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Review report on Doctoral Dissertation

of **Otgonsuren Sukhbat**

entitled „**SHAPING THE PHYSIOLOGICAL COMFORT PERFORMANCE OF MULTILAYER CLOTHING ASSEMBLIES FOR FIREFIGHTERS**“

(scientific supervisor Prof. Dr. Hab. Eng. Małgorzata Matusiak)

prepared based on the invitation in accordance with Resolution no. 61/7/IJK/2023 of the Council for Academic Degrees dated July 10, 2023

The review was performed on the basis of the Doctoral Dissertation in English. The doctoral dissertation consists of an introduction with the aim and scope of the work and seven chapters, including literature review related to the Dissertation topic, theoretical consideration of the heat and liquid moisture transfer through textile assembly for protective clothing, presentation of materials used in the research, and implemented methods, presentation of scientific experimental results, in-depth analysis of the results, conclusions and the final conclusion, and a list of references. The doctoral Dissertation contains 192 pages, 97 figures, and 51 tables.

The first chapter “The aim and scope of work” presents the aim of the dissertation, which was “to create theoretical bases enabling shaping the comfort-related properties of the multilayer clothing packages intended for the firefighter’s protective clothing”, and the range of the research work, hypothesis, the research problem and novelty.

The second chapter “The comfort of usage of the firefighter’s protective clothing - Literature Review” presents an overview of the current state of the problem and a review of the scientific literature. In this chapter, properties of the protective clothing, such as thermal comfort water-vapour permeability, liquid transport and the overall moisture management, as well as requirements for firefighter’s protective clothing considering environmental conditions of the firefighter’s work and construction of the firefighter’s protective clothing were overviewed and summarized. At the end of the chapter, conclusion from the literature review is presented. The literature review is based on 118 literature sources (with exception of 4 articles published by the author of the Dissertation and based on results presented in the Dissertation), ~50% of which are scientific papers published during the last 10 years.

In the third chapter “Theoretical considerations of the heat and liquid moisture transfer of textile assembly for protective clothing”, the theoretical analysis and principle of the heat and liquid moisture transfer in multilayer textile packages are presented. Thermal resistance and thermal conductivity are analysed based on structure and properties of individual layers and a set of these layers in the package as a whole, considering that there can be some distance (air spaces) between the individual layers which also has influence on the heat conductivity and resistivity. Liquid moisture transfer in a multilayer textile assembly is analysed based on wicking and wetting processes and properties of textile fibres and materials as well as methodology of measurement.

In the fourth chapter "Materials and methods", materials investigated and methods used are presented. Characteristics of four variants of multilayer textile packages (for protective clothing) and of seven variants of knitted fabrics (for underwear) are presented in this chapter. Also, description of the used methods, such as moisture management test, thermal properties test, water-vapour permeability and resistance test as well as statistical analysis methods are presented.

In the fifth chapter "Thermal insulation properties of textile materials for firefighter's clothing", results of an investigation of the thermal insulation properties of the four multilayer textile sets, seven knitted samples, and twenty-eight assemblies of the multilayer sets and knitted fabrics are in detailed presented and analysed. At the end of the chapter, an extended summarizing conclusion is presented.

In the she sixth chapter "Analysis of the water-vapour permeability properties of textile materials for firefighter's clothing", experimental results of the water-vapour resistance of the four multilayer textile sets, seven knitted samples are clearly and in detail presented. At the end of the chapter, a summarising extended conclusion is presented.

In the seventh chapter "Liquid moisture transport of textile materials for firefighter's clothing", experimental results of the liquid moisture transport properties of the four multilayer textile sets, analysing each layer separately, and of the seven knitted samples in both non-stretched and stretched states, as well as of protective assemblies made of sample sets and knitted fabrics are presented, analysed and discussed. The chapter is ended by summarizing conclusion.

In the eight chapter "Quality assessment of the multilayer clothing assemblies", results of an assessment of the created multilayer clothing assemblies are presented and discussed and summarized in an extended conclusion.

Figures and tables are correct and support the analysis of the findings. Obtained results are commented, explained and compared with results obtained by other researchers.

In the Final conclusions, the summarizing statements are presented.

