Flame and Burn resistance Behavior of Woven Hybrid Fabrics

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Abstract

Woven fabrics have been used extensively in protective garment. In this research we investigate the effects of their structural properties on flame resistance. Basic Geometrical and material parameters are identified to characterize the structure of hybrid fabrics. Also this research develops a new method to prevention ignition propagation through a protective fabric that exposed flame with using of glass yarn barrier in cotton fabric. Evaluation of fabric flammability and fabric burning behavior is made based upon standard test method (BS 5438) and a proposed method.
Finally, experimental results are evaluated according to a MANOVA analysis. How and at which level woven fabric parameters affect a fabrics̓ burning behavior is defined, and regression models of these parameters are obtained. Using these regression models, the burning behavior of woven fabrics is evaluated, and it is possible to rank them according to their burning characteristics.

Keywords::Woven Fabrics, Structural properties, Flame resistance, Ignition propagation, Glass yarn barrier, regression mode

1. Introduction

Textile combustion is a complex phenomenon [1] that involves heating, decomposition leading to gasification (fuel generation), ignition, and flame propagation. A self- sustaining requires a fuel source and means of gasifying the fuel and mixing the gaseous fuel with oxygen and heat. For protective clothing, there are several requirements, such as protection against heat by providing insulation, as well as high dimensional stability of fabric that, upon exposure to heat fluxes in carrying out the wearer̓s work, will not shrink, melt or form chars that may disintegrate if the wearer move.

Four ways of stopping combustion have been suggested, heat may be removed or cooling applied, the increase in pyrolysis temperature makes the material heat resistant; glass, semi-carbon fibers and aramid fibers are extremely stable and heat resistant, The third way of stopping combustion is to prevent evaporation, that is, to form char, combustion may be prevented by eliminating the oxygen from the combustion zone and thus stopping oxidation.

Important aspects of fire hazards of a fabric are expressed by ease of ignition, rate and extend of spread of flame and amount of heat evolved. In addition, the duration of flaming, the temperature at the surface of a burning fabric and the ease of extinction are important for studying the performance of a heat protective garment. krasny and his co-workers have observed that many heavy fabrics are less easily extinguished than light fabrics and may burn longer in accidents [2]. Miller et al studied extingiushability, or the ease with witch an ignited fabrics is extinguished, by determining the burning rates as a function of environmental oxygen index concentration [3].

Most research directed toward improving the flame resistance characteristics of these materials has been based on chemical treatments and changes in molecular structure [3, 4, 5, 6, 7 and 8]. However, inherently fire-resistant fibers and fiber systems containing fire retardant additives will still burn under sufficiently sever thermal conditions. In this way, it will be possible to produce end products with suitable physical and burning properties for used in the field. Fabric weight, air permeabilities, and cover factors cause change in the flame retardancy characteristics of fabrics, [7, 9, 10, and 11]. Accordingly, we have conducted research of plain-woven fabrics to investigate the effects of their properties on flame resistance. For this purpose we used glass yarn as a barrier to prevent from fabric combustion.

2. Experimental

2.1 Materials

Gray fabrics were produced in plain weave pattern with three different yarn densities. The fabrics evaluated are summarized in Table 1.

The fiber should have a low thermal conductivity, and also should not soften at higher temperatures. It may also be noted that aramid and glass fibers in spite of their high oxygen index [3, 12 and 13] and high thermal ability, have not be found suitable for preventing skin burns in molten metal splashes because of their high thermal conductivity. So the glass yarns are weaved as weft in each three yarn density in matrix of cotton yarn to investigate the effect of exist some barriers (flame resistance yarn) and to achieve optimum protection. The number of glass yarn that placed near each other as barrier were four cases in each yarn density; one, two, three and four barrier yarns and the distance between successive barriers in all samples are constant two centimeters that was equal with flame height to reduce the fuel source from burning zone and stop or reduce flame spread speed.

Specification of fabric, weight per unit area in g/m^2, air permeability in mm/s, and fabric thickness in mm were determined for the produced fabrics (Table 2).

2.2 Methods

2.2.1 Flame spread speed

Since the 90^0 orientation may be assumed to correspond most closely to the situation of textile fabrics used in garments, we chose the BS 5438 vertical flammability test method to evaluate flame spread rates [11]. This test has achieved the widest acceptance for determining the flame and glow resistance of fabrics [2].

Fore each fabric type, three fabric specimens, 170×670 mm length and width, were prepared and conditioned for 24 Hours before testing. The conditioned specimens were then mounted in a suitable clamp and placed in a standard cabinet that allows 2 mm/second airflow, and the bottom edge of the fabric was exposed to a standard flame. In order to consider the flame spread speed three marked line were made on the mounted specimens at 2, 32, and 62 cm from the bottom edge of fabric. The moment that flame reach to any of these lines was recorded by video camera. The speed of flame spread was obtained by dividing the length that burned to the time that was recorded. Flame spread speed(R mm/s) for the first30 and 60 cm were determined for all fabric specimens. The R value, because it does consider the rate at with a flame propagates, is acceptable as a measure of flammability [11].

