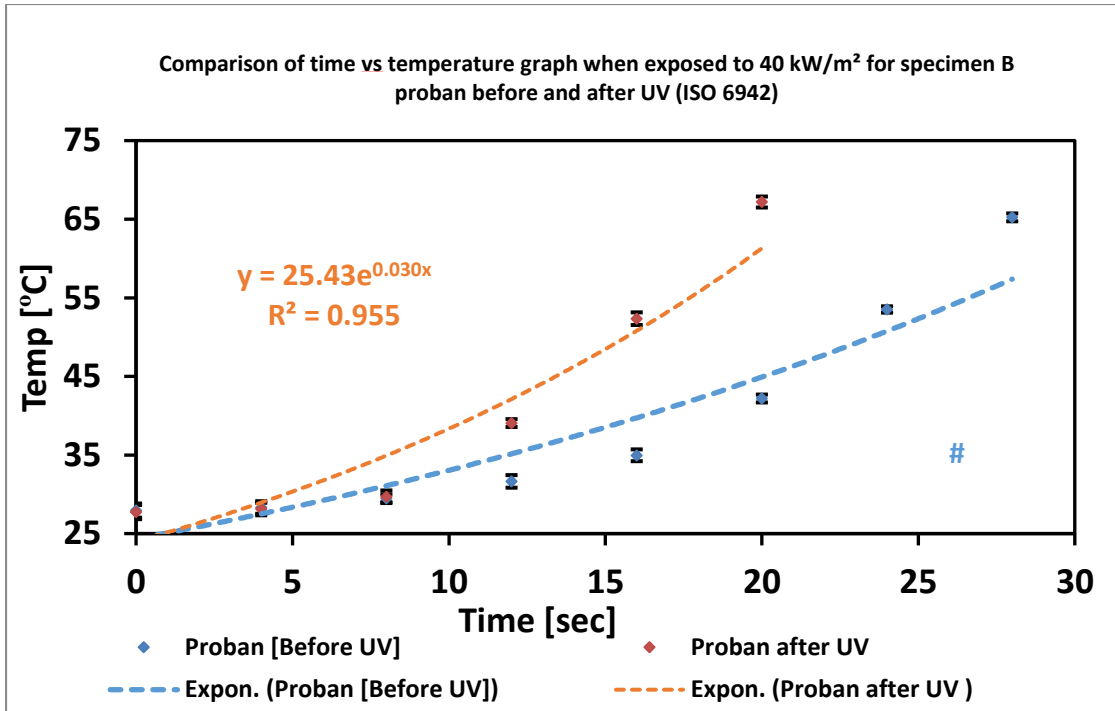


Figure 15: Comparison time vs temperature

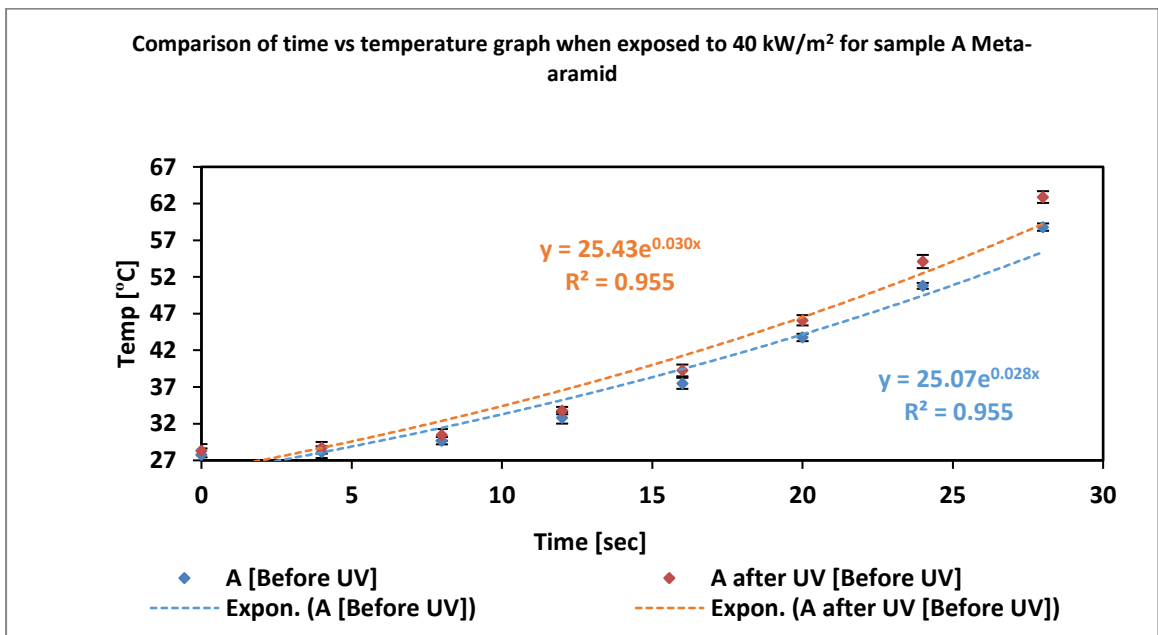


Figure 16: Comparison time vs temperature

In the graph 4 and 5 it shows the result of Proban and nomex 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 result of performed test is the average value of the three measurement we performed.

The study of percentage transmission factor ( $\% TF Q_0$ ) and transmitted heat flux density  $Q_c$  that least values of transmitted flux density  $Q_c$  ( $kW/m^2$ ) were examined for the given sample.

If the value of transmitted heat flux density is lower, less amount of heat is transmitted through the fabric. It provides more time for wearer to perform their work more conveniently and safely without no more injuries and better will be thermal protective performance.

The difference between RHTI 12 and RHTI 24, the value of transmitted flux density  $Q_c$  [ $kW/m^2$ ] 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.

With the experiment, we can analyse that the curves of proban and meta aramid before UV exposure is flatter than the curve of proban and meta aramid after the UV exposure. The curve is flat, which means that the temperature rises of sample takes place in slow rate. Flat curve means there is less damage in the fabric.

If the curve is steeper it means that the rate of rises in temperature speed is high with the time. And also result the faster transmission of heat exchange.

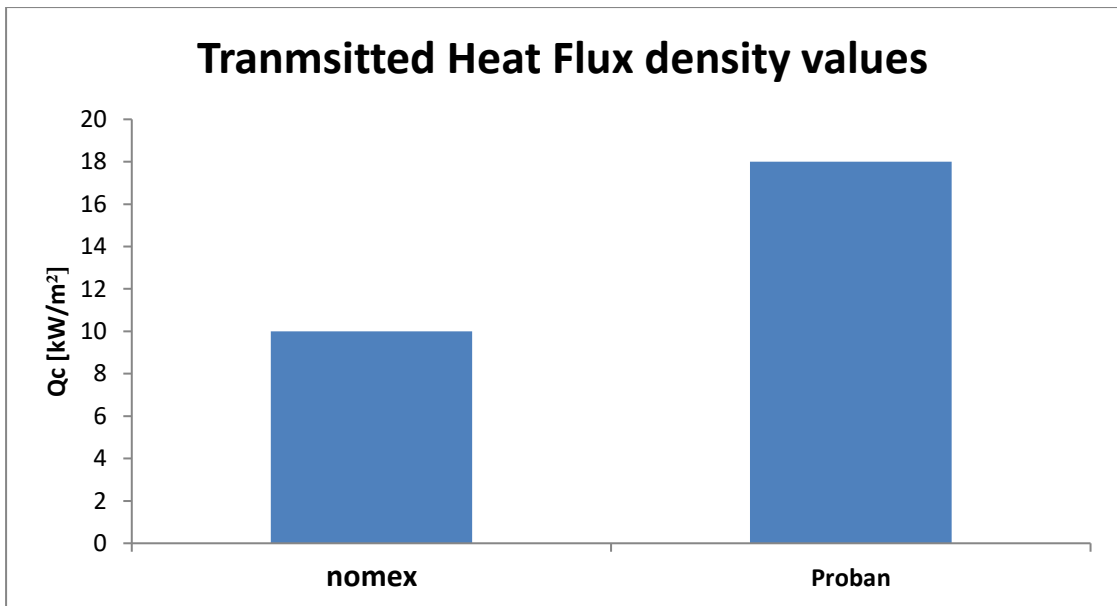


Figure 17: Showing transmitted heat flux density.

In the given figure the value of transmitted heat flux density of araid 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.

