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Analysis and Development of User-Friendly Firefighters Protective Clothing

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***Abstract*: Firefighters' protective clothing is a critical component of their personal protective equipment (PPE), designed to shield them from extreme heat, flames, hazardous materials, and other dangers encountered in emergency situations. However, the effectiveness of this protective gear is often limited by issues related to comfort, mobility, and usability, which can impair firefighters' performance and increase the risk of injury. This study aims to analyze and develop user-friendly protective clothing that enhances safety without compromising on comfort or functionality. The research involves a comprehensive assessment of the current protective clothing, identifying key areas where improvements are needed. These include thermal protection, breathability, weight distribution, ergonomic design, and the integration of advanced materials that provide enhanced protection while being lightweight and flexible. Additionally, the study considers the feedback from active firefighters to ensure that the proposed design modifications meet the practical needs of the end-users. Innovative materials such as phase-change materials (PCMs), fire-resistant fabrics, and advanced composites are explored to improve thermal management and overall wearability. The development process also incorporates advanced manufacturing techniques, such as 3D body scanning and computer-aided design (CAD), to create garments tailored to individual firefighters' body shapes, ensuring a better fit and increased comfort. The expected outcome is a prototype of firefighters' protective clothing that offers improved protection, comfort, and usability. This study not only aims to enhance the safety and efficiency of firefighters during emergency operations but also contributes to the broader field of protective clothing by setting new standards for the design and development of PPE.**

***Keywords*: firefighters protective clothing, user-friendly protective clothing, phase-change materials (PCMs), PPE.**

1. Introduction

The goal of firefighting and rescue work is to get the emergency situation under control as soon as possible and to minimize the eventual human and material losses worldwide. There are many thousands of organizations across the world involved in firefighting activities with millions of firefighters trained and equipped for this goal. The tasks performed by firefighters have become diverse. Their work on fire includes structural firefighting aircraft fires and other vehicle fires, wildland fire fighting another number of other types of fires. Firefighting is a dangerous profession that requires specialized equipment to effectively and safely mitigate a fire emergency so firefighters must wear heavy protective clothing and then the suit should be comfortable and easier off donning and doffing. Firefighter suit was first invented by Zachary Hansen in the 1600 600 early firefighter suits were made up of leather. Later in early 2000, protective clothing was invented. Fireman protective apparel is designed to protect a human's body against dangerous and harmful effects emerging during extinguishing a fire and liquidation of emergency cases, as well as during the execution of the related salvage operations. Design of the fireman suit, the materials, and accessories used to make a barrier to penetration of water and aggressive substances into the inner layers. The suit protects from climatic and heat influences, against high temperatures, possible flame outbursts, and contacts with hot surfaces, and allows rescuers to perform all kinds of activities during fire extinguishing as well as other works in the extreme situations. Skin burn injuries associated with exposures to firefighting conditions characterized by thermal energies below flashover have been long identified as a concern to firefighters. These below flashover exposures are usually several minutes in duration and are generally not sufficient to produce significant thermal degradation to the outer shell fabric of the turnout suit. Burns is thought to occur as a result of thermal energy transmitted to the garment from the heated firefighting environment. Subsequent compression of the heated turnout ensemble onto the body due to firefighter movement or external pressure is thought to exacerbate burns due to the discharge of thermal energy stored in the materials used in the construction of the turnout suit.

2. Material

1st Layer - Nomex [Meta aramid]

Table 1

S.No.	Existing protective clothing (outer layer) PBI-Polybenzimidazole	Meta aramid (outer layer)
1.	Thickness =0.082± 0.007 cm	Thickness =0.051 ± 0.002cm
2.	Specific mass = 284 (g/m²)	Specific mass = 263 ± 4.8 (g/m²)
3.	LOI PBI =23-25%	NOMEX=28-30%

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Table 2

S.No.	Properties	Nomex	Aluminized Aramid (Kevlar)
1	Color	White	Silver/Golden
2	Density	1.35g/cm square	1.45g/cm square
3	Moisture absorption	Upto 4.3%	Upto 6.5%
4	UV light absorption	Low	High
5	Dye sustainability	Low	Low
6	Temperature	Withstand upto 370°c	Withstand a ove500°c
7	GSM	300	490
8	Price	1300/meter	1200/meter

2nd Layer - PTFE coated glass fabric laminates
3rd Layer - Aluminized aramid (Kevlar)
4th Layer - Polyester (FR)

Outer layer as Nomex fabric | **Moisture barrier As PTFE coated Glass fiber fabric** | **Thermal liner as Aluminized Kevlar fabric**

Fig. 1.