2.2.2 Garment burning simulation

In order to represent actual human-response conditions, a simulated 'beating hand' was used to extinguish burning fabrics. Many fabrics stop burning on contact with a mannequin or living skin. The apparel flammability modeling apparatus (AFMA) represent two extremes occurring during real-life apparel fires; in the free-hanging mode, the specimens hang freely from a frame suspended near the top of the semi-cylinder, witch is inclined at 20^0 to the vertical and remains in this position throughout the test. In contact mode when one of the four sensors registers a heat rise of 5^0C the semi-cylinder moves to the vertical position and makes contact with the specimen. This simulates movement of, for example, a leg in burning trousers [2].

In this part with regard to these works a simple method for garment burning simulation was designed to represent actual human-response conditions. The specimens are located on a flat plate in a manner that were with contact with the plate except in the bottom of the plate where two centimeters of samples were free, although in contact mode there was randomly air between fabric and plate at some point. The plate located vertically in the cabin that described in previous part and the bottom of fabric was exposed to flame. It was observed that when flame reached to the area where fabrics were with contact with the plate the flame extinct and continues with glowing. This can simulate the apparels that are in contact with body in some area and is free in another area.

To quantities garment burning simulation three parameters are defined according to the observation as follows and their determined result are shown in table 2.

2.2.2.1 Ease of extinction

Usually in garment burning simulation there are two mode, contact mode and free hanging mode and many fabrics stop burning in contact with a mannequin or living skin [2, 14]**.** It was observed that when flame reached to the area where fabrics were with contact with the plate the flame extinct and continues with glowing. Ease of extinction was studied by determining the time when sample is ignited and when is extinguished. As this parameter be smaller the ease with which an ignited fabric is extinguished, is better and the burning resistance of fabric is higher.

2.2.2.2 Extend of spread of flame

This parameter is expressed by the ratio of burned fabric area (char area) to initial sample area. It is obvious that as this parameter is smaller the amount of heat evolved in combustion phenomenon is less.

2.2.2.3 Glowing spread speed

Glowing is combustion of a material in the solid phase with emission of light from the surface [15]

It is observed that when the burning fabric extinguished the samples glowed. This value is the result of dividing the length that glowed to the time that is needed and expressed in cm/min.

3. RESULTS AND DISCUSSION

3.1 The effect of yarn density and glass barrier on flame spread speed

After the physical tests, we conducted a vertical flammability and garment burning simulation test on each specimen. Once results were acquired, they were treated statistically with the help of multivariate analysis of variance (MANOVA) tables to indicate the general effect of yarn density and glass barrier on the flame spread speed. The result has shown in table 3.

As it is revealed from P-value the yarn density in first 30 centimeter at 98% confidence level and in 60 centimeter at 99% confidence level has significant effect. Dancan subgroup results (Table 4) show the flame spread speed in 60 centimeters is faster than first 30 centimeters, we can say burning of initial part of fabric evolved some heat and this heat raised the temperature of remain fabric (the test method is vertically and samples are located vertically) and it's surrounding that lead to fuel source (fabric) need less amount of energy to reach to the pyrolys temperature and subsequent burning temperature so they burn faster.

The ANOVA test (Table 3) shows no significant effect for glass barrier, that means exist of glass yarn- that is inherently flame resistant- has no effect on flame spread speed. This result is investigable from two views:

First, As table 5 shows the maximum weight ratio of glass yarns to cotton yarns i.e. minimum of yarn density (8 thread/cm) and 8 glass yarn is only 0.258, also in the area where there are glass yarn, the fuel source was not omitted completely because of warp cotton yarn that help to duration of flame propagation. Further yarn glasses have higher heat transfer index than cotton yarn and act as a duct to transfer heat to the next areas and this help these areas ignite faster. Second, this result is reveals this fact that glass and cotton yarn didn't has any negative inter action or fuel effect –similar what pointed in introduction for cotton and polyester blend- that is good result to permit production fabric from these two yarns with optimal properties.

3.2 Modeling the flame spread speed in cotton fabric

The linear regression analyses were carried out to provide a statistical model for prediction flame spread speed if structural parameters changed. The below linear equation defined as:

$$Rl_{30} = .037A - .153W - .031T + 1.043 \qquad (1)$$

Where R_{30}= flame spread speed for specimens at first 30 cm, A: air permeability (mm/s), W: weight per unit area (kg/m^2), T: thickness (mm).

ANOVA analyses for confirmation linearity of model was significant at 99% confidence level (P-Value<0.00).