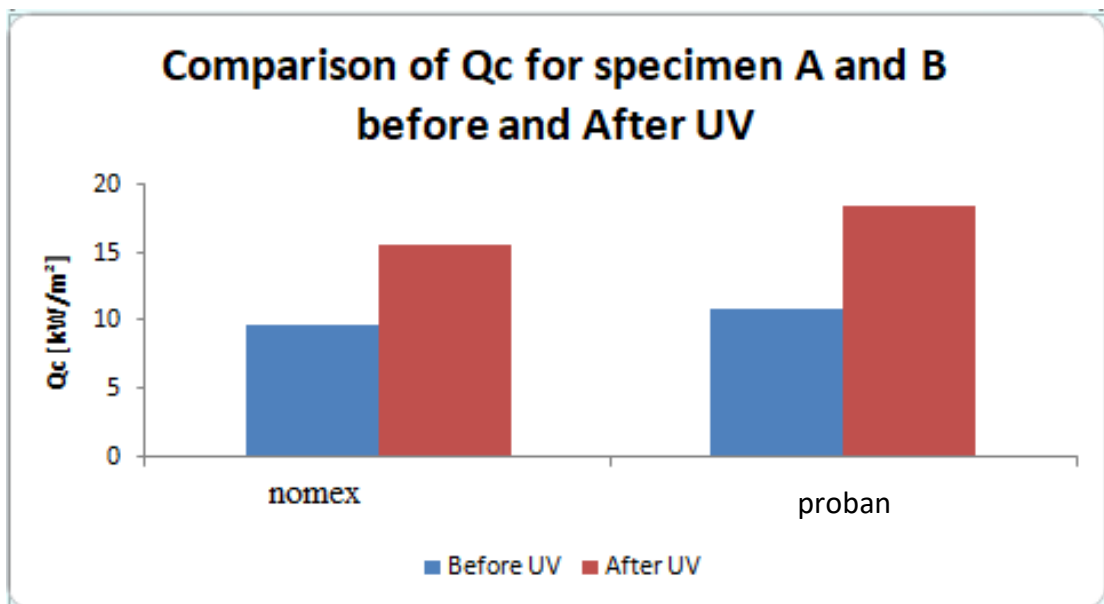


Figure 18: Qc comparison for nomex and proban after UV.

In the given graph the value of transmitted heat flux density 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 transmitted heat flux density of nomex is lower before UV and it increases after the UV. Which means the protective performance rate of nomex and proban will decrease after exposure. Both fabric fails to meet the minimum requirements as protective clothing after the exposure.

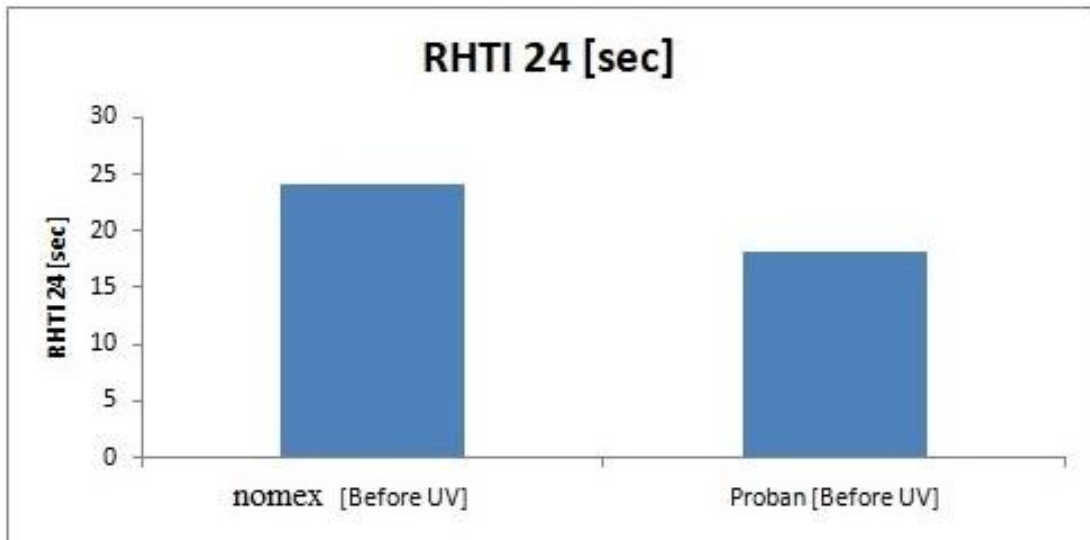


Figure 19: Showing RHTI 24 before exposure

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.

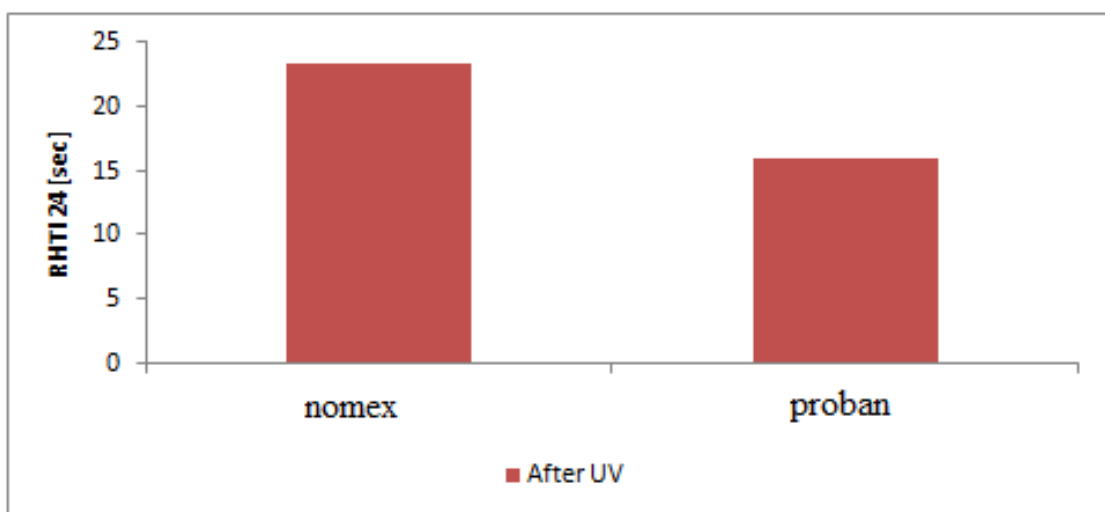


Figure 20: Showing the RHTI 24 after exposure

After the UV the time to rise for RHTI24 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 fabric. The raise in temperature in short time brings damage in the clothing cannot meet minimum standards for protective clothing.

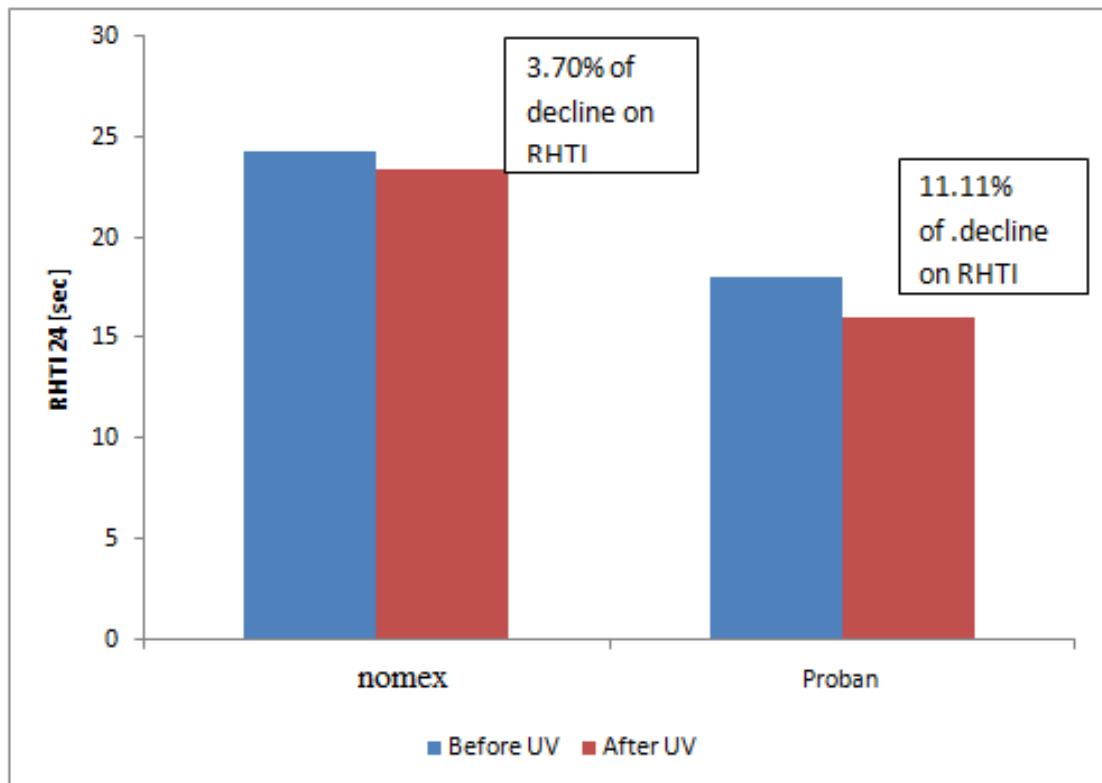


Figure 21: Comparison between the nomex and proban for RHTI 24

In the graph the comparison of RHTI 24 is shown. The RHTI 24 value of both fabric decreases after the exposure in UV. The RHTI of nomex 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 fabric declines in terms of RHTI. Which means the both fabric cannot meet the minimum requirements after as protective clothing after the exposure.

