



Analysis and design of fire resistance cloth in fire works industries

P.G. Gurusamy Pandian^a, K.M Ashifa^{b,*}

^a Department of Automobile Engineering, Kalasalingam Academy of Research and Education, Krishnankoil, Turkey

^b Department of Social Work, Istanbul Gelisim University, Turkey

ARTICLE INFO

Article history:

Received 15 May 2020

Received in revised form 29 June 2020

Accepted 2 July 2020

Available online 20 August 2020

Keywords:

Fluid Carrying lines

Flame Retardants

Resilient foam

Intumescent properties

ABSTRACT

Fire resistance cloth is a textile with high tensile strength and high resistance to heat, flame, chemicals, and weather that can be used in glass works foundries, chemical works, welding shops, plastic moulding shops, etc. They are made of the materials like Acrylic, Polyester and Nylon. Fire-resistant fabrics can resist ignition at high temperatures than natural fibers. The fabric is coated with fire retardant material that stiffens the fabric. Or the fabric can be treated with chemicals. Fireproof for a cloth is possible by making it less prone to catching and sustaining fire by using chemical mixtures by application of a 'flame retardant'. Fire Proof with respect to materials and parts used to confine fire in a designated fire zone, means the capacity to withstand at least as well as steel in dimensions appropriate for the purpose for which they are used, the heat produced when there is a severe fire of extended duration in that zone. It respect to other materials and parts means the capacity to withstand the heat associated with fire at least as well as steel in dimension appropriate for the purpose for which they are used. Fire Resistant with respect to sheet or structure members means the capacity to withstand the heat associated with fire at least as well as aluminium alloy in dimensions appropriate for the purpose for which they are used and with respect to fluid- carrying lines, fluid system parts, wiring, air ducts, fittings and power plant controls means the capacity to perform the intended functions under the heat and other condition likely to occur when there is a fire at the place concerns. This report presents the results of a review aimed at identifying test methods for protective clothing for first responders, as well as identifying areas in which further research is required. It is intended to identify gaps and limitations in evaluation technology and to provide information on test methods research that can guide the development of new first responder protective ensembles.

© 2019 Elsevier Ltd. All rights reserved.

Selection and Peer-review under responsibility of the scientific committee of the International Conference on Future Generation Functional Materials and Research 2020.

1. Introduction

1.1. Flame retardants

There are concerns about the human health and environmental risks associated with a number of flame retardant chemicals as well as many regulations impacting these chemicals [9]. Industries involved with cellular materials used as furniture cushions, carpet cushions and consumer products and as building insulation may need to know the chemical content of flame retardants in these materials. These industries include:

Producers of flexible foam, other cushion materials and cellular insulation

Manufacturers of furniture and consumer products such as infant and baby products that buy resilient foam for use in their products

Manufacturers of products made from post industrial recycled foam such as carpet cushions

2. Durable workwear & FR clothing

Head to the jobsite in proper, durable workwear. At Cavender's, carry a wide selection of work boots and high-quality, flame-resistant workwear to protect while the workers on the job [5]. Get maximum safety protection plus classic western styling in FR clothing designed to keep safe in hazardous environments. From rugged footwear to jeans, work shirts, outerwear and a variety of FR work clothes for men and women, Cavender's has the gear need to stay safe, comfortable and confident all shift long [6].

* Corresponding author.

E-mail addresses: pro@klu.ac.in (P.G. Gurusamy Pandian), ashifakattur@gmail.com (K.M Ashifa).

