ISSN 1392–1320 MATERIALS SCIENCE (MEDŽIAGOTYRA). Vol. 12, No. 2. 2006

Influence of Woven Fabrics Structure upon Flammability Properties

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Received 01 June 2005; accepted 01 July 2005

Fabrics flammability depends on various factors such raw material of fiber, its linear density, thread density, fabric construction, oxygen and humidity concentration in the environment, even on the weave type of fabric. In this presentation the influence of woven fabric's thread density and weave type upon flammability properties were investigated. Fabric woven from the metaaramid Nomex Delta TA 18.5 tex × 2 spun yarns were used for investigations. The flammability properties of all tested fabrics are determined using Burning Cabinet Type BKD for standard horizontal flammability test methods due to theirs similarity to fabric real flammability behavior. It has been found that fabric structure influenced on fabric hole burning time – the hole burning time increases if density of yarns or weave factor P_1 increases, too.

Keywords: flammability properties, metaaramid, weave factor.

INTRODUCTION

Materials that are not inherently flame resistant can increase the risk and severity of burn injuries when involved in flames, as they can melt onto the skin [1].

Fabric flammability is affected by various factors such as raw material of yarn, fabric construction, oxygen concentration in environment (moisture content, heat, air flow, etc.), and the effects of finishing materials [2].

Very important property of technical textiles, especially for fire resistant clothes, is its limited oxygen index (LOI) – the percent of oxygen in environment than flame is put on [3]. The fibres, LOI of which is more than 23, are fire resistant in normal environment (after the elimination of flame source the fire extinguishes).

This property is very important for organic textiles, which is used near a flame sources – clothes for fire-fighters, racers, pilots and etc. Flame resistant, protective garments made of aramide fibres can play a key role in providing people the possibility to escape and survive a flash fire. The protection that aramide fibres provide is inherent and permanent, "built into" the molecular structure of the fibre itself. It does not come from chemical treatment or add-ons. The exceptional flame resistance provided by arramide fibres cannot be washed out or worn away [4].

The LOI of aramide fibres is approximately 30. On the other hand the LOI of paraaramid and metaaramid are the same [5, 6], but the flammability [3] of fabrics from these fibres is different and depends not only on fibres nature of stock, but on fabric structure parameters (weave, linear densities and set of threads), also [7 – 9].

There are many structures of fabrics, which are used to manufacture fire resistant clothes [8 – 10, 13]. These fabrics differ not only by raw material and linen or density of yarns, but by structure parameters of fabric (set of yarns and weave) also. Each company manufacturing fire resistant clothes proposed fabrics of own design.

Therefore it is most important to define how fibres and fabric construction affect a product's final burning behaviour. In this way, it will be possible to produce final products with suitable physical and burning properties for end use [1].

Not many works considered actual effect of fabric properties, especially for one kind (for example, woven, knitted, nonwoven, etc.) of flame resistance. It is known that fabric weight, air permeability, and cover factor cause changes in the flame retardancy characteristics of fabrics [2].

The air permeability of fabric is one of very important properties of technical fabrics. Air permeability depends on shape and value of the pores and the interthread channels, which are dependent on the structural parameters of the fabric [11]. The main structural parameters, which have influence on fabric air permeability, are set, linear densities of yarns and weave.

Thread density and set can be empirically calculated. The estimation of fabric weave is more sophisticated. Weave factors are known, which can be calculated experimentally (the most commonly used is Brierley's fabric structure factor F^m [12]), and not experimentally, which are calculated directly from the weave matrix (the most objective is Milašius weave factor P1, because there is strong liner correlation between this criteria and Brierley's fabric structure factor F^m [13]).

All three parametres (set, linear densities of yarns and weave) compose the integrated firmness factor φ_1 [14]. It is known that air permeability property of fabric can be designed by the Brierley's MS/MD or Milašius φ_1 factor [15].

The goal of presented investigations is to show the dependence of fabric flammability on its structure parameters.

MATERIALS AND METHODS OF INVESTIGATION

Experimental investigations were carried out with 12 fabrics different in structure parameters (Table 1).

