The influence of the conditions of use of the protective clothing on its mechanical and comfort characteristics

Daniel Onuț Badea[1*] and *Florentina* Poruschi[1]

[1]INCDPM National Institute for Research and Development in Occupational Safety "Alexandru Darabont" – INCDPM, B-dul Ghencea 35A, Bucharest, Romania

Abstract. Protective clothing is used in many work environments, indoors or outdoors. In the case of outdoor use, in particular, the problem arises if it still maintains certain levels of performance regarding the mechanical resistance and comfort characteristics in the situation where it is soaked with an excess of moisture due to perspiration while working at above temperatures. 30^{0}C, in the context of current climate changes. The idea of such a study is an original idea, considering the hot periods of recent years and the observations received from users who request articles of protective clothing that are as comfortable as possible. The study proposes that on a first series of 5 materials used to make protective clothing for welders or electricians, who by the nature of the activity work indoors, as well as in the outdoor environment, attempts should be made to determine the tear resistance and some parameters which give some indications regarding the comfort of the users (permeability to water vapor and permeability to air) in different humidity conditions of the tested sample.

1 Introduction

Although today there is more and more talk and action for the automation and digitization of work, there are still enough jobs where it is necessary to use personal protective equipment and many of these involve the use of protective clothing. In particular, this study refers to protective clothing used in workplaces where thermal stress is ubiquitous.

For working in hot environments, there is no regulation that defines the temperature levels from which it can be considered that the activity is carried out in the presence of heat, i.e. that it represents a heat stress risk factor for workers. In specialized literature, temperatures above 30^{0}C for a sedentary activity and above 28^{0}C for a job that requires physical effort are considered working in a hot environment. Thus, for workplaces in iron and steel, metal or glass processing, the main source of heat is the radiant or convection heat emitted by the molten material (metal or glass). In the case of kitchens, canneries or laundries, the risk of exposure to heat is determined by the combination of the temperature of the working environment and the very high humidity. For works that take place in the outdoor environment (for example in construction, public works or agriculture), the main source of

* Corresponding author: dbadea@protectiamuncii.ro

heat is the sun and the main risks are determined by the high temperature in summer and the presence of ultraviolet radiation.

Because it is very difficult to cover all the working conditions in the workplaces mentioned above, we have proposed that in this study we focus on the textile materials used to make protective clothing for welders or electricians, who can perform their professional activity both indoors and outdoors. Another aspect taken into account is the fact that at these workplaces, the productive activity can also be carried out in open spaces, and so in this case, not only the worker is exposed to environmental conditions, but also the materials from which the protective clothing is made.

In this sense, it should also be mentioned that in recent years, due to increasingly longer periods of hot temperatures, users are requesting protective clothing made of the lightest possible materials and which still ensure:

- the technical characteristics corresponding to the protection requirements against the cumulative action of risks in the work environment, depending on the level, intensity and duration of exposure to them;
- the comfort characteristics that allow the maintenance of the wearer's state of health and psycho-physiological and motor characteristics, respectively the way in which the wearer can perform the movements required by the work process, as well as their precision, and the coordination of these movements;
- a reasonable lifespan, considering that for most workplaces, the main risks (heat and/or fire, chemical, biological, etc.) are associated with mechanical risks (abrasion, snagging, tearing, cutting), which lead to wear quick attrition of protective clothing.

2 Experimental aspects

Since the comfort sensation of a textile material can be characterized by a multitude of characteristics (flexibility, compressibility, elasticity, porosity, roughness, thermal character, etc.) and is impossible to quantify by a single physical property, for this study we have focused on two features, respectively:

- air permeability determined by the method of SR EN ISO 9237:1999 «Textile materials. Determining the air permeability of textile materials», because it is a characteristic of the materials through which comfort can be quickly appreciated. Air permeability helps to quickly remove sweat from the user's skin and dry the garment
- resistance to tearing by the method of SR EN ISO 13937-2:2001 «Textile materials. Tearing properties of flat textile materials. Part 2: Determination of tearing force on trouser specimens (Single tear method)', as it is the test method specified in the requirements standards in the case of protective clothing against the risks determined by the presence of heat and/or fire. In this sense, it should be noted that the resistance to tearing is a very important parameter for protective clothing, because while the tearing of the material can occur due to a high stress in a certain direction or due to the aging phenomenon of the material as a result of repeated maintenance or when exposed to abrasion, tearing can frequently occur as a result of the clothing product being caught either by protruding elements (wire ends, rubbing against rough surfaces, etc.) and tearing causes holes that directly affect the level of protection by creating the possibility of penetration inwards to the skin level of sparks or metal droplets from welding, or of chemicals or biological agents.