- Men
 - o Men's New Arrivals
 - o Cowboy Boots
 - o Men's Western Wear
 - o Men's Jeans
 - o Men's Outerwear
 - o Cowboy Hats
 - o Men's Western Belts
 - o Buckles
 - o Wallets
 - o Men's Work Boots
- Women
 - o Women's New Arrivals
 - o Cowgirl Boots
 - o Women's Western Wear
 - o Women's Jeans
 - o Women's Outerwear
 - o Cowgirl Hats
 - o Women's Western Belts
 - o Buckles
 - o Purses
 - o Jewelry
- Children
 - o Kid's New Arrivals
 - o Kid's Cowboy Boots
 - o Kid's Western Wear
 - o Kid's Cowboy Hats
 - o Kid's Western Belts
 - o Kid's Buckles
 - o Gifts
- Brands
 - o Justin Boots
 - o Ariat
 - o Wrangler
 - o Cinch
 - o Corral Boots
 - o Miss Me Jeans
 - o Lucchese Boots
 - o Tony Lama Boots
 - o Rafter C
 - o Double H Boots
 - o Twisted X Boots
 - o More.

Fire Retardant Intumescent Paint formulated Class A Intumescent Fire Retardant water base latex paint for Lumber (SYP, SPF, Oak, Hem Fir, Doug Fir, etc.), Plywood (SYP & FIR), OSB, MDF, Drywall (pre painted or not), Polystyrene Foam (close cell foam), EPS Foam, Open Cell Foam, Pre Finished Paneling, I-Joist and more [12]. A few projects can be attics, garage walls, basements, party walls/ceilings and other similar areas where a paint can be used easily [13].

FX Paint Guard is non-toxic, non-hazardous, environment safe, thermal barrier fire retardant that meets building codes and fire code requirements for most commercial and residential projects [7,8]. The treated material can be painted over with a color of latex or enamel paint of your choice. When subjected to a heat source, the intumescent properties will become active and create a foaming or charring barrier to protect the surface from igniting [13].

3. Recommended use

Lumber & Plywood of such species as Cedar, Redwood, Oak, pine, WW, SPF and fir are just some of the species that can be painted with FX Paint Guard. The material being treated will be protected due to the intumescent protective barrier between

the painted material and the fire. Retreatment may be required on all species of wood depending on traffic and wear. The retreatment requirements will vary depending on the elements, ambient temperature and foot traffic and so on [4,3].

FX Paint Guard is a Class A rated thermal barrier fire retardant that meets standard building codes and fire code requirements in most cities across the USA [13].

4. Application process

Material to be treated must be clean & dry before treating. Agitate or Stir product (like you would any paint) before and during application [10]. Apply FX Paint Guard as it's received, maybe sprayed, rolled or brushed on at a rate of 325–375 sf (3–5 wft) per gallon depending on material being treated. If more than one coat is required wait for the first coat to dry completely (8–12 hrs depending on temperature) before applying another coat. Rinse out equipment with water.

OSHA defines firefighters responding to medical emergencies as health care workers [10]. Therefore, the protective clothing they wear for such incidents must be capable of resisting the penetration of blood and other body fluid [15].

As with chemicals, most protective clothing readily absorbs blood. The effectiveness of clothing in preventing blood contact with skin depends on the type of clothing and materials used in its construction. Protective clothing can readily be contaminated with blood not only on the surface but on inner layers as well. Portions of the turnout coats such as the wristlets and the collar are particularly susceptible to this contamination because there are no barrier materials behind their knit material construction [14]. Even though skin itself is a barrier to blood penetration, skin scratches and abrasions common during the rough physical environments of emergency response increase the risk for infection [5]. Even when clothing provides an adequate barrier, contamination of the outer shell of clothing can still constitute a health hazard as some biological agents may remain viable even after drying [15].

5. Result and discussion

5.1. Hazards of contaminated protective clothing

When protective clothing becomes laden with particles and chemicals, the clothing's performance is diminished in several ways: Figs. 1 and 2

1. Soiled turnout gear reflects less radiant heat. After materials are saturated with hydrocarbons, they will tend to absorb rather than reflect the radiant heat from the surrounding fire (the original color of the fabric will also affect radiant heat absorption) [1].

2. Turnouts heavily contaminated with hydrocarbons are more likely to conduct electricity, increasing the danger to the firefighter entering a building or vehicle where wiring may still be live [2].

3. Clothing materials impregnated with oil, grease and hydrocarbon deposits from soot and smoke, can ignite and cause severe burns and injuries, even if the materials are normally flame resistant [2,17].