## 5.6 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.

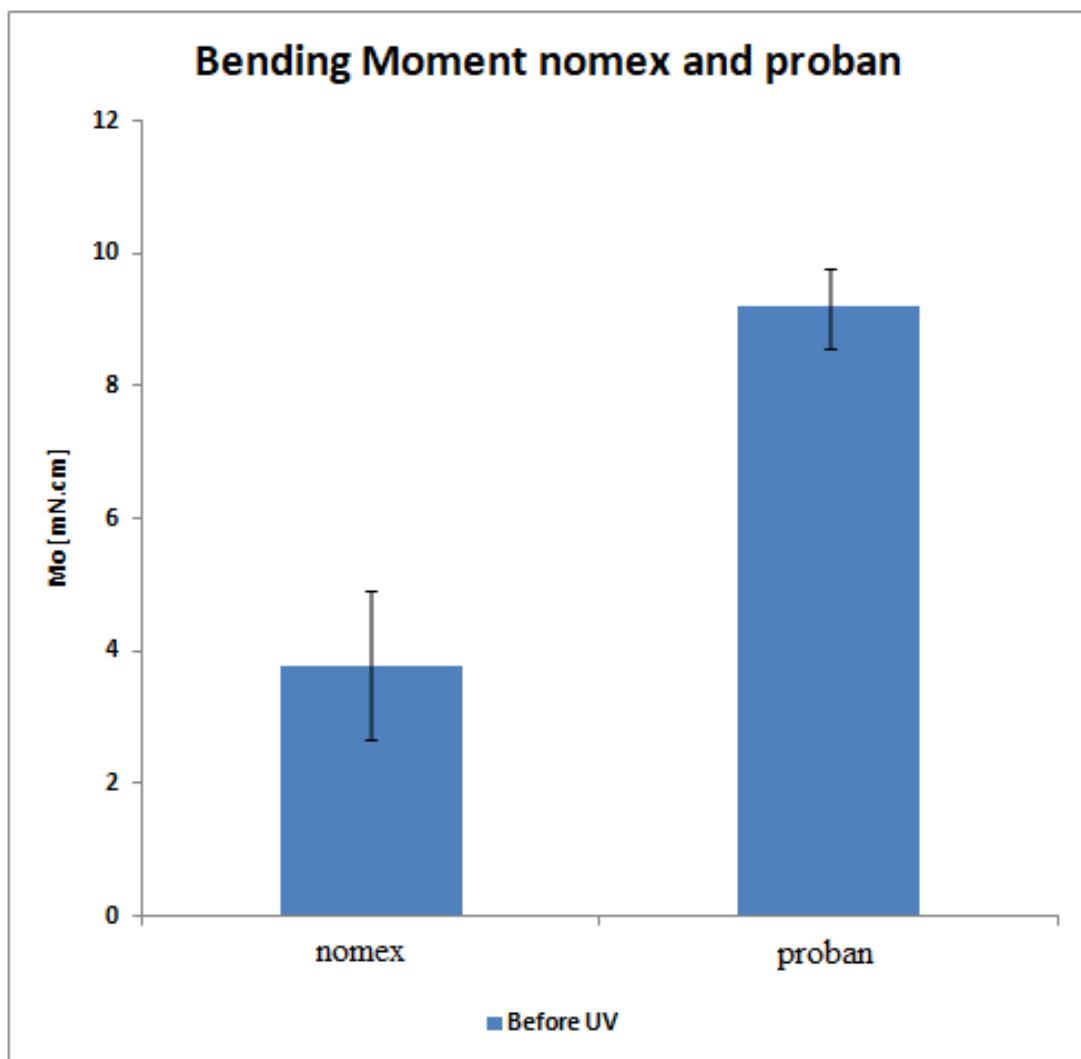


Figure 22: Showing the bending property of nomex and proban before UV

Before the UV exposure the nomex and bending value for both nomex and proban was 3.78Nm and 9.17Nm. 3.78 and 9.78Nm are the force that is required to bend the given sample by 60 degree. Before the UV exposure the fabric shows the normal bending moment.

## Bending Moment for nomex and proban

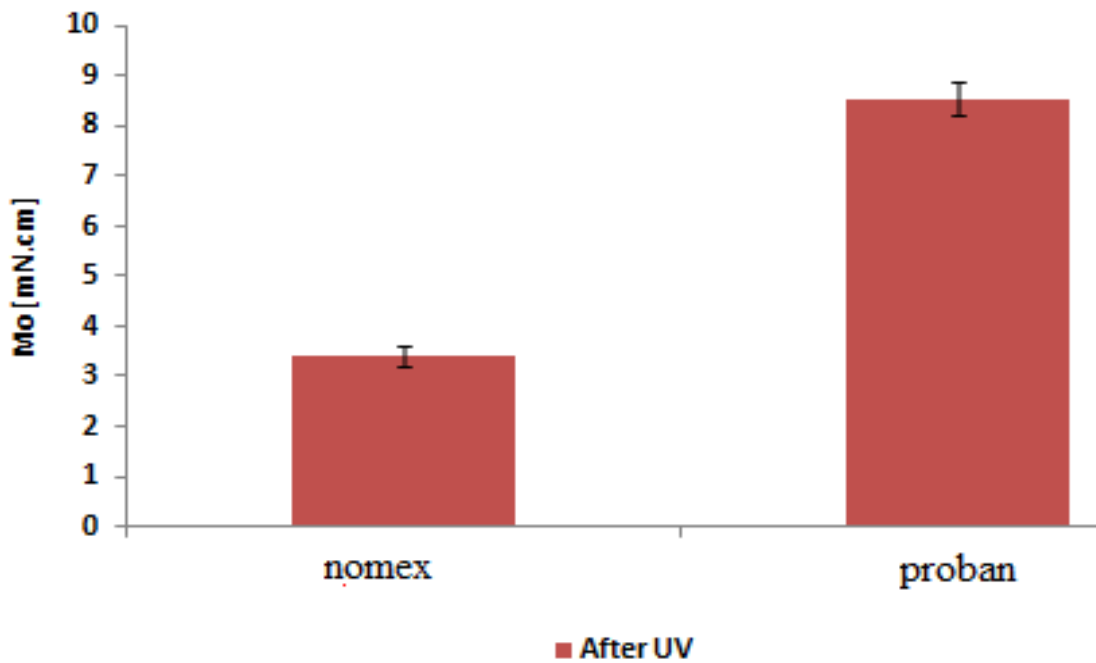


Figure 23: Bending property of nomex and proban after UV.

The bending property of nomex and proban after the UV exposure declines. The less force also can bend the given sample by 60 degree. The force is decreased to 3.41m.N and 8.54m.N for both nomex and proban.

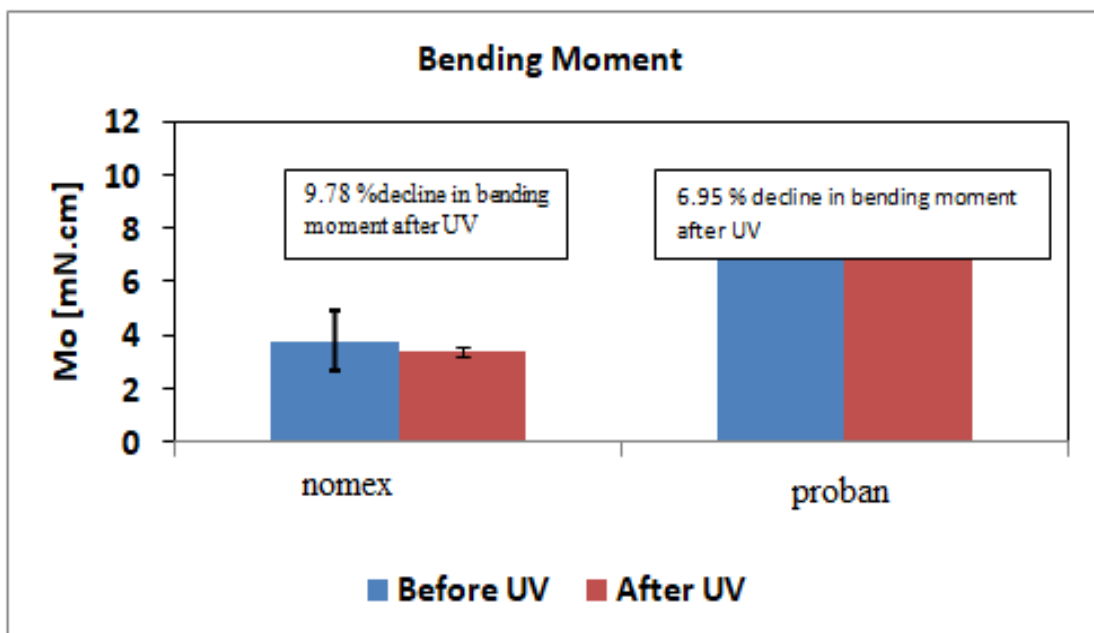


Figure 24: comparison of bending moment.

In the graph the comparison of bending moment properties between nomex and proban is shown. Before the 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 mN.cm force to bend it by 60 degree. After the UV there was less bending moment force applied to the fabric. Which 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 9.17m.N 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 8.54m.N. It shows there is the decline of 6.95% in bending moment of proban fabric.

