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Influence of the Number of Yarns in a Loop on the Flammability of Knits

Abstract
Investigations of the influence of knitted fabric structure on garment flammability, i.e. the number of yarns in a loop and comparison of the results with those of a multilayer packet are presented in this paper. The investigations were carried out using knits from Nomex Delta TA 18 tex × 2 yarns. Single yarn as well as folded yarns from two, three and four single yarns were used in the investigations. The investigations show that using the number of yarns in the loop, it is possible to increase the burning time of the knit more than using the same number of knits in the packet. Such a kind of knit is proposed for garments which do not need low rigidity and/or high air permeability.

Key words: *flammability, knits, loop structure, multilayer packet.*

Introduction

Fire-fighters' protective clothing provides a limited amount of thermal and flame protection from the environmental exposures produced by fires. This level depends on the structure, raw material and fits of the protective garment. To overcome thermal and flame hazards, heat and flame resistant fibres are used to produce thermal protective clothing. The structures of the clothing used are very different. For the manufacturing of woven fabrics, usually plane and twill 2/1 weaves are used, while for knitted fabrics, it is usually single jersey and rib patterns. Knitted fabrics are used in fire-fighter and Special Forces clothing, racers masks, gloves and socks as well as in other kinds of clothing manufacturing.

Thermal and flame protection properties also depend on the construction of clothing, i.e. on the number of textile layers in the garment [1, 2]. However, a garment packet also contains air interlayers between the fabric layers. Air interlayers appear because of the variability of joining the particular layers and the surface unevenness of the garment layers, which are also caused by the properties of the fabrics from which the garment is made, their thickness, density, structure, surface particularities, material structure, thread density etc. It is known that even a very thin additional layer of textile increases the thermal and flame protection of a garment [3-5]. High thermal protection can be achieved by wearing multilayer or thick textile materials, but this prevents good ventilation and thus causes high heat stress to the wearer, thereby reducing their work efficiency in battles against wild fires [6]. On the other hand, higher air permeability increases usage comfort [7], which is very important for users, and especially for head garments – masks. Not only excellent heat protection but also good moisture comfort is necessary when fire-fighters wear protective clothing during fire-fighting; they cannot work efficiently if they feel uncomfortable [8].

In a thermally hazardous environment, thermal protective clothing is the only barrier between the human and a harsh environment, whose main function is to slow heat transfer from the environment to the human skin. Depending on the thermal intensity and structure of the fabric system, a large amount of thermal energy stored during exposure can be discharged to the skin afterwards and can contribute to burn injury [9, 10]. The fabric system not only transmits heat from the source to the skin during exposure, but it can also store thermal energy during exposure and release it to the skin afterwards. The transmission of energy to the skin before and after exposure can cause skin burn injuries. Multilayer and thick fabric systems store more thermal heat than a single layer or thin fabric system. More thermal energy can be stored in a system with air gaps in the fabric layers, which affect thermal resistance differently depending on the quantity of existing moisture and the level of exposure [9, 10].

The thermal resistance of clothing as a set of textile materials depends mostly on the thickness and porosity of particular layers. Due to the fact that changes in the porosity of standard textile materials used in clothing are not large, the total thermal resistance of clothing is influenced mainly by the material thickness. Irrespective of the thermal resistance of clothing material, a key role in heat exchange is played by the size of air layers closed between the human body and clothing surface, as well as between the particular layers of clothing. In the case of one-layer clothing, thermal comfort depends on the clothing cut and fitting to the figure of the clothing user [11]. The thermal insulation of multilayer clothing depends not only on the thermal insulation of particular layers but also on their number and arrangement, as well as on the number and dimensions of air gaps [12].