3. Methodology

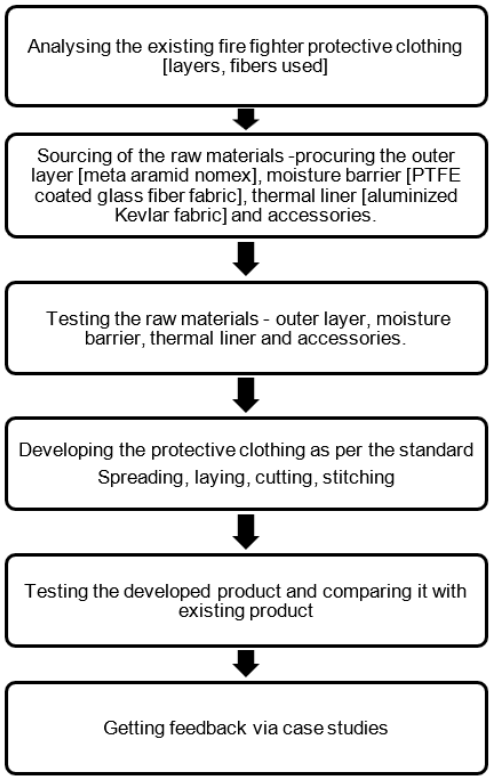
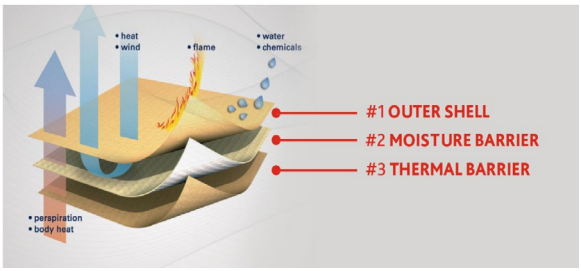


Fig. 2. Methodology

4. Sewing Methodology

Heming all parts
↓
Shoulder attaching
↓
Sew overarm
↓
Stitch sleeve length
↓



Side attaching
↓
Lining preparation
↓
Lining attachment
↓
Collar
↓
Bottom hemming
↓
Zipper attaching
↓
Velcro attaching
↓
Finishing
↓
Reflective tape attaching

Fig. 3. Developed product

A. Objectives

- To develop the firefighters protective clothing improve performance as well as comfort at optimum level.
- To analyse the existing firefighter's protective clothing and compare with developed protective clothing.
- To analyse the commercial aspects of developed firefighter's protective clothing.

B. Patterning for XL Size Standard - EN 469: 2005

Fig. 4. Pattern making

C. Cutting

- Cut out all pieces. Do not move fabric when cutting
  1. Front panel
  2. Back panel
  3. Sleeve and
  4. Collar
- Repeat for cutting the all the layers and lining

Fig. 5. Front panel

Fig. 6. Back panel

Fig. 7. Sleeve

D. Sewing

- Mark pocket position in both front panel and attach the pocket in the marked place.
- Then take a 1 panel and join the 3 layers.
  First layer is nomex
  Second layer is PTFE Coated Glass Fabric
  Third layer is Aluminised Kevlar Fabric
- As same as all the part are join with this 3 layers arrangements.

Fig. 8. Stitching

5. Result and Discussion

1. Outer layer =woven
   2/1 twill
   EPI=56
   PPI=54
2. Moisture barrier =PTFE coated glass fiber fabric.
3. Thermal liner = Aluminized Kevlar fabric.