### **5.7 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. The experiments 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 cm<sup>2</sup> (l/m<sup>2</sup>/s). Ten readings were done before and after the U.V degradation.

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. From the rate of air flow the air permeability is determined. 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 have 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 condition, i.e before and after UV exposure.

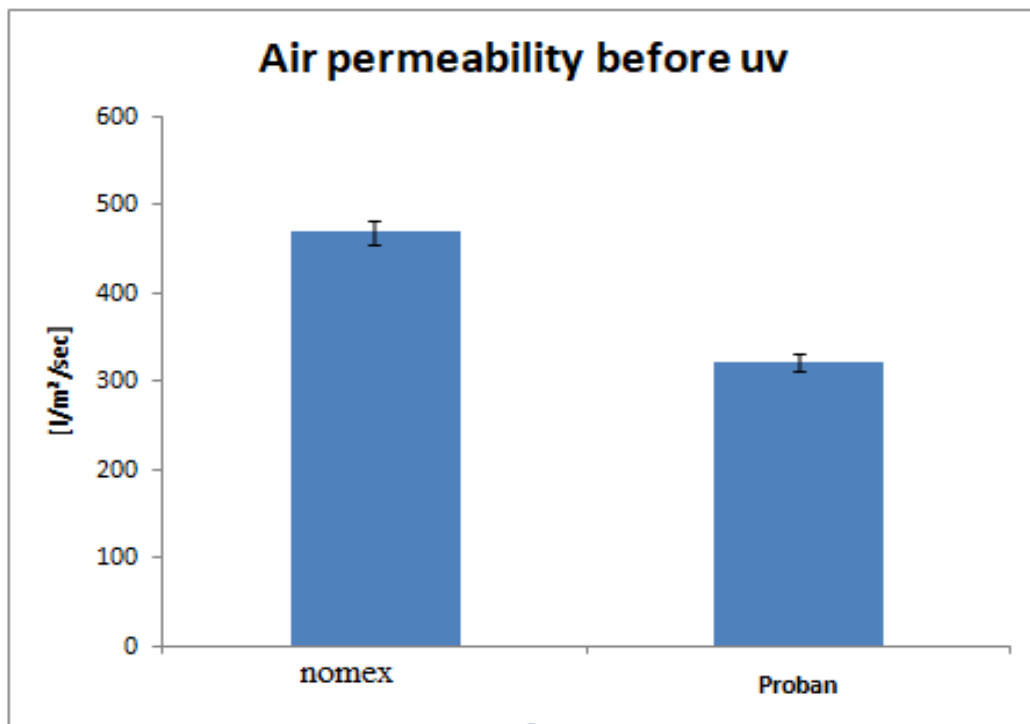


Figure 25: Air permeability before UV

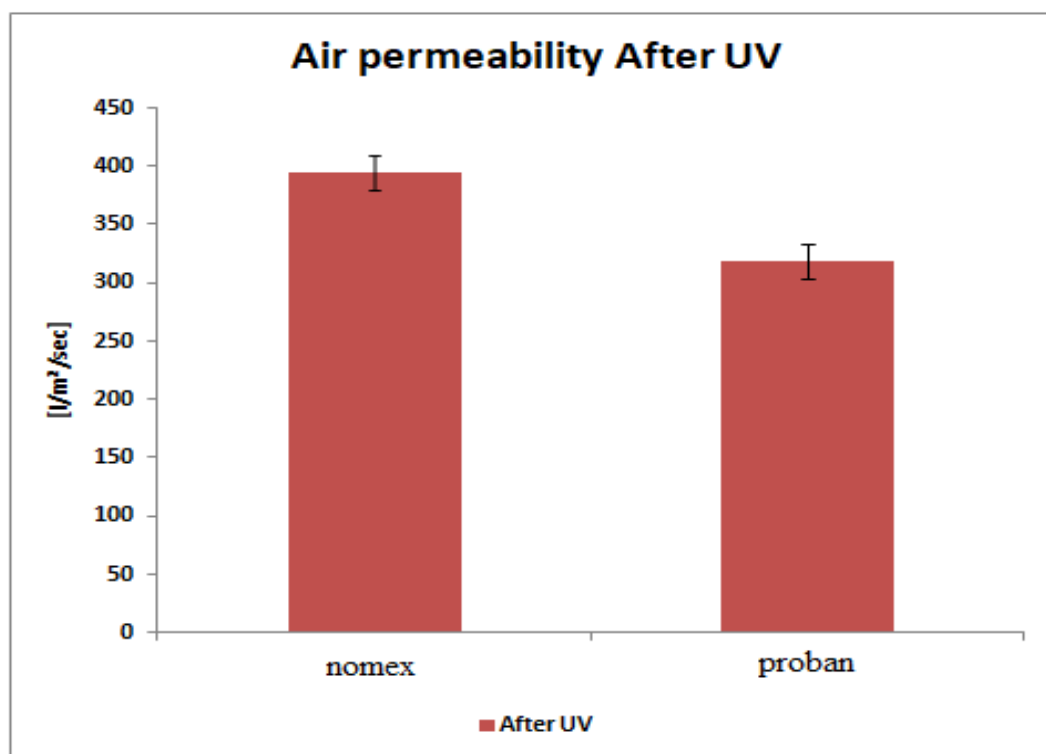


Figure 26: Air permeability after UV exposure.

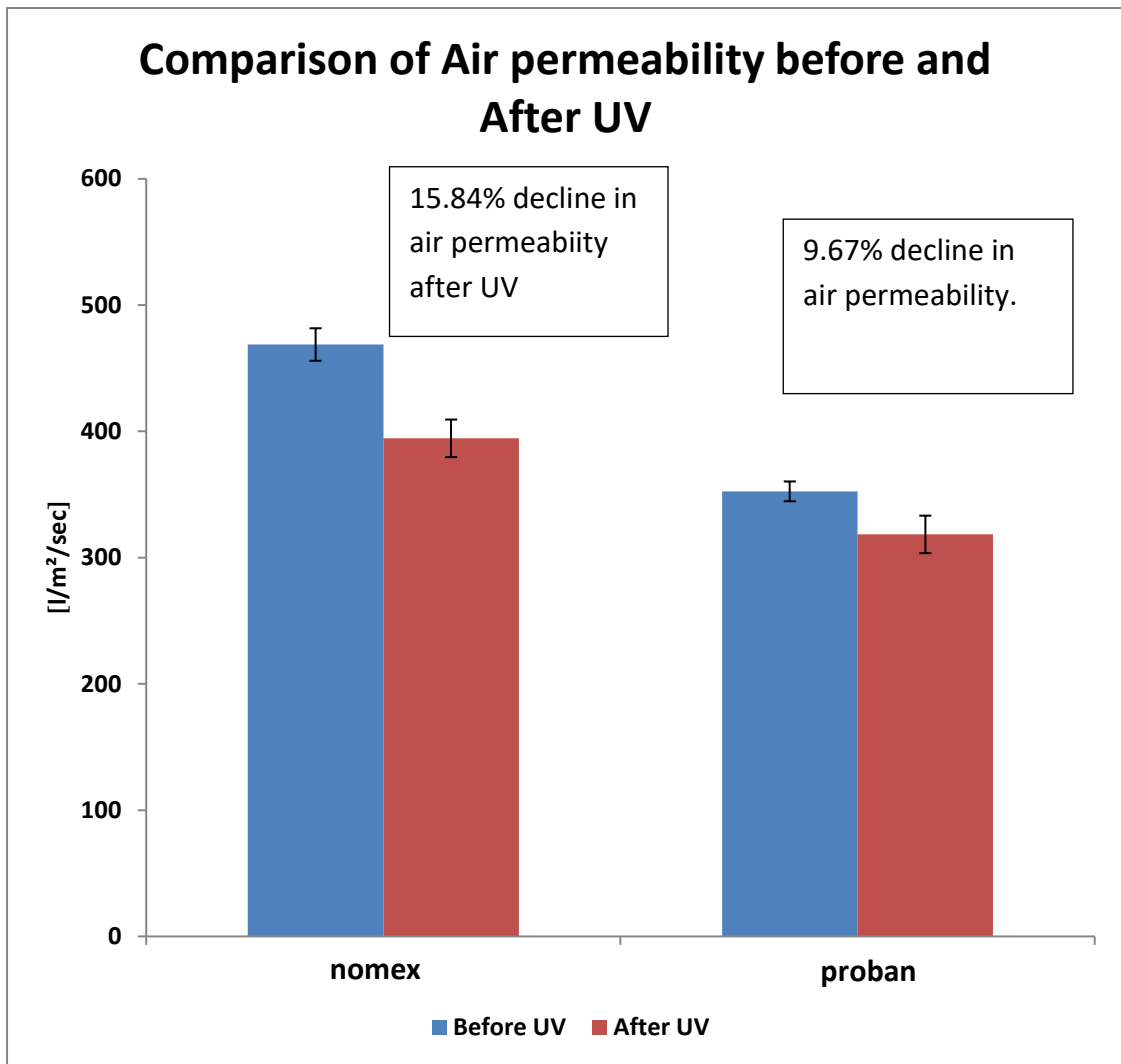


Figure 27: Comparison of air permeability before and after UV

After the exposure there is on the given sample the permeability of the air is declined and with the decline in the permeability of air it allows. In the graph the air permeability of fabrics decreases. The air permeability goes higher in short period of time which is not good for firefighter protective clothing.