Knitted fabrics provide outstanding comfort qualities and have long been preferred in many types of clothing. In addition to comfort imparted by the extensible looped structure, knits also provide lightweight warmth, wrinkle resistance, and ease of care [13]. The prediction of the thermal conductivity of knitted structures with varying porosity and moisture is very important for designing cooling garments which can be worn under spe-

Table 1. Parameters of knits

Variants	Yarn linear density, tex	Course density P_v, cm^{-1}	Wale density P_h, cm^{-1}	Loop length l, mm	Surface density, M, g/m^2	Tightness factor TF
I	18.5 × 2	9.5	8.25	5.1	147.89	11.93
II	18.5 × 2 × 2	10	8.25	5.1	311.36	16.87
III	18.5 × 2 × 3	11	8.00	5.1	498.17	20.66
IV	18.5 × 2 × 4	12	7.25	5.1	656.68	23.85

cial protective clothing. The moisture distribution and quantity, the structure of the fabric system and exposure intensity each affect the thermal protective performance of clothing [14 - 17].

The performance requirements of all types of protective clothing often demand the balance of the widely different properties: drape, thermal resistance, liquid barrier, water vapour permeability, anti-static, stretch etc. The seemingly contradictory requirement of creating a barrier e.g., against heat, cold, chemicals and bacteria, as well as breathability in high functional clothing has placed challenging demands on new technologies for producing fibres, fabrics and clothing design.

The goal of our research was to investigate the possibility of manufacturing a garment from knitted fabrics with lower flammability and higher comfort by changing only the construction of the knit, i.e. the number of yarns in a loop.

Materials and methods

Knitted fabrics made from Nomex Delta TA 18 tex × 2 yarns, which are used for fire-fighter clothing manufacture, were used for the investigations. This kind of yarn was chosen due to its high popularity for fire-fighter clothing manufacturing. In the following text these yarns are named as "single yarns". The knits were manufactured on a circular one bed 14E gauge machine, with the same kind of pattern (single jersey) and at the same setting of the knitting machine (loop length in all variants was 5.1 mm). Four variants of knits were manufactured: variant I - from single yarns, variant II - from two folded single yarns, variant III -from three folded single yarns and variant IV - from four folded single yarns. The parameters of the knits investigated are presented in ***Table 1***.

4 combinations of packets from variant I (single fabric, two layers of single fabric, three layers of single fabric and four layers of single fabrics), 2 combinations from variant II (single fabric and two layers of single fabric), a single layer of variant III and a single layer of variant IV were used in the investigations. A flammability test was carried out according to DIN 50050-1:1989. The horizontal flammability test was used, and the burning time from the start till fabric or upper layer of packet break-up was measured. The height of the flame was 4 cm, and the distance between the flame source and materials investigated was 2 cm. The air permeability was investigated according to Standard EN ISO 9237:1995 using a pressure of 200 Pa. Average values of all tests were calculated from five tests. The coefficients of variation for all the tests do not exceed 5 %.

Results and discussions

During the investigations, the influence of the number of yarns in a loop of knits and the number of layers in a packet on the burning time was investigated. The results are presented in ***Figures 1 & 2***.

As is seen from ***Figures 1*** and ***2,*** the number of yarns in the loop and the number of layers increased linearly the burning time of the materials. It is necessary to note that the number of yarns in a loop influences flammability more than the number of layers. The usage of four yarns in a loop increases flammability by 5.2 times (from 59.4 s for a knit made from single yarn to 310 s for a knit made from four folded single yarns), while the usage of a multilayer packet increases flammability by only 3.8 times (from 59.4 s for single knit to 226.8 s for a packet made from four knits of single yarns).

In the next stage of the investigations, the correlation between flammability, fabric or packet surface density and air permeability was checked. These two characteristics of materials were chosen because they both influenced the comfort of clothing –clothing with a higher air permeability and lower surface density will be more comfortable during use. The surface density also has some economical aspects. Correlations between the properties investigated are presented in ***Figures 3*** and ***4***. The white points in both figures show the results for single fabrics, and the black points – the results for a multilayered packet.