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Table 1. Sets and weaves of investigated fabrics

No. of fabric	Fabric weave	Set of warp S_1	Set of weft S_2
1	plain	27	17
2	twill 2/1	27	17
3	twill 2/1	27	18
4	twill 2/1	27	19
5	twill 2/1	27	22
6	twill 2/1	27	24
7	twill 2/1	27	24
8	twill 2/1	30	22
9	warp rib 2/2	33	28
10	elongated twill	33	28
11	twill 3/3	33	28
12	basket weave 3/3	33	28

All these fabrics were woven on an airjet loom PN-170 from "Nomex Delta TA" 18.5 tex × 2 spun yarns (both in warp and in weft).

Fabric flammability properties were investigated with horizontal test method according to DIN 50050-1:1989.

Horizontal flammability test method is designed applicable for all textile materials. Fabric specimen in it is clamped wrinkle free between two plates in a horizontal position. Meantime the flame is positioned to ignite the surface of the fabric as opposed to the edge. The test is used to measure the ignition with reference to burning capacity of the sampled fabric. Analysis is made by measuring the time up to the start of fabric crack and ignition.

Air permeability of tested fabrics was established according to the conditions of LST EN ISO 9237:1997 standard. According to it air permeability is the air yield passed through a definite area of a fabric during a specified period of time with the pressure difference of 200 Pa (the instrument L 14 DR).

Fabric thickness was established according to the conditions of LST EN ISO 5084:2000 standard, surface density was established according to the conditions of LST EN 12127:1999 standard (instrument – KERN balances), number of threads per unit length was established according to the conditions of LST EN 1049-2:1998 standard, method 2.

Fabric integrated firmness factor was calculated recording to equation:

$$\varphi_1 = \sqrt{\frac{12}{\pi}}\,\frac{1}{P_1}\sqrt{\frac{T_{avg}}{\rho}}\,S_2^{\frac{1}{1+2/3\sqrt[3]{T_1/T_2}}}\,S_1^{\frac{2/3\sqrt[3]{T_1/T_2}}{1+2/3\sqrt[3]{T_1/T}}}, \qquad (1)$$

where: $S_{1/2}$ is the set of the warp and weft, respectively; $T_{1/2}$ is linear density of warp and weft; $\rho_{1/2}$ is warp and weft fiber density ($\rho_{1/2} = 1.4$); P_1 is the weave factor calculated directly from the weave matrix [13].

RESULTS AND DISCUSSION

During the experiment fabric's crack time and its ignition time were investigated.

Fabric's crack time is the time when the fabric's structure is broken. Fabric's crack moment is shown in Fig 1. In Fig. 2 the ignition – moment of fire appearance above the fabric is shown.

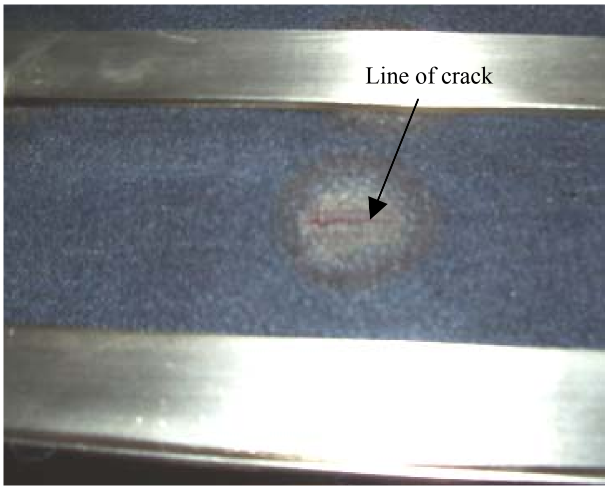

Fig. 1. View of fabric's crack moment

Fig. 2. View of fabric's ignition

In Table 2 crack and ignition times in seconds of investigated fabrics are presented. The coefficients of variation of all experimental points do not exceed 10 %.

Table 2. Values of fabric crack and ignition times

No. of fabric	Crack time, s	Ignition time, s
1	43.7	66.2
2	45.3	70.6
3	50.2	71.1
4	49.3	71.9
5	53.6	78.5
6	59.6	86.2
7	52.7	78.8
8	50.3	78.5
9	55.2	86.5
10	61.8	94.8
11	68.0	99.8
12	71.2	101.7

Values presented in this table show some correlation between fabric crack time and ignition time (number of fabrics correspond to Table 1).

The correlation between these two properties is presented in Fig. 3.