To study these parameters, were selected six samples of materials frequently used in the manufacture of protective clothing, which have various fibrous compositions and different specific weights, presented in table no. 1.

Table 1. Materials studied.

Sample	Fibrous material composition	Fibrous material composition	Mass per surface unit (g/m2)
1	Art. Sonora	80% Bbc + 19% PES + 1% AS	185
2	Art. Resistech	75% bbc + 24% PES + 1% AS	275
3	Art. Nomex 265	98% fibre aramidice (93% Nomex/ 5% Kevlar) şi 2% AS	265
4	Art. Wooltechs	54% Viscoza FR + 20% Lână + 20% PA + 5% fibre aramidice+1% AS	375
5	Art. 345	26% Bbc + 41% PES + 32% modacrilice+1% AS	330
6	Art. Fiji	99% Bbc +1% AS	220

3 Tests performed within the study

To carry out the study, the test conditions were established, respectively:
- Carrying out tests on samples in new condition, so that there are terms for comparison; -
Carrying out tests after maintenance pretreatment at the minimum number of treatments specified in the requirements standards (5 washing cycles) and the maximum number of washing cycles declared by the manufacturers of protective clothing (the number of 50 washing cycles was taken into account, as being the most frequent) and performing tests in the dry and wet phase of the material;
- Carrying out tests after conditioning for 7 hours in a salt water solution (25 g salt per 1 liter of water), to simulate working conditions in a sweaty state of the worker and the article of clothing, also on samples in a dry state and in wet wet condition, to see if the parameters under study are affected.

Pre-treatment by washing was carried out according to standardized methods, namely SR EN ISO 6330:2012 «Textile materials. Domestic methods of washing and drying for testing textile materials», by procedure 6N (washing at 60 ^{0}C and drying in the dryer at 70 ^{0}C).

The coding used to interpret the results and graphs in the study is as follows:
- Initial – material in new condition;
- 5 UP – material subjected to 5 wash and dry cycles;
- 50 SUS – material subjected to 50 wash and dry cycles;
- SOL SAR US – material subjected to 5 washing cycles and kept for 7 hours in salty solution and dry;
- 5 SUD – material subjected to 5 washing cycles and tested in a wet state;
- 5S+SOL SAR UD – material subjected to 5 washing cycles and kept for 7 hours in a salty solution and tested in a wet state;
- 50 SUD – material subjected to 50 washing cycles and tested in a wet state;
- 50S+SOL SAR UD – material subjected to 50 washing cycles and kept for 7 hours in saline solution and tested in wet condition.

The results of the tests performed on the material samples are presented below, in tables no. 2, 3 and 4.

Table 2. Air permeability results in mm/s (equivalent to l/m^{2}s).

Sample	In new condition	5SUS	50SUS	SOL SAR US	5SUD	5S+SOL SAR UD	50SUD	50S+SOL SAR UD
E1	269,54	247,49	224,78	189,71	155,98	55,14	203,41	184,03
E2	112,22	105,54	115,23	63,13	57,75	60,96	53,17	18,54
E3	141,62	147,29	162,66	74,25	144,29	38,74	152,30	6,35
E4	28,69	38,51	38,64	18,50	4,73	0,74	2,08	4,18
E5	58,58	64,96	70,14	71,48	23,98	9,25	47,03	48,06
E6	119,24	173,35	141,95	123,58	77,35	4,28	111,89	44,09

Table 3. Longitudinal tear strength results in N.

Sample	5SUS	50SUS	SOL SAR US	5SUD	5S+SOL SAR UD	50SUD	50S+SOL SAR UD
E1	15,08	16,31	12,63	19,73	17,21	14,51	17,00
E2	29,80	31,28	32,15	30,56	31,39	31,31	29,31
E3	73,36	54,36	75,27	53,34	54,46	55,30	61,64
E4	51,33	52,50	54,95	39,09	39,13	42,70	42,65
E6	28,70	30,47	28,91	29,24	28,23	23,97	26,13

Table 4. Transversal tear strength results in N.