Even with the advent of specialized hazardous materials response teams within major fire departments, various chemicals can be encountered in normal fire fighting activities. Additionally, exposure to oils, fuels, and lubricants may occur around fire station vehicles. During responses, exposures to liquids ranging from pesticides to acids to chemical solvents may occur either knowingly or unknowingly. These exposures, in addition to being hazardous, can also degrade protective clothing material [18,19]. For example:



Fig. 1. Brown Duck Hooded Jacket - EXCEL FR Com for Touch JLH4 \$152.99.



Fig. 2. Brown Duck Universal Fit Snap-On Hood - EXCEL FR Com for Touch HLH2_Brown \$43.99.

- Clothing fabrics may become weakened and tear more easily.
 - Thread or seam sealing tape may become loose.
 - Water repellency treatments may be removed.
 - Reflective trim can become less visible.
 - Helmet shells/ face shield or SCBA masks visors may pit or craze.
 - Clothing or equipment hardware may be corroded [2].
- Table 1 contents Hazard Risk Category.

6. Safety standards compliance

6.1. Nfpa 70E

The standard requires that:

“Employees shall wear arc-rated clothing wherever there is possible exposure to an arc flash above the threshold incident-energy level for a second degree burn...” ..NFPA 70E Details [11].

6.2. Nfpa 2112

Regarding the manufacture of FR garments, NFPA 2112 states: “The standard shall specify the minimum performance requirements and test methods for Flame Resistant fabrics and components and the design and certification requirements for garments for use in areas at risk from flash fires.” ..NFPA 2112 Details [11]. Test result for new cloth material given in Graph 1 as per the FTIR reading Table 2.

6.3. Nfpa 2113

Specifies...

“...the minimum selection, care, use, and maintenance requirements for Flame Resistant garments for use in areas at risk from flash fires by industrial personnel that are compliant with NFPA 2112, Standard on Flame Resistant Garments for Protection of Industrial Personnel Against Flash Fire.” ..NFPA 2113 Details

6.4. Nfpa 45

Regarding fire protection for laboratories using chemicals states:

“In educational and instructional laboratories where experiments are conducted by students, the instructor shall be responsible for...the personal protective equipment required for the experiment...” and that, “Fire-retardant clothing shall meet the requirements of NFPA 2112.” ..NFPA 45 Details

7. Sateen decorating fabric

Silky all-purpose flame retardant fabric in a wide variety of colors [16], Fig. 3.

- 100% Polyester Sateen Fabric
- Fire Retardant NFPA 701-CA Fire Marshall
- This light weight Satin fabric is the decorators choice for swaging, festooning, draping, false ceilings and a host of other general purpose decorating ideas.
- Available Sateen Widths: 30"- 40"- 60"- 122" (approximate)
- Wholesale Fabric Bolt lengths: 50 and 100 yards
- View Color Samples

Table 1
Hazard Risk Category.





Hazard Risk Category	Clothing Description Typical number of clothing layers is given in parentheses.	Required Minimum Arc Rating of PPE cal/cm ²
 1 HRC	FR shirt and FR pants or FR coveralls (1 layer)	4
 2 HRC	Cotton underwear plus FR shirt and FR pants (1 or 2 layers)	8
 3 HRC	Cotton underwear plus FR shirt and FR pants plus FR coveralls, or Cotton underwear plus two FR coveralls (2 or 3 layers)	25
 4 HRC	Cotton underwear plus FR shirt and FR pants plus multilayer flash suit (3 or more layers)	40

Table 2
FTIR Machine Reading.