Various researchers have suggested that final inches of the fabrics burn faster than the initial inches and Ozcan suggested a linear regression model for this concept as follows:

$$R_{60} = -4.165 + 0.580\ R_{30} + 1.877\ Rw + .0623\ \text{ignition time} \qquad (2)$$

R_{60}= flame spread speed for specimens at 60 cm, R_{30}= flame spread speed for specimens at first 30 cm, Rw= flame spread speed widthwise.

As it has been shown in Figure 1 the ratio of flame spread speed at 60 centimeter to flame spread speed at 60 centimeter changed with the changing of parameters (weft yarn density or weight per unit area, etc). Therefore the following model has been suggested for flame spread speed at 60 centimeter:

$$R_{60}=1.02R_{30}+0.42A-1.63W-0.016 \quad (3)$$

3.3 Garment burning simulation

3.3.1 The effect of weft yarn density and glass barrier yarn

In this part the effect of yarn density and glass barrier yarn were studied using MANOVA method and the result were shown in Table 6. As it is considered glass barrier yarn has significant effect at 98% confidence level on Extend of spread of flame and at 95% confidence level on Glowing spread speed**.** With increasing the number of glass yarn barriers the values of extend of spread of flame and glowing spread speed decreased but glass barrier yarn has no effect on ease of extinction**.** From this result and with regard to the result of flame spread speed that glass barrier yarn didn't have any effect on it, it can be concluded that in situation that there is not flame and the heat evolution is low the barrier has

desired effect that it will be achieved by finishing cotton with flame retardant material or using flame resistance yarn, and then not only the flame retardant fabric will be produced but also the heat transfer properties of fabrics reach optimize situation. Eight and four glass yarn have minimum value for extend of spread of flame and glowing spread speed and zero and one glass yarn has maximum value.

3.3.2Observation

Although, there is no difference between the glowing of the fabrics with one glass yarn barrier and without yarn barrier, but the former has stable structure after burning. But when two or more glass yarns are used, it was observed that the after glowing in contact with these barriers was stopped in length direction and burning extends in width direction parallel with barrier yarn (Figure 2). The fabrics witch are produced with two and more number glass yarns specially in a more compact weft density, the Width of flame when reached to the glass barrier in the most of its width is getting extinction and mostly the flame penetrate only through away in a narrow path, and after crossing the barrier again spread in width direction but the maximum width that achieved is less than the previous part (Fig3).

3.3.3The modeling of extend of spread of flame in simulated model

Because of the importance of the extend of spread of flame (the ratio of the area of burned fabric to the initial area) following statistical model has been provided:

$$E = -0.156W -0.387G+0.065A-24.261T+73.175 \quad (4)$$

Where E is Extend of spread of flame, G=the number of glass barrier, W= weight per unit area, A= air permeability and T is fabric thickness.

4. Conclusions

The results of this study indicate that

1-Flame spread speed increase with the decrease of weft.

2-Flame spread speed at the ending parts of fabric is faster than initial part of fabric.

3-Glass barrier has no significant effect on flame spread speed.

4-A regression model for flame spread speed at first 30cm is presented as below:

$Rl_{30} = 0 .037A -0.153W - 0.031T + 1.043$

5-A regression model for flame spread speed at 60 cm in terms of flame spread speed at first 30cm and other main structural parameters is given as below

$R_{60}=1.02R_{30}+0.42A-1.63W-0.016$

6-In simulated model, glass barrier has significant effect on extend of spread of flame and glowing spread speed and has no significant effect on ease of extinction. With increasing the number of glass barrier extend of spread of flame and glowing spread speed decrease and. A regression model for Extend of spread of flame is provided.

$E = -0.156W -0.387G+0.065A-24.261T+73.175$

7-With increasing fabric weight and density, the fabric's resistance against burning will be increased.

5. Acknowledgments

We wish to thank AmirkabirUniversity of technology, textile engineering Department for their support and help during the course of this work. Thanks also to Dr. M. Amani, who helped in statistical analyzes.