Sample	5SUS	50SUS	SOL SAR US	5SUD	5S+SOL SAR UD	50SUD	50S+SOL SAR UD
E1	14,57	15,57	11,95	16,74	14,31	17,76	14,59
E2	26,33	27,87	25,65	28,73	28,91	30,03	28,20
E3	66,20	49,03	61,90	47,46	47,34	47,93	48,77
E4	43,64	26,83	38,33	19,91	20,60	23,39	23,09
E6	22,30	22,20	22,66	20,38	19,55	16,76	18,36

4 Interpretation of results

To Carrying out this study which takes into account both the possible direct sensory effects on the user wearing the protective clothing and the extent to which the materials used still retain certain levels of performance regarding the mechanical resistance and comfort characteristics in the situation where it is soaked with an excess of moisture due to perspiration while working at temperatures above 30^{0}C, is an original idea, considering the

hot periods of recent years and the comments received from users who request protective clothing as comfortable as possible.
For these reasons, various materials with different specific weights and different fiber compositions were studied, some of which have a majority cotton content, which in the specialized literature is recognized as the most comfortable during normal use. Another part of the samples also contains other types of fibers that generally ensure superior mechanical characteristics during wear than those with a majority content of cotton.
The interpretation of the results obtained in this first study is done for each measured characteristic.

4.1 Interpretation of the results obtained for air permeability

One of the important factors currently taken into account in assessing the comfort provided by protective clothing at work is the weight of the product, as the sum of all the weights of the materials included in it, a determining factor in hot and humid microclimate conditions. In addition to this factor, the air permeability of the materials (their breathability) is taken into account, which allows the rapid transport of warm air from the surface of the body, thus contributing to the cooling of the body. The air permeability obtained on the six material samples is shown in the graph in figure no. 1.

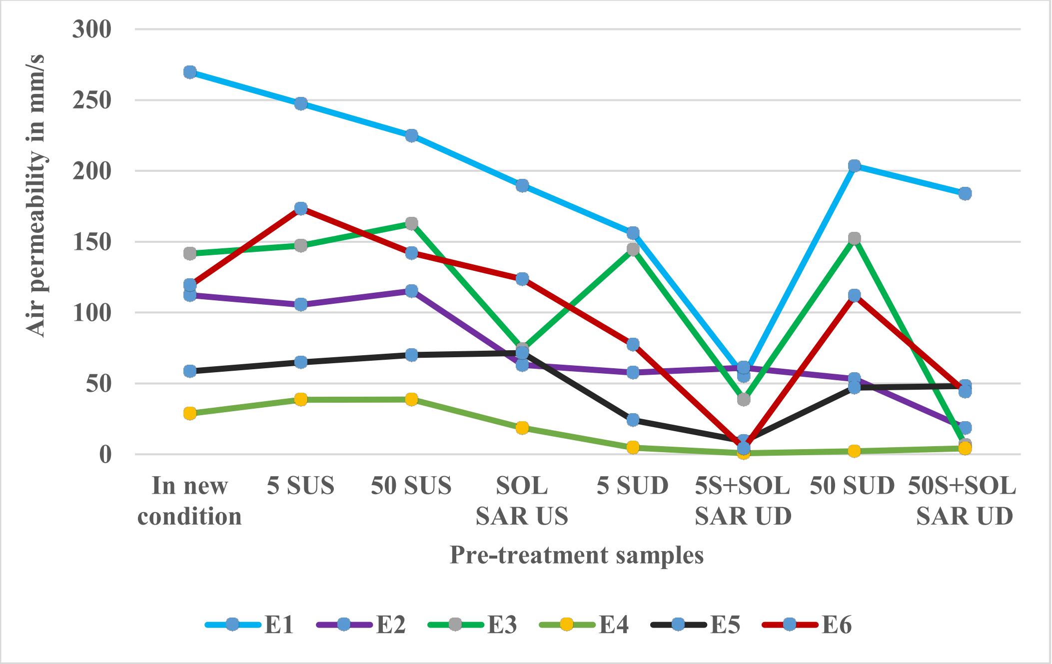

Fig. 1. Air permeability on the samples taken in the study.