As is seen from ***Figures 3*** and ***4***, the burning time has a medium correlation with air permeability and surface den-

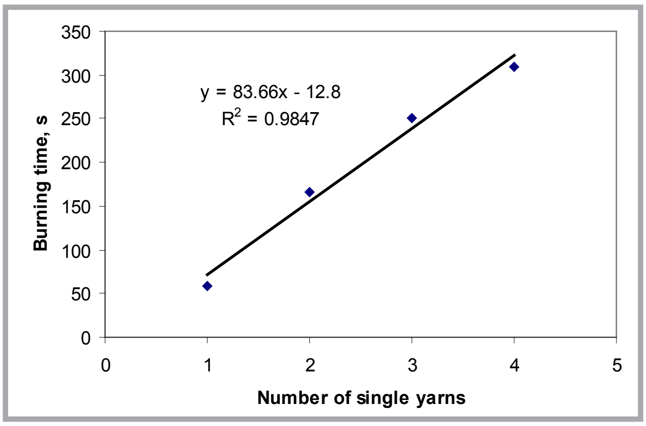


Figure 1. *Influence of the number of single yarns in a loop on the knit's flammability.*

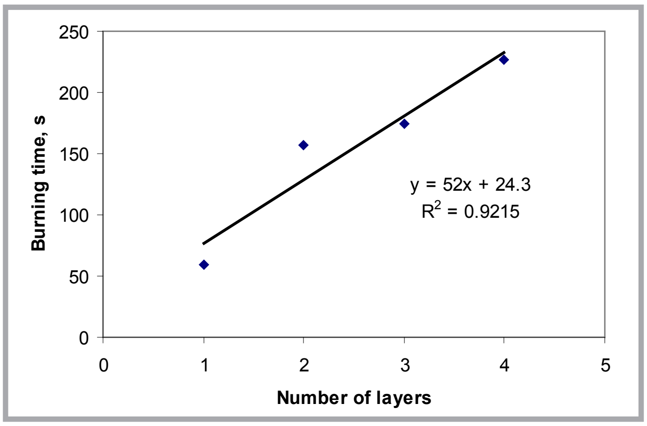
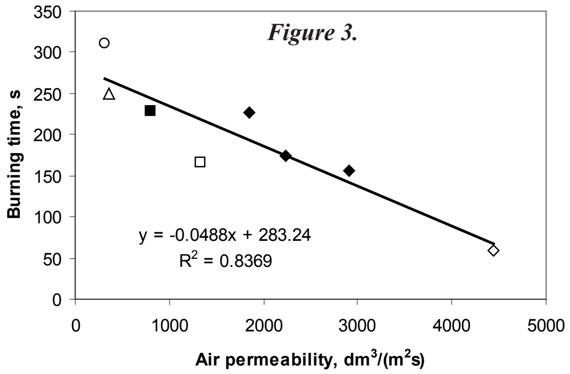
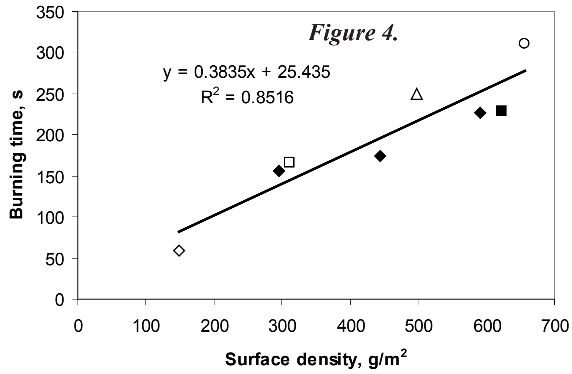


Figure 2. *Influence of the number of layers (knits of I variant) in a packet on the flammability.*