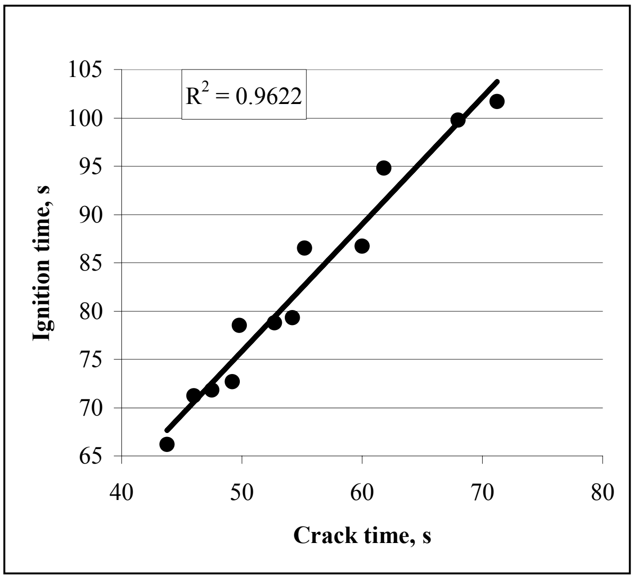

Fig. 3. Correlation between fabric ignition time and its crack time

The coefficient of determination of the linear curve is equal to 0.9622, i.e. it is sufficiently high. It means that correlation exists between these two characteristics, i.e. when one parameter is determined it is not necessary to determine the other.

The crack can be easily noticed because it reveals with noise. Appearance of ignition is subjective factor. It is not simple to estimate fire apparition. Therefore latest investigations were carried out according the fabric crack time.

Fabrics No. 2 ÷ 6 (number of fabrics correspond to Table 1) were chosen to describe fabric crack time when only thread density varied (the weave type being the same).

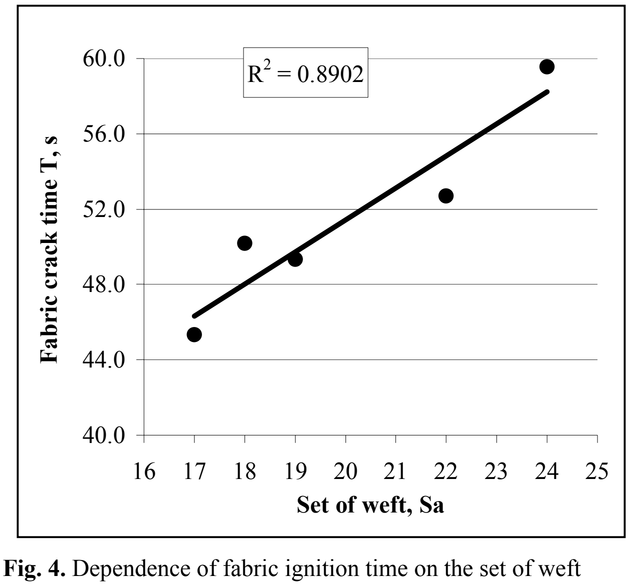

Fig. 4. Dependence of fabric ignition time on the set of weft

The influence of fabric threads density on its flammability properties was estimated changing only weft density (Fig. 4).

Fig. 4 shows the linear dependence between fabric crack time and set of weft when warp density is constant. The determination coefficient of the linear curve is equal to 0.8902, i.e. it is rather high. It can be stated that when the set of weft is increasing the fabric ignition time rises, too.

The influence of fabric weave on its flammability properties was investigated keeping the weft and warp densities constant. There were chosen fabrics No. 9 ÷ 12 (see Table 1).

The determination of fabric crack time on weave factor P_1 is presented in Fig 5.

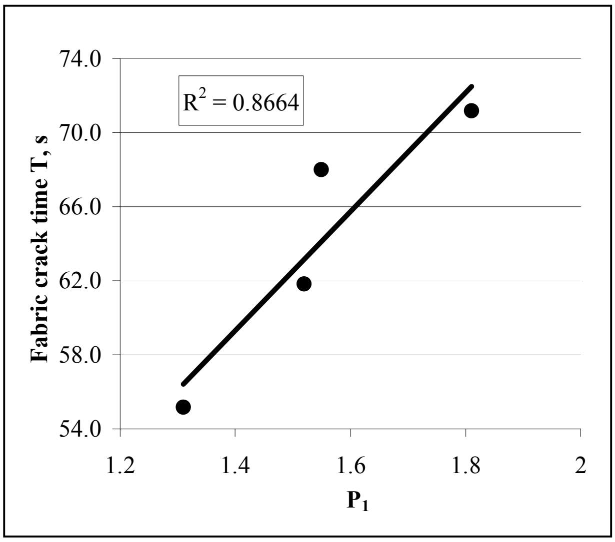

Fig. 5. Dependence of fabric crack time on weave factor

The determination coefficient of the linear curve is equal to 0.8664, i.e. it is rather high. It means that fabric flammability properties depend on weave factor P_1.