As can be seen from the graph, the air permeability is dependent on the fiber composition, specific gravity and material structure (all materials are diagonally bonded, except sample 1, which is cloth bonded, considered a more porous structure). Thus, for E1, E2 and E6 with a cotton content of more than 75%, high values of air permeability in the dry state are observed, but which decreases after pretreatment as a result of the thickening effect after washing and drying, and an even more pronounced decrease for the material in a wet state, especially after exposure to simulated perspiration.

For the sample E3 it is observed that the air permeability is not influenced by the washing pretreatments, but it decreases a lot if it is soaked with the perspiration simulation solution, so it can be concluded that the aramid fiber is damaged by the contact with basic solutions. Sample E4 which contains FR viscose (also cellulosic fiber at the base) and aramid fibers and sample E5 which contains modacrylic fibers and wool shows an almost linear evolution of air permeability, i.e. it does not show major influences after pretreatments and after exposure to simulated sweat contact.
An explanation of the decrease in air permeability would be the fact that in a wet state, through capillary absorption of moisture, the fibers swell and therefore the interstitial space (porosity) of the material decreases significantly. In this situation, it can be said that materials with a medium or low content of cotton or similar fibers would be more wearable in hot periods, considering the fact that a faster exchange of air can be made between the surface of the skin and the surrounding environment.

4.2 Interpretation of results obtained for tear strength

The results obtained for the tear strength are presented in figures no. 2 and 3, in longitudinal and transverse direction. In this case it is mentioned that the sample E5 was removed because it was of insufficient size and for carrying out the tests after the pretreatment at 50 washing cycles.

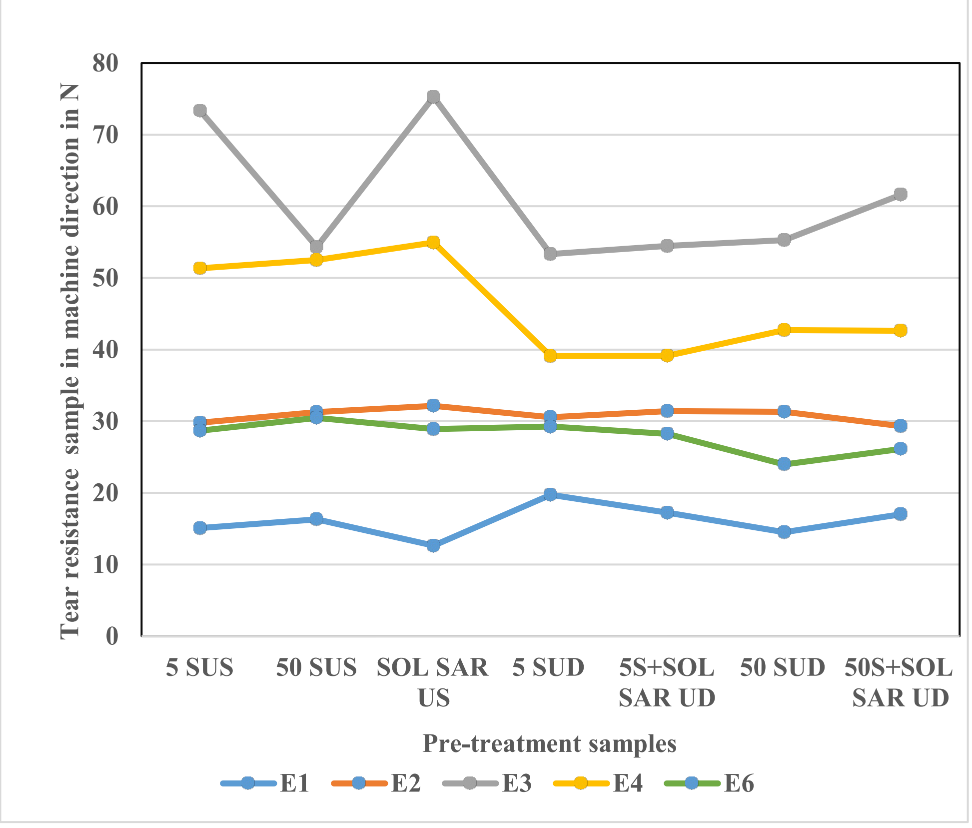

Fig. 2. Tear strength in longitudinal direction (warp).