Table 1
Flammability test 90 degree

S.No.	Layer	Values	Class
1	Outer layer	Does not ignite	I
2	Moisture barrier	Does not ignite	I
3	Thermal barrier	Does not ignite	I

Table 2
Testing result

Name of the test	Test result
Cloth cover factor	21.69
Water penetration	Does not penetrate

Table 3
Limited oxygen index

Sample Specification	LOI (O2%)
NOMEX	35
PTFE	40
KEVLAR	43

Table 4
Thickness test

Layer	Existing in Mm	Our Product in mm
Outer layer	0.82 mm	0.56 mm
Moisture barrier	0.68 mm	0.25 mm
Thermal barrier	0.46 mm	m

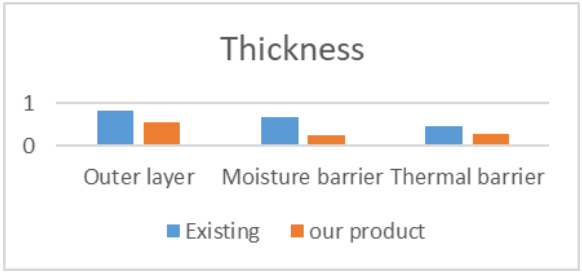


Fig. 9. Thickness

Table 5
GSM

S.No.	Layer	GSM [Existing]	GSM [Our Product]
1	Outer layer	294	263
2	Moisture barrier	443	306
3	Thermal barrier	430	320

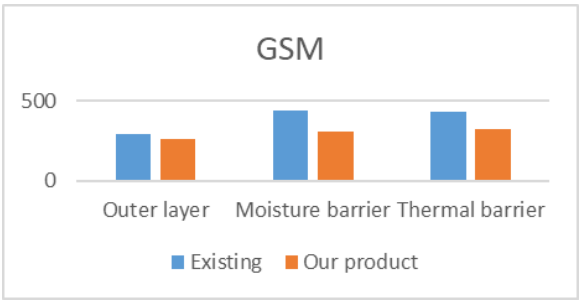


Fig. 10. GSM

Table 6
Thermal conductivity test

Sample Description	NOMEX + PTFE + Kevlar Material
Mean Temp (°C)	70.00
Delta Temp (°C)	10.00
Thermal Conductivity W/m-k	0.046038
Thermal Resistance M^2 *k/w	0.060732
Thermal Conductivity (Clo/Inch)	3.564945
Thermal Resistance (Clo)	0.392427

6. Conclusion

The analysis and development of user-friendly protective clothing for firefighters highlight the critical need for gear that not only meets stringent safety standards but also addresses the practical needs of those who wear it. Through comprehensive research and testing, key areas such as thermal protection, mobility, comfort, and ergonomics have been identified as essential components in the design of effective protective clothing.

User feedback and real-world testing have played pivotal roles in refining the design, ensuring that the protective gear is not only functional but also comfortable for prolonged use in high-stress environments. The integration of advanced materials and innovative design techniques has resulted in clothing that provides enhanced protection without compromising on mobility or comfort.

Moreover, the focus on user-friendliness has led to improvements in the ease of donning and doffing the gear, as well as better integration with other essential equipment. These developments contribute significantly to the overall safety and efficiency of firefighters, ultimately supporting their ability to perform their duties under hazardous conditions.

In conclusion, the successful development of user-friendly firefighting protective clothing represents a significant advancement in occupational safety. By prioritizing both protection and comfort, this new generation of protective gear stands to reduce injury rates, improve performance, and enhance the overall well-being of firefighters on the job. Continued innovation and user-centered design will be crucial in maintaining and advancing these standards in the future.

7. Scope of Future Work

- To upgrade the firefighter's protective clothing by introducing a sensor to sense the fire temperature, smoke detection.
- This will warn the fire fighters in hazardous situations.
- In the area of nanotechnology there are possibilities of

incorporating the phase changing materials, shape memory alloy, thermochromics materials.

- Then the suit becomes a smart suit.

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