## **RESULT AND DISCUSSION**

The UV was performed in the outer layer of the firefighter fabric and was performed in the two fabric types Nomex, which contain meta aramid and is inherent flame resistance and the other is Proban, which is the flame resistance coating specially in cotton fabric. The testing specimen was performed before and after exposure to UV. 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 proban and the bending moment of nomex was also better in both case before and after exposure. The tensile strength and thermal barrier of nomex was better than the proban in both before and after UV exposure. If the time for exposure 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.

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 decrease 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.



## **CONCLUSION**

Firefighting is the job that could have exposure to many types of thermal and other hazards while performing the task. In this job the amount of heat and mass transfer may rise from the source or hazards to the firefighter's 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 injury is effected by the protective performance of the firefighter protective clothing. Even though there are various surroundings factors such as wind speed, temperature humidity and more to effect the aging and protective performance of firefighter clothing, but the research provided us the broad study of ultra violet weathering of firefighter clothing. The main purpose of this research was to compare between the protective performance of outer layer of two different firefighter fabric nomex and proban. The result from the research tells us that the protective performance of nomex is better in comparison to proban.

## **FUTURE WORK**

- i. Evaluation of breaking strength of proban before and after UV exposure can be done.
- ii. To find out the water vapour permeability of Aramid and Proban respectively can be the study for future for fire fighter protective clothing.
- iii. Future experiment is can be carried out on the stitched fabric of fire fighter clothing.
- iv. Experiment can be done for the performance of the stitching thread used in firefighter protective clothing.
- v. Experiment can be performed in various wavelength and various temperature of of UV exposure.

## REFERENCES

- [1] U.S. Firefighter Injuries on the Fireground, Fire Technology- 2010–2014
- [2] Predicting tensile strength of fabrics used in firefighters' protective clothing after multiple radiation exposures. The Journal of The Textile Institute, 2018-Yehu Lua,b,c, Lijun Wangb and Qiang Gaoc
- [3] Richard Campbell\*, National Fire Protection Association, Quincy, MA, USA
- [4] BBC NEWS: Accessed on 20<sup>th</sup> july 2020 <https://www.bbc.com/news/world-australia-50384950>
- [5] Honeywell international inc. Accessed on 10<sup>th</sup> july 2020 [https://www.honeywellsafety.com/Products/Protective\\_Clothing/Outer\\_Shells.aspx?site=/asia#](https://www.honeywellsafety.com/Products/Protective_Clothing/Outer_Shells.aspx?site=/asia#)
- [6] NIST Technical Note 1746 Accelerated Weathering of Firefighter Protective Clothing: Delineating the Impact of Thermal, Moisture, and Ultraviolet Light Exposures- Shonali Nazaré Rick D. Davis Jyun-Siang Peng, Joannie Chin. Accessed on 20<sup>th</sup> july 2020 <https://doi.org/10.1080/00405000.2017.1345603>
- [7] Canadian firefighter- **Fire dynamics** June 14, 2018 By Lance Bushie
- [8] Accelerated weathering of polyaramid and polybenzimidazole firefighter protective clothing fabrics- Rick Davis , Joannie Chin , Chiao-Chi Lin, Sylvain Petit. Accessed on 20<sup>th</sup> july 2020 [www.elsevier.com/locate/apthermeng](http://www.elsevier.com/locate/apthermeng)
- [9] Guidelines for the specification of a PCM layer in firefighting protective clothing ensembles- A. Fonseca, T.S. Mayor, J.B.L.M. Campos
- [11] EFFECT OF CLIMATIC FACTORS ON THE RESULTS OF BENCH FIELD TESTS OF FABRIC WEATHERING -V. E. Bedenko,\* I. Yu. Tropanikhin, and A. E. Erokhina
- [12] A new approach to predict heat stress and skin burn of firefighter under lowlevel thermal radiation- Jie Yang, Yun Su, Guowen Song, Rui Li, Chunhui Xiang
- [13] Ballycare accessed on 25<sup>th</sup> july 2020 <https://ballyclarelimited.com/xenon-firefighter-suits-structural-firefighting-kit-rescue-suits-i47.html>
- [14] WEATHERING OF SIDE EMITTING POLYMER OPTICAL FIBRES - Funda Büyük Mazari
- [15] Atlas materials testing solutions- guide book

- [16] Generational energy accessed on 25<sup>th</sup> july 2020 <http://www.generationenergy.com/whats-new-solar-film.html>
- [17] Autex Research Journal, Vol. 7, No 1, March 2007 © Autex <http://www.autexrj.org/No1-2007/0192.pdf> 53 UV PROTECTION TEXTILE MATERIALS D. Saravanan Department of Textile Technology Bannari Amman. Institute of Technology. Accessed on 23<sup>rd</sup> july 2020 <https://indiantextilejournal.com/articles/FAdetails.asp?id=2837>
- [18] A new approach to predict heat stress and skin burn of firefighter under lowlevel thermal radiation- Jie Yang, Yun Su, Guowen Song, Rui Li, Chunhui Xiang.
- [19] THERMO-PHYSIOLOGICAL COMFORT CHARACTERISTICS AND BLENDED YARN WOVEN FABRICS- V.Kothari, Deptment of textile technology, IIT Delhi.
- [20] Slideshare accessed on 18<sup>th</sup> july 2020 <https://www.slideshare.net/HimanshuSingh498/fire-retardant-textiles>
- [21] Mustafa Ertekin, in Fiber Technology for Fiber-Reinforced Composites, 2017
- [22] N. Bhatnagar, N. Asija, in Lightweight Ballistic Composites (Second Edition), 2016
- [23] Aramid fibers- an overview-Manjeet jassal, Sourabh Ghosh. IIT Delhi
- [24] DUPOINT NOMEX, NOMEX KNOWLEDGE CENTER accessed on 21<sup>st</sup> july 2020 <https://knowledge.nomex.com/what-is-nomex>
- [25] Recent trends and future scope in the protection and comfort of fire fighters' personal protective clothing- Rajkishor Nayak, sahdi Houshyar, and Rajiv Padhye
- [26] SOLVAY PROBAN accessed on 24<sup>th</sup> july 2020 <https://www.solvay-proban.com/en/frequently-asked-questions-faqs>
- [27] Effect of Chemicals and Binders on the Durability of Flame Retardant Treated Cotton Nonwovens- Hatice Mercimek, University of Tennessee - Knoxville
- [28] Mechanical Properties of Textile Fibers | Mechanical Properties of Textile Materials- Mazharul Islam Kiron) Accessec on 30<sup>th</sup> june 2020 <https://textilelearner.blogspot.com/2011/07/mechanical-properties-of-textile-fibers.html#:~:text=The%20mechanical%20properties%20of%20textile,durability%20of%20the%20textile%20goods.>
- [29] Comparison of thermal performance of firefighter protective clothing at different

- levels of radiant heat flux density. Authors Jawad Naeem, Adnan Ahmed Mazari, Zdenek Kus
- [30] Marina textile accessed on 10<sup>th</sup> July 2020 <https://marinatextil.com/textile-standard/iso-6942-protection-fabric-standard>
- [31] Determination of the permeability of fabrics to air. Accessed on 15<sup>th</sup> July 2020 <https://ipstesting.com/find-a-test/iso-test-methods/iso-9237-air-permeability/>
- [32] Analysis of thermal properties, water vapour resistance and radiant heat transmission through different combinations of firefighter protective clothing. Jawaad Naeem, Adnan Ahmed Mazari, Engin Akcagun, Antonin Havelka.
- [33] EFFECT OF AIR PERMEABILITY ON GRAINLINES, AGED, WASHED AND MOISTED WOVEN FABRIC Frederick Fung , Antonin Havelka Technical University of Liberec – Faculty of Textile Engineering, Department of Clothing,
- [34] Laboratory and accelerated weathering spectra compared to sunlight through automotive glass - Patrick J. Brennan
- [35] Comparative study of radiant heat flux density transmission through firefighter protective clothing- Jawad Naeem, Adnan Mazari, Zdenek Kus, Pavel Kejzlar.
- [36] Clothing Biosensory Engineering(2006)- J.Y.Hu, Y.I.Li, K.W. Yeung.
- [37] International standards ISO13934- textile tensile properties of fabrics- determination of maximum force and elongation at maximum force using the strip method.
- [38] Impact of UV radiation on the physical properties of polypropylene floating row covers.
- [39] An analysis on the moisture and thermal protective performance of firefighter clothing based on different layer combinations and effect of washing on heat protection and vapour transfer performance. - Ozguar Atalay, Senem Kurun Bahadir, and Fatima Kalaoglu., Istanbul technical university.