	Peak	Intensity	Corr. Intensity	Base (H)	Base (L)	Area	Corr. Area
1	420.48	52.91	23.89	432.05	408.91	814.550	277.513
2	445.56	60.38	5.77	455.20	439.77	559.527	40.227
3	499.56	49.11	20.18	518.85	484.13	1428.794	356.275
4	586.36	67.98	3.68	603.72	570.93	993.415	63.148
5	721.38	10.00	71.27	746.45	640.37	5247.639	2672.783
6	792.74	71.48	4.73	804.32	746.45	1281.823	122.952
7	846.75	61.75	6.26	858.32	804.32	1731.956	116.116
8	869.90	56.41	12.48	891.11	858.32	1159.281	172.495
9	968.27	59.43	6.00	983.70	914.26	2302.556	81.917
10	1016.49	39.41	20.89	1031.92	983.70	2253.285	378.097
11	1093.64	25.32	42.35	1159.22	1031.92	6675.644	2596.083
12	1242.16	24.88	54.77	1323.17	1182.36	6014.048	3291.024
13	1338.60	70.25	17.96	1355.96	1323.17	659.350	274.551
14	1408.04	72.85	15.82	1425.40	1375.25	891.485	289.768
15	1506.41	84.97	4.02	1516.05	1490.97	321.974	55.410
16	1710.86	31.37	61.83	1759.08	1622.13	4046.346	2830.132
17	2162.20	90.62	3.71	2171.85	2148.70	169.978	43.552
18	2183.42	90.51	2.73	2193.06	2171.85	175.031	31.645
19	2204.64	90.30	4.06	2220.07	2193.06	200.076	53.280
20	2233.57	92.73	2.73	2247.07	2220.07	164.063	41.476



Fig. 3. Sateen decorating.



Fig. 4. Duvetyne decorating fabric.



Fig. 5. Vinyl sheeting.

- Typical applications include film and photographic studios and set, theatrical sets, and AV presentations
- Note on Care: Washing will remove flame retardant.
- 54" width, Bolt lengths: 25 and 50 yards
- Bulk quantities available upon request, please call or email
- Black Only

9. Vinyl sheeting

Attractive, colorful flame retardant embossed vinyl sheeting, Fig. 5.

- Taffeta embossing
- Fire Retardant NFPA 701-CA Fire Marshall
- This inexpensive alternative to cloth is often used as a general purpose decorating fabric as well as for table top covering. Its superior opacity, deeper color, and fire retardant quality, make it a clear upgrade from the thin plastics found in party stores.
- Available Widths: 29" - 35" - 54" (approximate)
- Bolt lengths: 100 yards
- View Color Samples

10. Conclusion

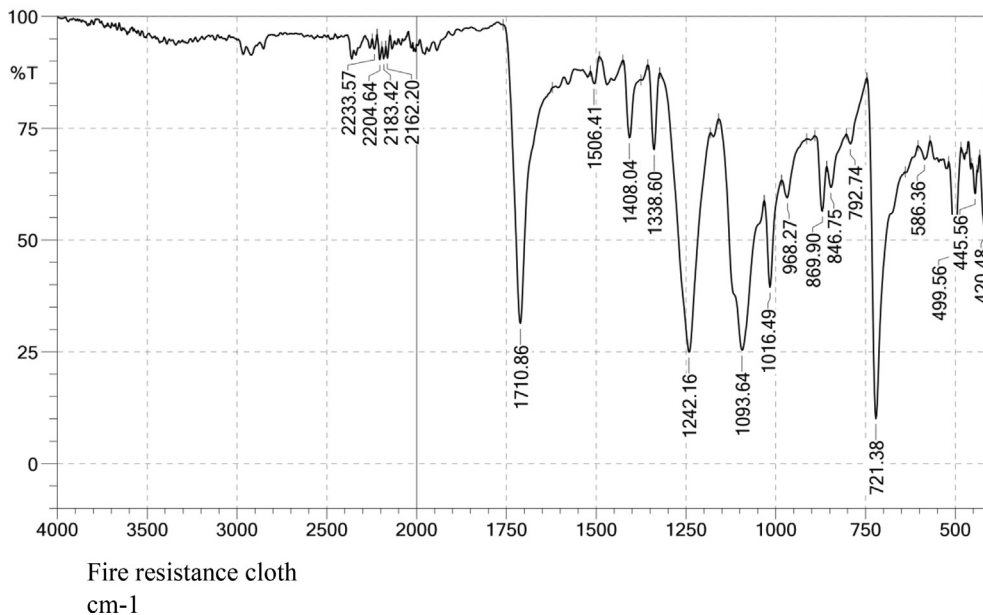
Taffeta embossing vinyl sheeting material tested and reported as above and material not getting fire even by sparking with match box. Hence the same may be used in fire work industries for dresses and head covering cloth. The FTIR analysis of the flame retardant cloth gives the various functional groups attached with the cloth [Table 2 and Graph 1]. Fire resistant means resistant to catching fire which does not melt or drip when exposed directly to extreme heat. Retardant is defined as a material that is chemically treated to self-extinguish. Fire resistance is a very important in any structure and so the structural elements should possess resistance to overcome flames and spreading of fire. In some composite structures, high-composite fiber content promotes the flameretardant characteristics. For a material to be Fire Resistant, it should have the following properties. It should not disintegrate

