# IMPACT OF STRUCTURAL FABRIC PARAMETERS ON PROTECTIVE THERMAL PROPERTIES OF FABRIC AND COMFORT

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## ABSTRACT
This paper explores the influence of structural and structural characteristics of woven fabric made from meta aramide yarns on their thermal properties and properties associated with comfort. The aim of the research is related to the objectives of the project that supports this study and publication of this paper, which is development of woven fabric with improved thermal protection properties, produced on conventional weaving machines and designed by various fabric structures on the front and the back of the woven fabric with the selection of high performance fibers.
**Key Words:** thermal protection, protective woven fabrics, firefighter protective clothes

## 1. INTRODUCTION
The profession of firefighting is one of the most dangerous occupations in the world. Firefighters face numerous hazards, especially those of heat, flame, and high temperature exposure. Performing demanding tasks in hot environments is associated with an increased heat stress which is further intensified with use of personal protective clothing since they limit the heat loss and vapor transfer between the skin and the environment. The degree of personal protective clothes thermal and vapor insulation will depend on the fabric thickness, trapped air between layers or in the woven structure and fiber characteristics (e.g., weave, coatings and membranes). Personal protective clothes have to provide a specific protection and minimize subjects thermal and physiological strain in order to avoid injuries and not limit their performance.
Improvements in thermal protection have been created by adding multiple fabric layers to the turnout ensemble which increases the weight and decreases air and moisture transfer necessary for heat loss [1]. An increase in garment weight and bulk makes heat dissipation more difficult and leads to a greater risk of overheating [2].
To reduce the risk of heat stress and to improve the physiological comfort of structural firefighter garments, it is necessary to produce protective suits made from the fabric that will provide sufficient heat and flame protection and at the same time provide a body of overheat which can be achieved by proper fabric construction.
In previous studies of behavior prediction of the woven fabric subjected to different thermal conditions, the material is reduced to a simpler form assuming that the fabric can be identified with almost homogeneous plate material where the fiber volume ratio (the volume fractions) is constant throughout the plate system [3]. Of course, such a situation is not realistic since the fabric is highly complex, non-homogeneous, anisotropic and highly deformable material and, in practice, the fibers, although all aligned, are very rarely uniformly distributed, resulting in a variation in the above-mentioned ratio of fibrous and aerial fraction [4, 5].
Clothing for heat and flame protection is always worn as an outer layer of clothing and should be designed to fit well and to be comfortable.

## 2. EXPERIMENT
In the experimental part of the paper, woven fabric samples in different weaves from meta-aramide fibers and mixtures were studied.

## 2.1 Methodology

### 2.1.1 Determination of structural and construction parameters of woven fabric

Određene su strukturne i konstrukcijske karakteristike uzoraka standardnim metodama i to: finoća osnove i potke, gustoća niti osnove i potke, vez, pokrivni faktor i debljina uzoraka.
The structural and construction characteristics of the samples were determined by standard methods: warp and weft fineness, fabric density, weave, the cover factor and the thickness.

### 2.1.2 Determination of thermal properties of fabric samples

Thermal properties of fabric samples were tested by 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 $HTI_{24} – HTI_{12}$.
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.
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.

### 2.1.3 Measurement of water vapour permeability of textiles

EN ISO 15496:2018 – a relatively simple water vapor permeability determination method (WVP) by the potassium acetate method, which used to absorb water vapor passing through the sample. Based on the potassium acetate mass difference before and after the test, the water vapor transfer WVP / $m^2$Pa/W is calculated.

## 3. RESULTS AND DISCUSSION

Table 1 shows the tested samples and their structural, construction and thermal characteristics. Three of the four samples have been woven in different weavs and are of the same raw material composition. Two of the four samples were in the same weave, but different compositions.