## APPENDIX

### APPENDIX 1: AIR PERMEABILITY OF PROBAN

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

APPENDIX 2: AIR PERMEABILITY OF NOMEX

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

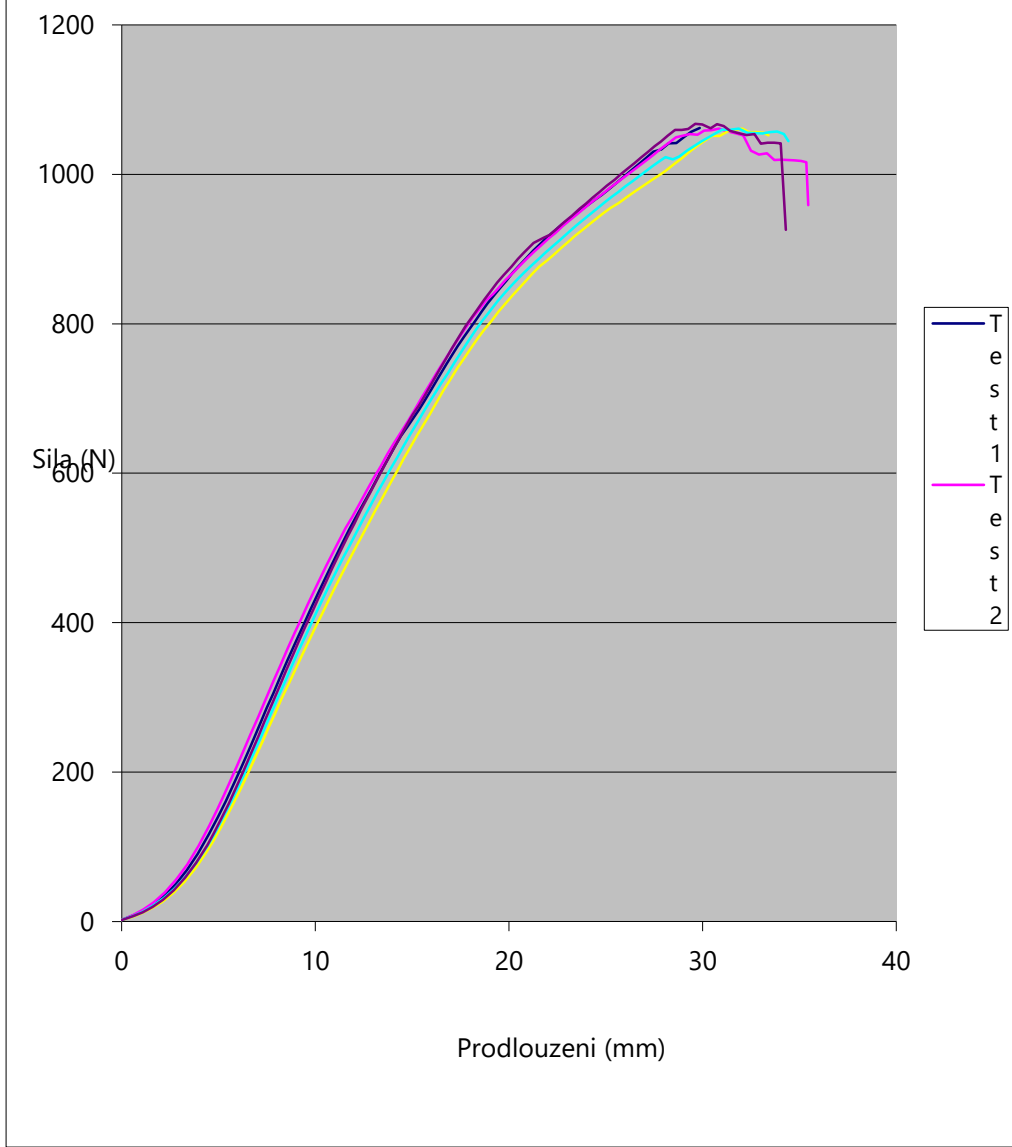
Poznamky :

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)



#### 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**

**Sírka : 100,000 mm**

**Tloustka : 0,810 mm**

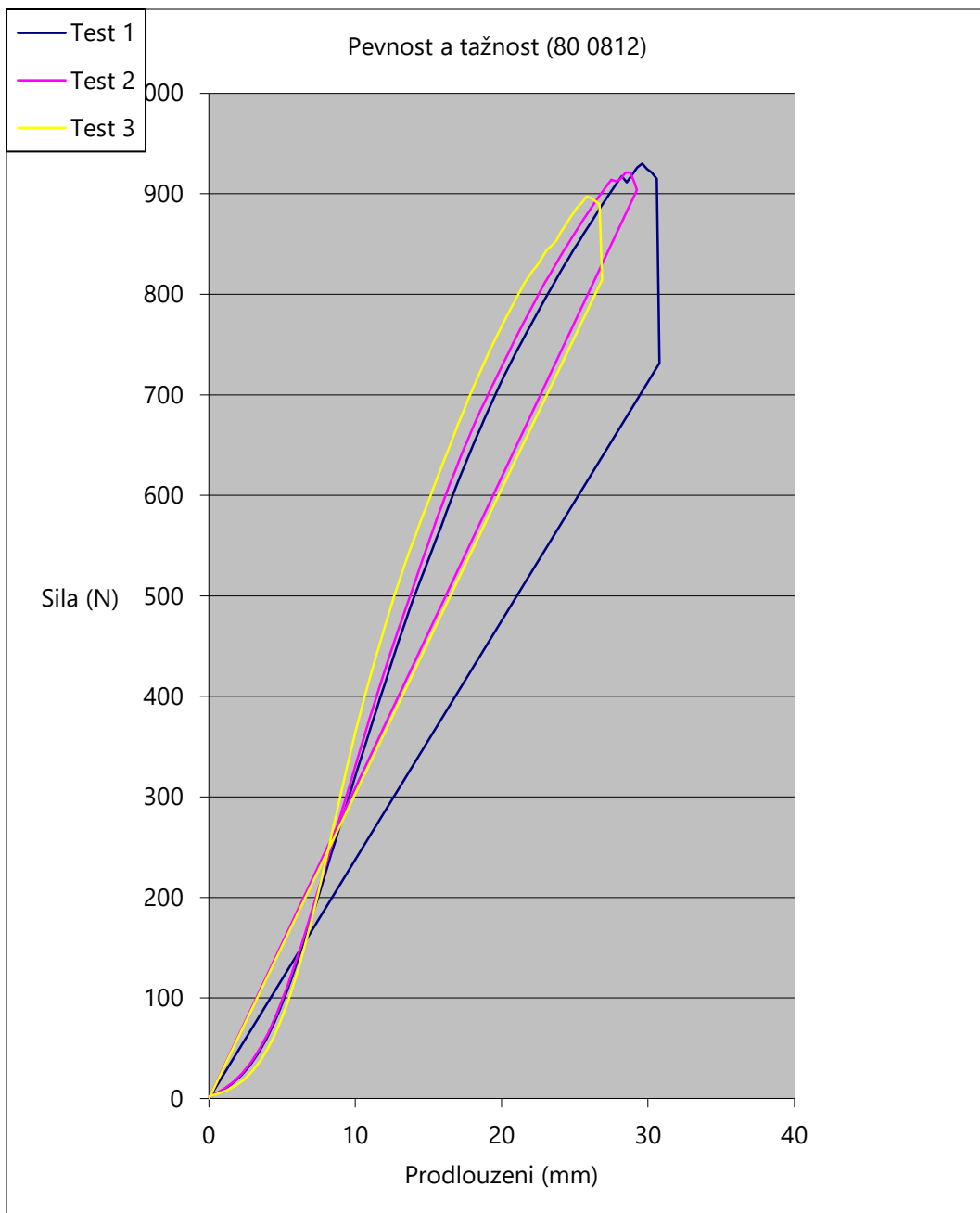
**Delka vzorku : 150,000 mm**

Poznamky :

**Zkouska Nejvyssi Prodlouzen Taznost**

<b>c.</b>	<b>pevnost (N)</b>	<b>i pri neyv. Pevnosti (mm)</b>	<b>pri nejvyssi pevnosti (%)</b>
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