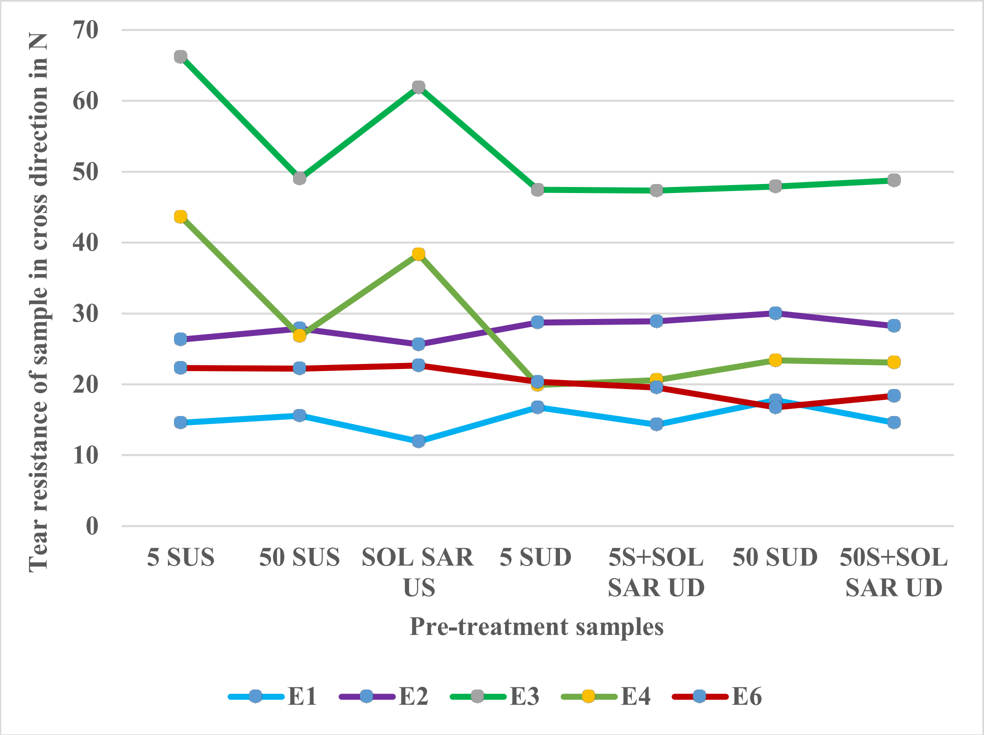

Fig. 3. Tear strength in transverse direction (weft).

Analyzing the obtained results, it is observed that for samples E1, E2 and E6 with a cotton content of more than 75%, the tear resistance is not significantly influenced by pretreatments or exposure to the simulation of contact with sweat, but it is worth noting that in the condition wet, a slight increase in tear resistance can be observed. For samples E3 and E4, what is already known is confirmed, namely the fact that the presence of aramid or modacrylic fibers in the content gives the materials mechanical resistance characteristics superior to those of materials with a high cotton content.

5 Conclusions

With regard to the users' requests regarding the provision of protective clothing made of the lightest possible materials, so as to reduce the wearing discomfort during hot periods, it should be noted that indeed materials with a high cotton content, a low specific weight and a less dense structure , may have better comfort parameters but have lower mechanical characteristics compared to materials with a low cotton content or multiple fiber blends that are not greatly influenced by exposure to environmental conditions and have higher mechanical resistance characteristics. In this case the rapid deterioration of the clothing may cause more inconvenience regarding the injury than a minimal discomfort in wearing. At the end of this small study, we can say that the results of the tests are promising and that the analysis of all the implications regarding the direct exposure of the materials used to make the protective clothing to environmental factors at the workplace (caloric or solar radiation, short-term accidental weather, contact with various substances, etc.), as well as to the factors determined by the wearing conditions (extensive technological movements, frequency of dynamic stresses or soaking with sweat, etc.) is an extensive study that we intend to continue, especially by studying the effect on materials of solar radiation. should be centred and should be numbered with the number on the right-hand side.

References

1. SR EN ISO 9237:1999, Textile materials. Determining the air permeability of textile materials (1999)
2. SR EN ISO 13937-2:2001,Textile materials. Tearing properties of flat textile materials. Part 2: Determination of tearing force on trouser specimens (Single tear method) (2001)