Physical-mechanical properties of thermal protective fabric subjected to textile care

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Abstract. Today, it is increasingly demanding, more complex and harder to achieve certain properties of fabric which are prescribed by standards for a particular purpose, and it is even more difficult to achieve the sustainability of these properties during use. In this paper, the most relevant physical-mechanical properties of thermal protective woven fabrics, made from meta-aramide yarns, after subjection to textile care, are investigated. This research is related to the objectives of the scientific project MF-WCOMPROTECET, which is based on the development of innovative multifunctional woven fabrics and composites for thermal protective clothing that will overcome the properties of the previous fabrics in the application.

1. Introduction

Protective fabrics are characterized by high quality properties and high numerous requirements placed on human body protection from the various external conditions present in different application areas. Development of protective textiles has been identified as a key market segment, due to its exceptional innovations, answering broader strategic, social, ecological and economic challenges and general benefit. With respect to market research and development requirements, there is a large number of projects funded in the segment of protective clothing [1-3]. MF-WCOMPROTECT (Multifunctional woven composites for thermal protective clothing) is one of them, which is funded by the Croatian Science Foundation (2018-2022). This project is focused on the fabric design process which will result in the creation of innovative, multi-layered, breathable and lightweight fabrics that will overcome the properties of the previous fabrics in the application for thermal protective clothing. Their protective properties will be based on the use of new high performance fibres but primarily on the construction of fabric parameters, forming multi-layer woven fabric that will provide properties of specific and strong protection, but simultaneously enhance wear comfort. Such compact fabric will have the function of a lightweight and thin composite and reflect the image of a protective high performance fabric. The compactness of such materials, taking into account the physical-mechanical properties, gives them an advantage over single-layer fabrics and well-known composite. Whereby it is reasonable to achieve properties of exceptionally good strength, abrasion resistance, durability and relevant external conditions, breathability, wear comfort and textile care [4-6]. In order to achieve the set objectives of the project, it is necessary to analyse the existing protective clothing products on the market with the aim of improving them through all segments of the specific requirements. This research continues on previously conducted research, which explored the influence of structural characteristics of woven fabric made from meta-aramide yarns on their thermal properties and properties associated with comfort [7].
Fabrics made from aramide yarns have high slitting and impact resistance, high strength, good chemical resistance and stability, high temperature resistance, high resistance to abrasion, acids and aggressive gases and are characterized by exceptional comfort and durability. The orientation of meta-aramid fibres allows molecule flexibility, providing exceptional textile properties for the use in making protective clothing for firefighters who are facing numerous hazards, especially those of heat, flame, and high temperature exposure [4].

Protective clothing, in addition to providing a high protection level, must be comfortable and easy to maintain. Washing, as a textile care process, is a cyclic hydrothermal treatment regulated by chemistry, mechanical agitation, temperature and time. One of the main importance in care is that washing has minimal negative impact on the protective fabrics properties. Negative influence of washing on woven fabrics physical and mechanical properties is decreasing breaking properties as well as the properties gained by surface treatments and increasing surface roughness [8]. Therefore, this paper will explore the influence of washing on the physical-mechanical properties of thermal protective woven fabrics.

2. Experimental

2.1. Materials and methods

The samples used for this research are fabrics woven in different weaves from meta-aramid fibres and mixtures. Their specifications are shown in Table 1. Three samples have been compounded from the same raw material (98% m-AR/2% HPCF) but in different weaves. The fourth sample K_AR.CV was woven in the same weave as K_AR but different raw material composition.

| Designation | Raw material composition | Weave       |
|-------------|--------------------------|-------------|
| Kc_AR       | 98% m-AR / 2 % HPCF      | Twill 2/2   |
| K_AR        | 98% m-AR / 2 % HPCF      | Twill 2/1   |
| P_AR        | 98% m-AR / 2 % HPCF      | Plain weave |
| K_AR.CV     | 68% m-AR / 30% viscose FR / 2 % HPCF | Twill 2/1 |

The structural and construction characteristics of the tested samples were determined by standard methods: warp and weft fineness (ISO 2060 (HRN F.S2.012)), fabric density (ISO 7211 (HRN F.S2.013)), fabric thickness (ISO 5084 (HRN F.S2.021)) and the fabric cover factor.