#### **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  $Q_0$ : 40.100 kW/m<sup>2</sup>

Mass  $M$ : 0.036 kg

Specific heat  $c_p$ : 0.38500 kJ/kgK

Area  $A$ : 0.002500 m<sup>2</sup>

Absorption coefficient  $\alpha$ : 0.90

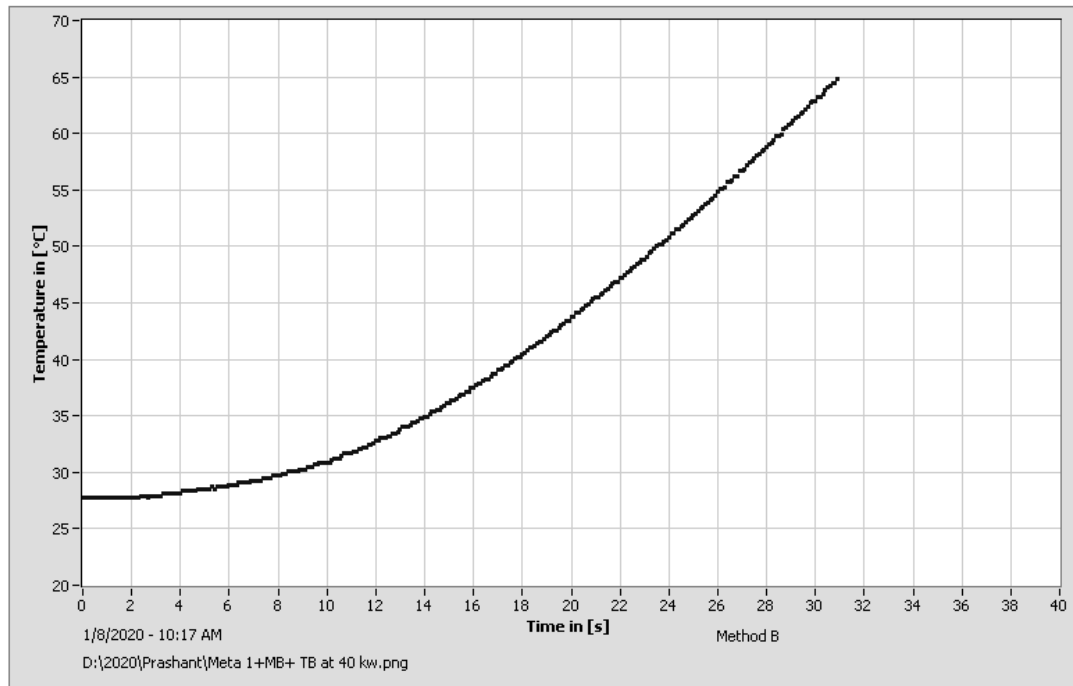
Distance  $d$ : 16.9 cm

		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

		<b>t12: 17.2 s</b>	<b>t12: 17.6 s</b>	<b>t12: 16.9 s</b>	<b>t12: 16.8 s</b>
		<b>t24: 24.0 s</b>	<b>t24: 24.5 s</b>	<b>t24: 23.3 s</b>	<b>t24: 23.2 s</b>
	<b>Results</b>	<b>Qc: 9.784 kW/m2</b>	<b>Qc: 9.642 kW/m2</b>	<b>Qc: 10.395 kW/m2</b>	<b>Qc: 10.395 kW/m2</b>
		<b>TF: 0.244</b>	<b>TF: 0.240</b>	<b>TF: 0.260</b>	<b>TF: 0.260</b>