8. Duvetyne decorating fabric

No gloss flame retardant cotton fabric Fig. 4.

- Commonly used for temporary masking and draping where light reflection is undesirable
- 100% Cotton brushed finish with topical F/R, 8 oz per linear yard
- Fire Retardant NFPA-701

Tested Result for the new Cloth Material:



Graph 1. Test result for new cloth material.

under the effect of heat and should not expand under heat. It should not catch fire easily and it should not lose its strength when subjected to fire. Some popular fire retardant fibers are Modacrylic, Nomex and Kevlar with inherent flame-resistant qualities many other additional properties such as high strength.

CRedit authorship contribution statement

P.G. Gurusamy Pandian: Data curation, Writing - original draft, Conceptualization. **K.M Ashifa:** Methodology, Investigation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

- [1] J.A. Foster, G.V. Roberts, [Measurements of the firefighter environment - Summary report, Fire Eng. J. 55 \(178\) \(September 1995\) 3034.](#)
- [2] J. Frim, T.T. Romet, "The Role of the Moisture/ Vapour Barrier in the Retention of Metabolic Heat During Fire Fighting," Report DCIEM No. 88-RR-40, prepared for Department of National Defence - Canada, Defence and Civil Institute of Environmental Medicine, Downsview, Ontario, October 1988.
- [3] Garland, Charles E., Lynn E. Goldstein, and Campbell Cary, "Testing Fully Encapsulating Chemical Suits in a Simulated Work Environment," Performance of Protective Clothing, ASTM STP 900 (R. L. Barker and G. C. Coletta, Eds.), American Society for Testing and Materials, Philadelphia, PA, 1986, pp. 276-285.
- [4] A. Geshury, R.L. Barker, W.P. Behnke, "Measuring the Effects of Intense Heat and Dynamic Mechanical Forces on Thermal Protective Fabrics," High-Tech Fibrous Materials, Vigo and Turbak, Eds., ACS Symposium Series No. 457, Chapter 18, American Chemical Society, Washington, DC, 1991.
- [5] T.K. Ghosh, R.L. Barker, "Thermal Protective Performance of PBI and Aramid Fabrics: Measuring the Effect of Mechanical Stress," Journal of Industrial Fabrics, Vol. 4, No. 4, 1986. 55. Gohlke, D.J., "Total Heat Loss Test Method," Performance of Protective Clothing: 6th Volume, ASTM STP 1273, J.O. Stull and A.D. Schwoppe, eds., American Society for Testing and Materials, West Conshohocken, PA, 1997.
- [6] R.F. Goldman, [Clothing design for comfort and work performance in extreme thermal environments, Trans. N. Y. Acad. Sci. Ser. II 36 \(6\) \(1974\) 531-544.](#)
- [7] R.F. Goldman, "Heat Stress in Firefighting: the Relation Between Work, Clothing, and Environment," Fire Emergency, 1990.
- [8] R.V. Grimes, J.C. Mulligan, H. Hamouda, R. Barker. "The Design of a Surface Heat Flux Transducer for Use in Fabric Thermal Protection Testing," Performance of Protective Clothing: Fifth Volume, ASTM STP 1237, James S. Johnson and S.Z. Mansdorf, Eds., American Society for Testing and Materials, West Conshohocken, PA, 1996.
- [9] Guidotti, L. Tee, Veronica M. Clough, "Occupational Health Concerns of Firefighting," Annual Review of Public Health, Vol. 13, 1992, pp. 151-71.