Table 2 The average of measured parameters

Weft density (cm^{-1})	The number of glass yarn	Rl_{30} (cm/s)	Rl_{60} (cm/s)	Ease of extinction (S)	Glowing spread speed (cm/min)	Extend of spread of flame	Thickness (mm)	Air permeability (mm/s)	weight per unit area (kg/m^2)
12	0	2.44	3.04	11.75	1.33	0.99	0.75	12.75	0.24
12	1	2.63	3.34	12.41	1.30	0.95	0.76	13.21	0.25
12	2	3.80	3.42	12.75	1.28	0.59	0.80	12.50	0.26
12	4	2.80	3.60	12.76	1.23	0.59	0.81	12.58	0.25
12	8	2.95	3.03	10.78	1.22	0.57	0.79	12.5	0.24
10	0	3.30	3.72	13.80	1.84	0.95	0.80	15.58	0.22
10	1	3.52	3.83	11.99	1.27	0.85	0.77	15.46	0.22
10	2	3.15	3.73	14.20	1.35	0.91	0.77	14.42	0.23
10	4	3.10	3.66	8.96	0.99	0.85	0.82	16.42	0.22
10	8	3.57	4.24	8.32	1.46	0.88	0.75	15.03	0.21
8	0	3.14	4.01	7.98	1.83	.95	0.88	17.71	0.2
8	1	3.22	3.83	5.69	1.61	0.98	0.88	18.75	0.19
8	2	3.31	3.87	6.98	1.55	1	0.85	19.83	0.19
8	4	3.58	4.30	7.76	1.51	0.89	0.92	19.75	0.19
8	8	3.76	4.41	3.49	0.77	0.35	0.79	21.25	0.19

Table 3 The MANOVA results for flame spread speed

speed \ Effective parameter	The effect of weft density	The effect of barrier (glass yarn)	weft density χ barrier yarn
Flame spread speed at first 30cm	Significant(p-value 0.10)	No significant	No significant
Flame spread speed at 60cm	Significant(p-value 0.00)	No significant	No significant

Table4 Dancan subgroup for the effect of weft density on flame spread speed (cm/s)

B)30cm

Weft density	subgroup 1	subgroup 2
12/cm	2.99	
10/cm		3.33
8/cm		3.40

A) 60cm

Weft density	subgroup 1	subgroup 2
12/cm	3.29	
10/cm		3.84
8/cm		4.08

Table5 The weight ratio of glass yarn to cotton yarn

Weft density / The number of glass yarn	8	10	12
1	0.03	0.03	0.03
2	0.06	0.06	0.05
4	0.13	0.12	0.11
8	0.26	0.23	0.21

Table 6: The result of MANOVA for simulated model

The effective parameters / Defined parameters	The effect of weft density	The effect of barrier (glass yarn)	weft density × barrier
Extend of spread of flame	Significant(p-value0.01)	Significant(p-value0.01)	No Significant
Glowing spread speed	Significant(p-value0.01)	Significant(p-value0.01)	No Significant
Ease of extinction	Significant(p-value0.01)	No Significant	No Significant

Table (7-A): Dancan subgroup for Extend of spread of flame based on the number of glass yarn

The number of glass yarn	subgroup		
	1	2	3
8	0.73		
4	0. 79	0. 79	
2		0.91	0.91
1		0.94	0.94
0			0.97

Table (7-B): Dancan subgroup for Glowing spread speed based on the number of glass yarn

The number of glass yarn	subgroup	
	1	2
8	1.27	
4	1.36	1.36
2	1.37	1.37
1	1.41	1.41
0		1.68

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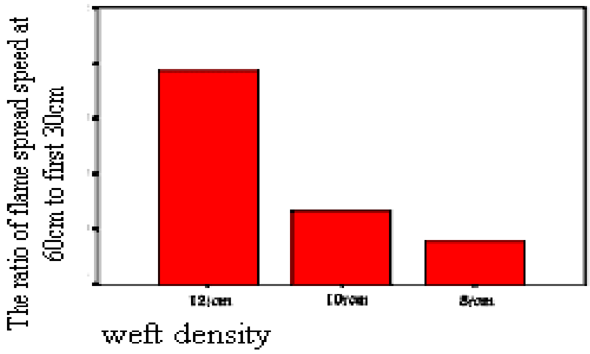

Figure 1The effect of weft density on the ratio of flame spread speed at 60cm to first 30cm

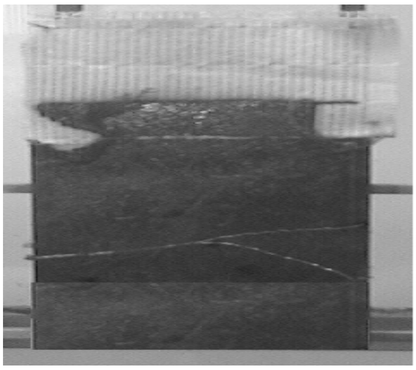

Figure 2　Glowing propagation in contact with barrier

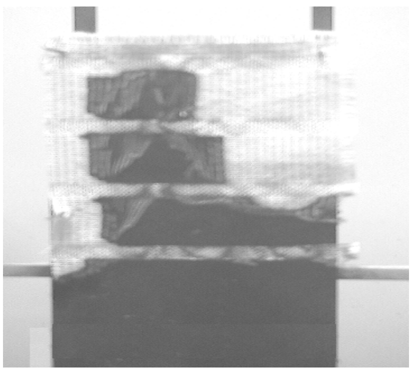

Figure 3 The effect of barrier on the glowing propagation