**Table 1.** Structural, construction and thermal characteristics of woven fabric samples

| Oznaka | Composition | Weave | Yarn fineness, Tex | | Fabric density / thr. /cm | | Thickness, mm | Cover factor, % | $HTI_{24}$ - $HTI_{12}$ | $Q_C$, kW/m$^2$ | TF $Q_0$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | warp | weft | warp | weft | | | | | |
| Kc_AR | 98% m-AR / 2 % HPCF | Twill 2/2 | 16,5 | 16,5 | 36 | 23 | 0,56 | 93,8 | 1,57 | 5,70 | 0,29 |
| K_AR | 98% m-AR / 2 % HPCF | Twill 2/1 | 16,5 | 16,5 | 36 | 23 | 0,54 | 99,6 | 1,53 | 5,56 | 0,28 |
| K_AR_CV | 68% m-AR / 30% viscose FR / 2 % HPCF | Twill 2/1 | 18,0 | 18,0 | 31 | 26 | 0,55 | 99,8 | 1,70 | 5,89 | 0,29 |
| P_AR | 98% m-AR / 2 % HPCF | Plain weave | 22,0 | 22,0 | 26 | 20 | 0,52 | 97,1 | 1,57 | 5,53 | 0,28 |

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 were also determined by analyzing the image obtained by Dino-lite microscope, 60x magnification, by placing the sample on a plate with background light. The highest cover factor values have fabric in twill 2 /1 weave , then the twill 2/2 fabric. The smallest cover factor has a plain weave fabric which results from its structure and slightly lower density.
The same table shows the thermal characteristics of the fabric samples such as the difference in the heat transfer indexes to the warming up of the sample at 24 ° C and 12 ° C ($HTI_{24}$ - $HTI_{12}$), the permeability of the thermal flux density (through the sample to calorimeter) ($Q_C$) and the heat transfer factor ($TFQ_o$).
Comparison of fabric samples of equal structural characteristics and different raw material composition shows that the raw material composition affects all three parameters, ie 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 samples with smaller cover factors have a faster heat transfer of flame while the sample in the plain weave, which is most compact (the least thickness - maximum number of interlacements) has the highest resistance to radiative heat (0.53kW / m$^2$), followed by a fabrics in the twill 2/1 (medium thickness - average number of interlacements) (5.56kW / m$^2$) and at the end of the fabric woven in at least compact twill 2/2 weave (the largest thickness - minimum number of interlacements) (0.70kW / m$^2$). Heat transfer factors in all samples are not significantly different.

After the heat action at 180 ° C for 5 minutes, none of the samples ignited, melted, charred, or damaged, resulting in hole formation, meaning that all the samples had high resistance to convective heat. Also, none of the samples did not significantly change the dimensions at the same temperature and duration. Dimension change values ranged from -0.5% to 0.4%.

Figure 1 shows the water vapor permeability of the samples which is correlated to comfort of wearing. From the graph it is apparent that samples with the smallest cover factor, associated with vertical fabric porosity, have the highest rate of water vapor transfer and vice versa.

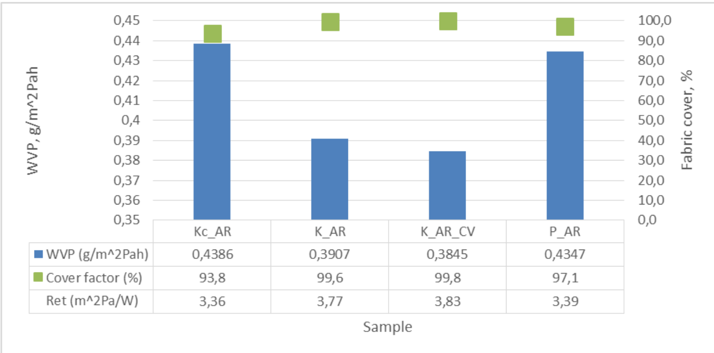


**Figure 1.** Water vapor permeability

## 4. CONCLUSION

From the results obtained, it can be concluded that the cover factor of the fabric is related to vertical porosity, which is affected by the weave, the fabric density and the warp and weft fineness, has an effect on the water vapor transfer rate and thus on the wearing comfort.

Samples with smaller cover factors will also have a faster heat transfer by flame.

Woven fabric of more compact structure, which generally have less thickness, will have the greatest resistance to radiation heat.

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