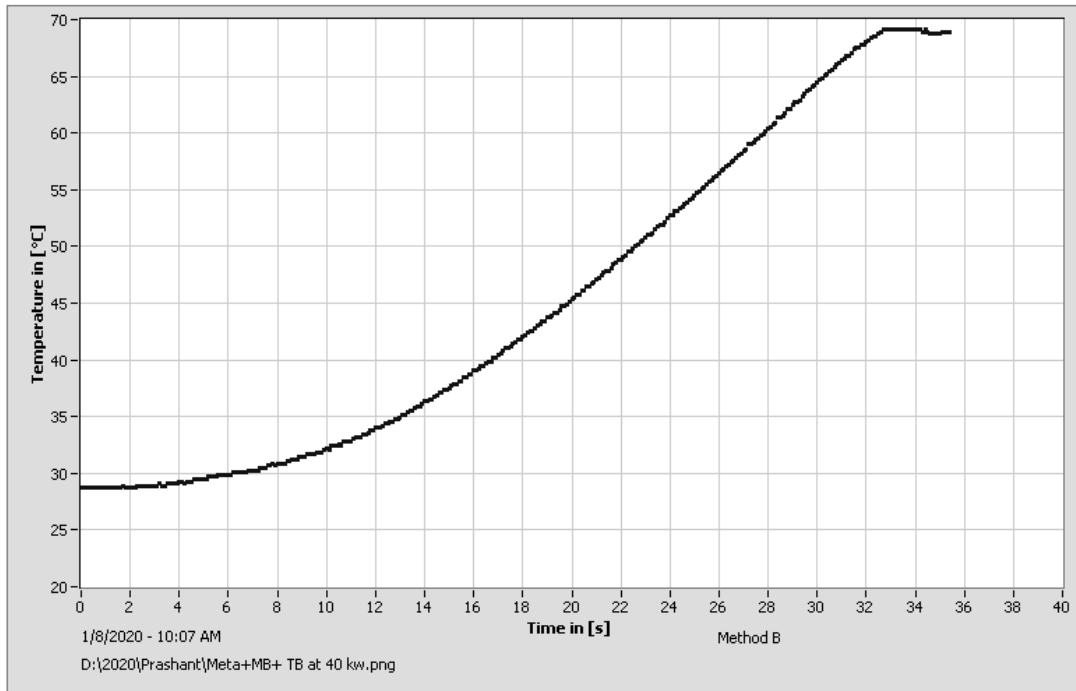
Meta aramid before UV

Meta1



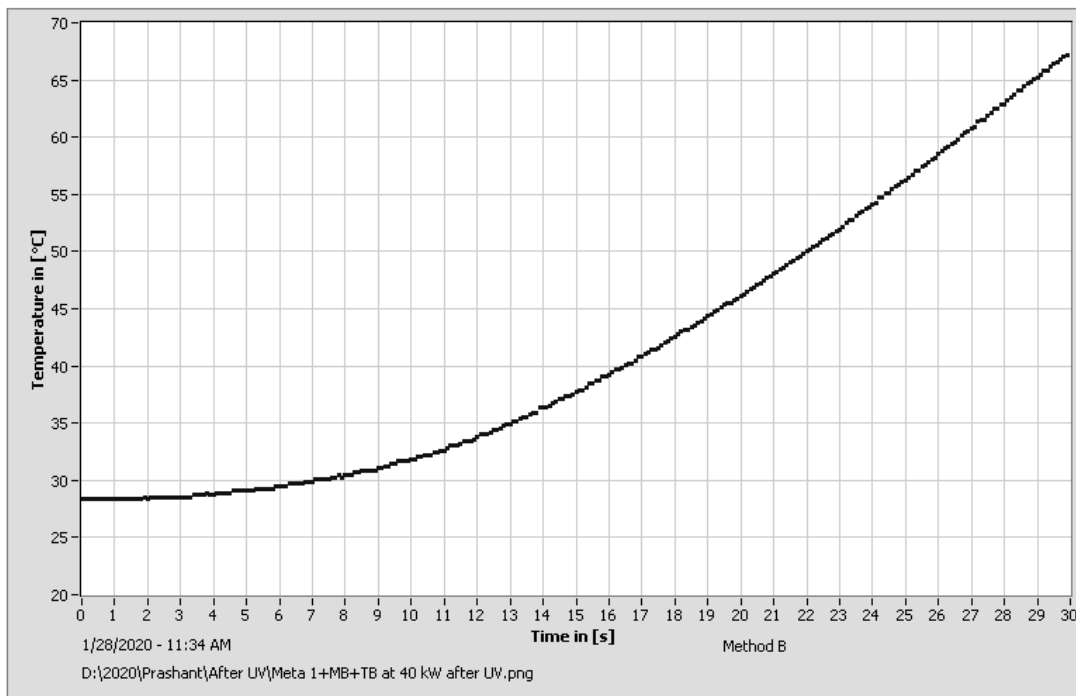
Meta



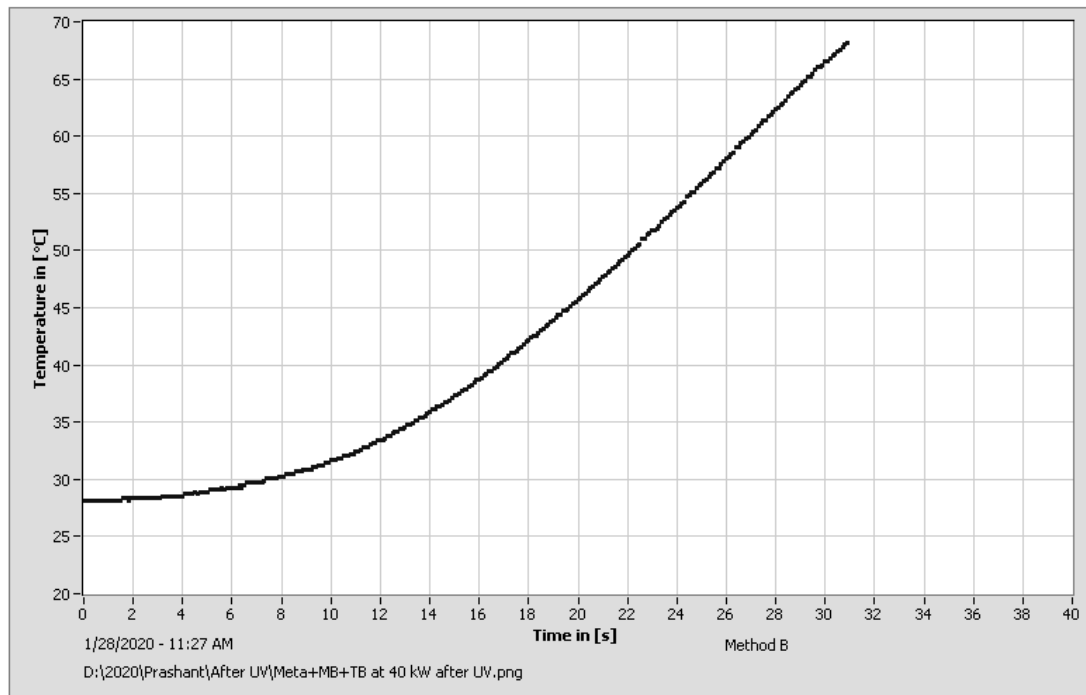


Meta aramid after UV

Meta1



Meta



## APPENDIX 8: TRANSMISSION OF RADIANT HEAT FOR PROBAN

After UV

Mode: Method B

System parameters

Heat flux  $Q_0$ : 40.100 kW/m<sup>2</sup>

Mass  $M$ : 0.036 kg

Specific heat  $c_p$ : 0.38500 kJ/kgK

Area  $A$ : 0.002500 m<sup>2</sup>

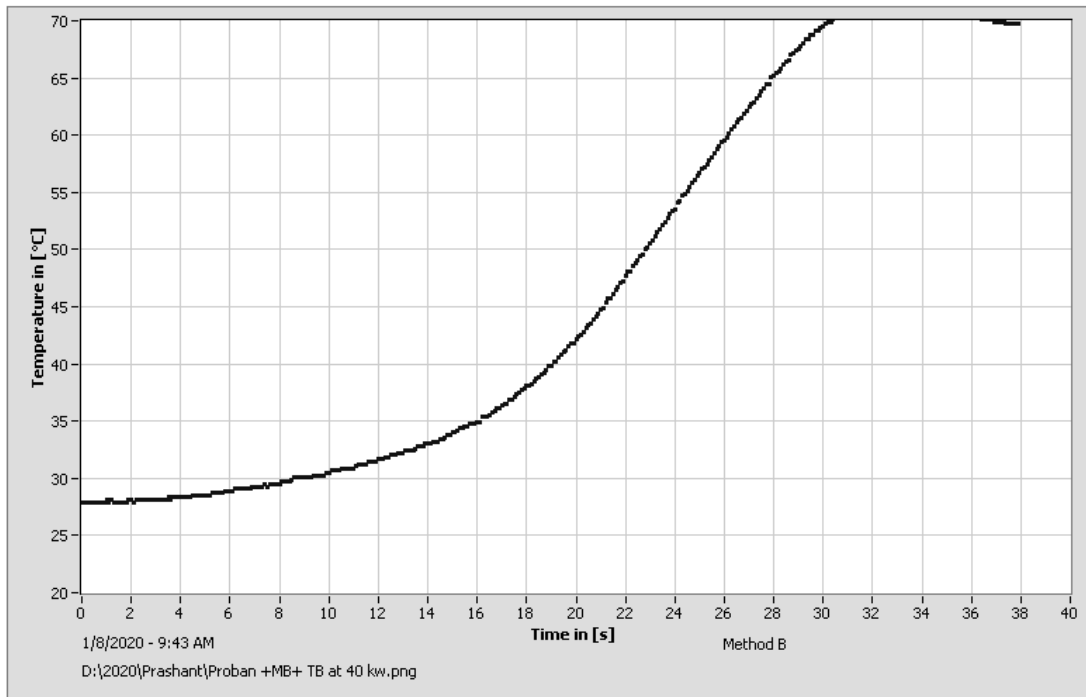
Absorption coefficient  $\alpha$ : 0.90

Distance  $d$ : 16.9 cm

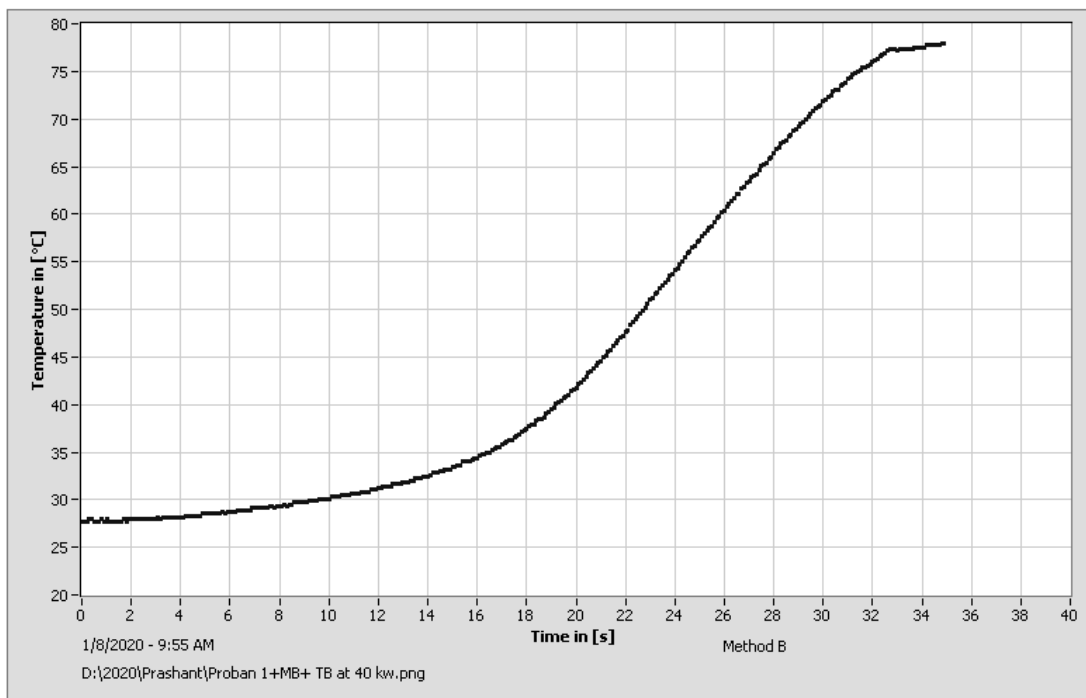
		Proban before UV		Proban after UV	
SR.N	Time [sec]	Proban	Proban1	Proban	Proban1
1	0	27.92	27.73	27.92	27.73
2	5	28.51	28.51	28.51	28.51
3	10	30.46	30.07	30.66	30.66
4	15	33.98	33.39	35.54	36.71
5	20	42.18	41.79	49.60	52.34
6	25	56.64	57.22		
	<b>Results</b>	<b>t12: 19.1 s</b> <b>t24: 23.5 s</b> <b>Qc: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

Graph: proban before UV

Proban

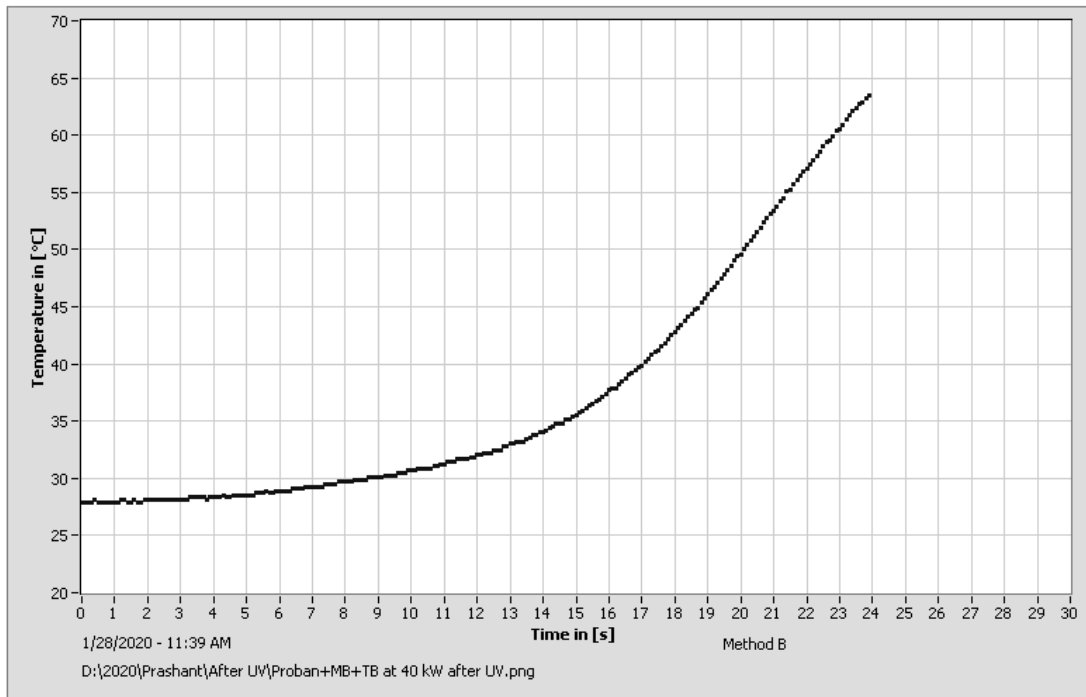


Proban1



Graph: proban after UV

Proban



Proban1