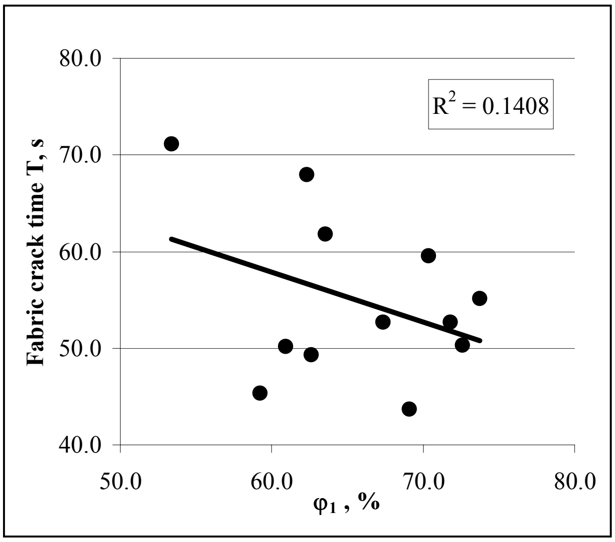

Fig. 6. Dependence of fabric crack time on the integrated firmness factor

At the next stage the dependence of flammability properties on fabric integrated firmness factor φ_1 was investigated (Fig. 6).

From Fig. 6 it can be seen that there is no correlation between those two parameters. The determination coefficient of the linear curve is equal to 0.1408, i.e. it is very low.

Fabric's air permeability investigations confirm the absence of this correlation.

The dependence of fabric crack time on air permeability Q is shown in Fig. 7.

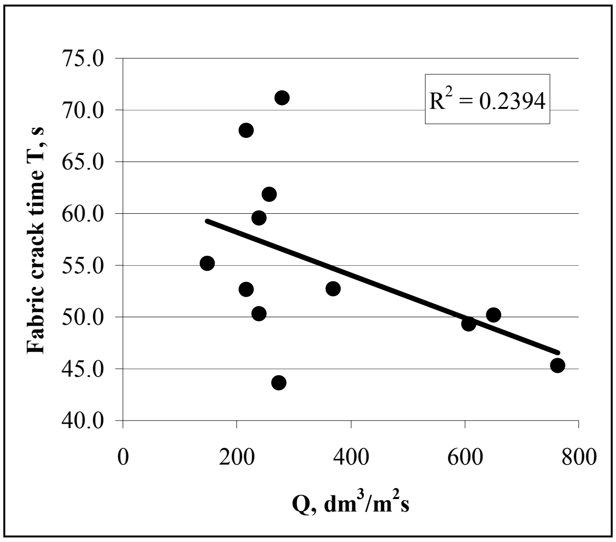

Fig. 7. Dependence of fabric crack time on air permeability

As it is seen the coefficient of determination of presented linear dependence is very low, too ($R^2 = 0.2394$). In this case air permeability is not the parameter, which influences fabric's burning level.

After the investigation of flammability property upon both air permeability Q and the integrated firmness factor φ_1 it was found that there is no dependence on these parameters (the correlation is not existing between these parameters) so it may be state thought the fabric burning depends on its threads density and weave but it can't be designed by the integrated firmness factor φ_1.

CONCLUSIONS

The correlation between fabric's ignition time and its crack time was estimated.

The crack of fabric appears with noise and it is more objective factor than ignition time.

Threads density and weave factor strightly influence fabric's flammability. When the density and weave factor P_1 increases, i.e. length of float increases, the flammability decreases.

Thought fabric's burning process depends upon its density and weave type, the integrated firmness factor φ_1 can't be used for the fabric flammability forecasting. Weak correlation between the fabric's crack time and its air permeability confirms that.

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DOI: 10.5755/j02.ms.26425