- [10] J.J. Halin, R.L. Barker, H. Hamouda, J.C. Mulligan, "A One-dimensional Finite Element Model of Heat Transfer through Human Skin and Burn Damage Assessment," Performance of Protective Clothing, Fifth Volume, ASTM STP 1237, James S. Johnson and S. Z. Mansdorf, Eds., American Society for Testing and Materials, Philadelphia, PA, 1996.
- [11] Hansen, Charles M., Clare B. Billing, Jr., Alan P. Bentz, "Selection and Use of Molecular Parameters to Predict Through Fluoropolymer-Based Protective Clothing Material," Performance of Protective Clothing: Fourth Volume, ASTM STP 1133 (J. P. McBriarity and N. W. Henry, Eds.), American Society for Testing and Materials, Philadelphia, 1992, pp. 894-907.
- [12] Hansen, Charles M. and Kristian M. Hansen, "Solubility Parameter Prediction of the Barrier Properties of Chemical Protective Clothing," Performance of Protective Clothing: Second Symposium, ASTM STP 989 (S. Z. Mansdorf, R. G. Sager, and A. P. Nielson, Eds.), American Society for Testing and Materials, Philadelphia, PA, 1988, pp. 197-208.
- [13] M.A. Hartsky, K.L. Reed, D.B. Warheit, "Assessments of the Barrier Effectiveness of Protective Clothing Fabrics to Aerosols of Chrysotile Asbestos Fibers," Performance of Protective Clothing: Issues and Priorities for the 21st Century: Seventh Volume, ASTM STP 1386 (C. N. Nelson and N. W. Nelson, Eds.), American Society for Testing and Materials, Philadelphia, 2000, pp. 141-154.
- [14] [Ellen F. Helneman, Carl M. Shy, Harvey Checkoway, Injuries on the fireground: Risk factors for traumatic injuries among professional fire fighters, Am. J. Ind. Med. 15 \(3\) \(1989\) 267-282.](#)
- [15] Henry, Norman W. III, David C. Montefiori, "The Resistance of Clothing Materials to Biological Liquids," Performance of Protective Clothing: Fourth Volume, ASTM STP 1133 (J. P. McBriarity and N. W. Henry, Eds.), American Society for Testing and Materials, Philadelphia, 1992, pp. 58-64.
- [16] Henry, Norman W. III, "Comparative Evaluation of a Smaller Version of the ASTM Permeation Test Cell Versus the Standard Cell," Performance of Protective Clothing: Second Symposium, ASTM STP 989 (S. Z. Mansdorf, R. G. Sager, and A. P. Nielson, Eds.), American Society for Testing and Materials, Philadelphia, PA, 1988, pp. 236-242.
- [17] [Norman W. Henry III, C. Nelson Schlatter, The development of a standard test method for evaluating chemical protective clothing to permeation by Hazardous liquids, AIHA J. 43 \(3\) \(1981\) 202-207.](#)
- [18] [F.C. Henriques Jr., A.R. Moritz, Studies of thermal injuries: The relative importance of time and surface temperature in the causation of cutaneous burns, Am. J. Pathol. 23 \(1947\) 695-720.](#)
- [19] Hobbs, E. Nancy, Billie G. Oakland, "Use of Methylene Blue Dye to Predict Fabric Penetration by Malathion," Performance of Protective Clothing: Second Symposium, ASTM STP 989 (S. Z. Mansdorf, R. G. Sager, and A. P. Nielson, Eds.), American Society for Testing and Materials, Philadelphia, PA, 1988, pp. 236-242.