Determination of thermal properties of fabric samples was conducted according to the standard methods: EN ISO 9151:2016 – Method B (Determination of heat transmission on exposure to flame – the result of the test is the difference between the heat transfer index HTI24 – HTI12), ISO 17493:2016 (Test method for convective heat resistance using a hot air circulating oven intended to evaluate physical changes in a material at a given exposure temperature) and EN ISO 6942:2003 – Method B (Evaluation of materials and material assemblies when exposed to a source of radiant heat where protective effect of the materials is determined).

One of the most important indicators of textile material quality and the value of the finished product is its use durability, depending on the application. Therefore, the samples were subjected to textile care - washing process that entails 5 washing cycles with constant temperature of 60 °C. Relevant properties for thermal protective woven fabrics were tested before and after subjection to washing.

Breaking properties (breaking force and elongation at break) were determined according to standard method (EN ISO 13934-1). Another very important parameter is the abrasion resistance, and to test it, the Martindale method was used in accordance with ISO 12947-2 (Determination of specimen breakdown). For determination of water repellence, standardised method EN ISO 4920 (Determination of resistance to surface wetting – Spray test) was applied, while for determination of oil repellence, EN ISO 14419 (Oil repellence – hydrocarbon resistance test) was used.
3. Results and discussion

Table 2 shows the structural parameters of tested samples of thermal protective woven fabrics. Cover factor were determined by analysing the image obtained by Dino-lite microscope, 60x magnification, by placing the sample on a plate with background light. From the Table 1 can be seen the differences in the weave construction, what have an impact on fabric thickness and cover factor. The results show that the thickness of tested samples does not differ significantly. Nevertheless, woven fabric in plain weave has the smallest thickness, as expected, while the fabric sample in the twill weave 2/1 has medium and the sample in twill 2/2 largest thickness. Cover factor of fabrics woven in twill 2/1 is higher than the fabric woven in twill 2/2 fabric, while the smallest cover factor has a fabric woven in plain weave resulting from its structure and slightly lower density.

Table 2. Structural parameters of tested woven fabric.

| Properties                  | Sample       |
|-----------------------------|--------------|
|                            | Kc_AR | K_AR  | P_AR  | K_AR_CV |
| Yarn fineness, Tex          | warp   | 16.5  | 16.5  | 22.0    | 18.0 |
|                            | weft   | 16.5  | 16.5  | 22.0    | 18.0 |
| Fabric density, threads/cm  | warp   | 36.0  | 36.0  | 26.0    | 31.0 |
|                            | weft   | 23.0  | 23.0  | 20.0    | 26.0 |
| Thickness, mm               |         | 0.56  | 0.54  | 0.52    | 0.55 |
| Cover factor, %             |         | 93.8  | 99.6  | 97.1    | 99.8 |

The Table 3 shows the thermal characteristics of the tested fabric samples, such as the difference in the heat transfer indexes to the warming up of the sample at 24 °C and 12 °C (HTI24 - HTI12), the permeability of the thermal flux density (through the sample to calorimeter) (QC) and the heat transfer factor (TFQo).

Comparing fabric samples of identical structural characteristics and different raw material composition shows that the raw material composition affects all three parameters, i.e. the FR viscose component will reduce radiation resistance and accelerate heat transfer to flame, while the difference between heat transfer factors is negligible.

By comparing samples of the same raw material composition, but with different weaves, it can be concluded that fabric cover factor and thickness influence on rate of heat transfer of flame. Therefore, sample with smaller cover factor and highest thickness (with minimum number of interlacements) (twill 2/2) have a faster heat transfer of flame (5.70kW/m²). In contrast, fabric woven in plain weave, because of maximum number of interlacements (resulting in highest compactness), has the highest resistance to radiative heat (5.53kW/m²). Heat transfer factors in all samples also does not differ significantly.