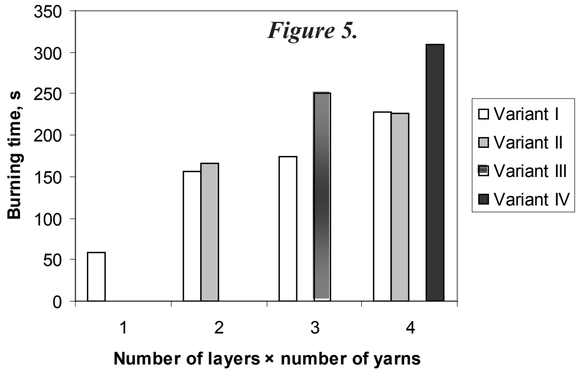


Figure 3. *Correlation between air permeability and burning time: ◊ - single fabric and ♦ - packets from variant I knits (2, 3 and 4 layers), □ - single fabric and ■ - packet from variant II knits (2 layers), Δ - single fabric of variant III, ○ - single fabric of variant IV.*

Figure 4. *Correlation between surface density and burning time (marked as in Figure 3).*

Figure 5. *Influence of the number of layers of knits and number of yarns in the loop on the burning time.*

sity. However, in both figures it is possible to find two areas where a similar burning time is possible to achieve with very different values of air permeability or surface density – the first area has a burning time of 165 ± 10 s and second area has a burning time of 240 ± 10 s, i.e. the burning time varies within the limits of error. Here the same flammability properties are possible to achieve with a very high difference of air permeability and surface density values. The implication is that the prediction and designing of clothing flammability in accordance with air permeability or surface density is impossible, meaning that it is possible to increase the comfort of clothing and not decrease the burning time - to design clothing with higher air permeability or/and lower surface density. The latter also has an economical effect.

At the last stage of our investigations we analysed all the results, concluding that it is possible to design clothing with the same or similar surface density using different numbers of folded yarns in the loop and the same number of knit layers from single yarns in the packet or changing both characteristics. Such a parameter can be characterised as a multiplication of the values of two parameters - the number of single yarns in a loop and the number of layers in the packet. The results are presented in ***Figure 5***.

As is seen from ***Figure 5***, a much higher burning time is possible to achieve using folded yarns than using the same number of layers in the packet, especially when more than two layers of knits or folded yarns are used. The burning time of a two layer packet knitted from single yarns is only 5.5% lower than the burning time of knit made from two folded single yarns, i.e. within the limits of error, while the same difference in burning times of three layers and four layers is 25 ÷ 30%, i.e. it is evident. Herewith, it is possible to note that the first air layer influences flammability much more than the second and subsequent air layers. The burning time of a two layer packet is 2.6 times higher than for a single layer one, while that for a three layer and four layer packet is approximately only 12% higher than for one with two and three layers, respectively. Also it is necessary to note that in the case of a two layer packet, similar flammability will be achieved using two yarns in the loop. It is evident that the manufacturing process of two knits will be twice more expensive than producing from one knit with two yarns in the loop. Hence, the usage of two yarns in the loop will be more cost-effective than using a packet with two layers. Moreover an analogous situation would be if we compare packets with three or four layers of a single knit with three or four yarns in the loop. In such cases we will achieve a higher burning time even more, till 45%. Of course, not always can we change a multilayer packet into a knit with several yarns in the loop, because the rigidity of such a knit is much higher than the rigidity of the packet; however, in some cases it is possible to change and achieve better properties with an economical effect also. On the other hand, the rigidity of the knit is easy to decrease by increasing the loop's length, i.e. by decreasing the loop's density. Investigations in this field will be the area of our further investigations.

Conclusions

- A higher number of yarns in a loop as well as a higher number of knits in the multilayer packet linear increase the burning time of the garment.
- The usage of air permeability or surface density for the prediction of knit flammability is not the right way – the same burning time is possible to achieve for knits which differ in their air permeability and/or surface density to a great degree.
- By using a different number of yarns in the loop it is possible to increase the burning time of the knit more than by using the same number of knits in the packet. On the other hand, such a knit

will have lower air permeability and higher rigidity.

- For garments where rigidity is not a very important property, it is better to use a higher number of yarns in the loop than in the multilayer packet. Such a way also has some economical aspects – the manufacture of one knit with a higher number of yarns in the loop is cheaper than the manufacture of a multilayer packet knitted from single yarns.

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