In the list of references, 169 sources are presented, approx. 50% of which are scientific papers, published during the last 10 years.

In the Dissertation, the author has analysed properties of textile materials and their assemblies for firefighters clothing, such as thermal properties by using Alambeta device, water-vapour permeability, liquid moisture transport that are related to the comfort of a wearer hardly working in an extreme environmental conditions. The topic of the Dissertation fully corresponds to the problems of the field of materials engineering. It is the finished scientific work presenting original results, it has clear and logic description and meets requirements of doctoral dissertations. Conclusions are based on the research results. Results of the scientific research are published in four articles in scientific journals, two of which are from the list of CA WoS, and in four international conferences, two of which were held outside Poland (in Portugal and Germany).

Questions and remarks:

- In the symbols list, in several cases the same symbol is used to present different meanings, for instance, "m"- it is "mass per square meter of fabric", "number of air layer between individual textile layers in clothing assembly" and "number of assessed assemblies (materials). It is a bit confusing.
- It is not clear what exact structure of the investigated knitted fabrics KF3-KF7 is? Are these fabrics knitted in a single jersey pattern from yarns which are a mixture of listed fibres or there are single-plated structures with a strict arrangement of yarns of different fibre composition?

- In the methodological part, it is not mentioned exact percentage of knitted samples stretch used in the moisture management testing. The 15 % value can be found only in the 7.2.1 subchapter.
- Different thickness' values of knitted fabrics are presented in Table 4.2 (page 64) and in Table 5.6 (page 88). How can it be explained?
- Different investigated knitted fabrics represent different thermal properties. The author explained it mainly by thickness of the fabric and raw composition. And what about the influence of the knitting structure which also influences tightness and porosity of the fabric surface?
- The thermal resistance of a material is the inverse of the thermal conductivity. How can be explained that the same knitted fabric, for example KF4, has the lowest thermal resistance and the lowest thermal conductivity in comparison to other investigated fabrics?
- How can it be explained that in some cases thermal conductivity values of clothing assemblies made of four multilayer sets combination with a knitted fabric varies in the ranges of error (for example, SS1, SS2, SS3, SS4 + KF6) and in other cases there is a significant difference between these values (for example, SS1, SS2, SS3, SS4 + KF1 in Figure 5.12, page 100)? The same question is for the results presented in Figure 5.15. However, in Figure 5.18 (page 105), it can be found that assemblies of all knitted fabrics and multilayer set SS3 have the lowest thermal resistance, i.e., investigated assemblies have very different behaviour if compared to thermal conductivity investigation.
- It is stated in the Dissertation that knitted fabrics KF2, KF3, KF6 and KF7 are "waterproof fabrics" (page 136). What is the reason, that liquid absorption, spread and one-way transport so much differ from the knitted fabrics KF1, KF4 and KF4, which were characterized as "water-penetration fabrics" (page 135)? Also, what is the reason that statistically significant difference of WTB (wetting time of the bottom side) was found only between KF6 and KF7 knitted fabrics?
- What would be a recommendation of the author of the Dissertation for the middle layer fabric of the multilayer textile package to improve its water-vapour permeability?
- A reasoning why liquid moisture transport characteristics (especially wetting time of the bottom surface) of the KF2 fabric "most significant" changed after stretching in 15 % would improve the discussion part (the same – for the KF3 fabric).
- How can it be explained why values of Overall Moisture Management Capacity (OMMC) of different variants of assemblies of KF6 and multilayer sample set (SS1 – SS4) are similar, while in the most other cases they are significantly different?
- Final conclusion lacks specificity; it should reflect the results of scientific research.

Conclusion: The presented Dissertation makes contribution to the development of the scientific discipline of materials engineering, at the same time it fulfils all formal requirements set forth in Article 187 of the Law on Higher Education and Science dated July 20, 2018, and conforms to principles and requests to the structure of scientific research for the degree of doctor. In my opinion, the Dissertation submitted by Otgonsuren Sukhbat is ready to be defended orally in front of the respective committee. Therefore, I recommend the Dissertation for the next procedure at the Lodz University of Technology. In case of positive results of the defence of the Dissertation, I recommend awarding O. Sukhbat the title of Ph.D.

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