Table 3. Thermal properties of tested woven fabric.

| Properties | Sample       |
|------------|--------------|
|            | Kc_AR | K_AR  | P_AR  | K_AR_CV |
| HTI24 - HTI12 | 1.57  | 1.53  | 1.57  | 1.70    |
| QC, kW/m²  | 5.70  | 5.56  | 5.53  | 5.89    |
| TF Qo      | 0.29  | 0.28  | 0.28  | 0.29    |

The results of mechanical properties in Table 4, shows significant differences between samples woven in different weaves. Fabric sample in the plain weave has the highest breaking force properties comparing to other samples due to its maximum interlacement. Twill 2/2 fabric (Kc_AR) has higher breaking force in warp than in weft direction, than the fabric woven in twill 2/1. Furthermore, the breaking force of Kc_AR is approximately three times lower in warp direction and almost two time
lower in weft direction than the breaking forces of other fabrics. After the washing process, those relations are relatively detained in warp direction, while in the weft direction the values are almost equalized. Properties of elongation at break increases (for even 30%) after conducted washing process at all tested samples. Such changes after washing process occurs because of warp and weft crimp change due to fabric shrinkage/relaxation during washing. This results in lower tensile modules in the first elongation phase, which is reflected in the amounts of elongation at break.

The evidence that textile care (5 washing cycles) does not have negative impact on tested woven fabrics, is conducted test of abrasion resistance to wear, resulting in unchanged results regardless weave nor raw material.

The results of conducted tests of determination of water (resistance to surface wetting) and oil repellence shows that the samples Kc_AR and K_AR does not have resistance properties neither to wetting nor oil, due to non-applied surface treatments. At the same time, sample P_AR reduces its properties of surface wetting resistance for 10%, while the level of oil repellence was retained due to washing process. Sample K_AR_CV which is compound of 68% m-AR/30% viscose FR/2% HPCF under the subjection to washing reduce its properties for 30%.

| Table 4. Physical-mechanical properties of tested woven fabric. |
|---------------------------------------------------------------|
| **Properties** | **Sample** | **Kc_AR** | **K_AR** | **P_AR** | **K_AR_CV** |
| Breaking force, N | Before washing warp | 393 | 1193 | 1228 | 1224 |
| | weft | 451 | 846 | 990 | 806 |
| | After washing warp | 367 | 1117 | 1045 | 1241 |
| | weft | 559 | 597 | 511 | 857 |
| Elongation at break, % | Before washing warp | 10.5 | 28.4 | 31.63 | 32.8 |
| | weft | 10.8 | 20.6 | 24.86 | 19.1 |
| | After washing warp | 12.4 | 37.6 | 24.84 | 41.4 |
| | weft | 15.5 | 15.8 | 19.73 | 22.2 |
| Abrasion resistance to wear, cycle/12kPa | Before washing | > 50 000 | > 50 000 | > 50 000 | > 50 000 |
| | After washing | > 50 000 | > 50 000 | > 50 000 | > 50 000 |
| Water repellence | Before washing | - | - | 90-100 | 100 |
| | After washing | - | - | 90 | 70 |
| Oil repellence | Before washing | - | - | 6 | 5-6 |
| | After washing | - | - | 6 | 4-5 |

4. Conclusion
Conducted research gives an overview of the basic woven fabrics parameters intended for protective clothing, where high protection and comfort level must be obtained. From the obtained results, it can be concluded that the woven fabric cover factor is related to vertical porosity (affected by the weave), the fabric density and the yarn fineness effects the parameter of water vapour transfer rate and thus on the wearing comfort. The smaller cover factors of woven fabric is the faster heat transfer by flame. Woven fabric with more compact structure (which generally have less fabric thickness) will have the highest resistance to radiation heat. Furthermore, such fabrics must be easy to maintain and stabilize, with minimal negative impact on the relevant protective fabrics properties. Changes in tensile properties arising as a result of the washing process have no effect on the properties of abrasion resistance to wear. Furthermore, from the obtained results, we can conclude that raw material composition affects the decrease in water and oil repellence, where greater reductions were observed in samples with raw material composition of 68% m-AR/30% viscose FR/2% HPCF.
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