THE RELATIONSHIP BETWEEN COMFORT AND PERFORMANCE IN FR PROTECTION CLOTHING

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ABSTRACT
This article investigates the relationship between comfort and mechanical performance in FR protection garments, considering the physiological and tactile impacts of the use of this equipment in the industrial environment. From the characterization of three fabrics with different flame retardant technologies, tests were carried out according to ASTM, AATCC and ISO standards to evaluate mechanical performance (abrasion and tearing) and comfort (physical and thermophysiological). The fabric with inherent FR fibers achieved the best results in terms of comfort and durability. As a novelty, the study proposes a critical discussion based on the international literature and presents suggestions for methodological advancement for future research.

Keywords: Comfort. Protective clothing. Flame retardant.

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INTRODUCTION

The use of Personal Protective Equipment (PPE) is regulated by Regulatory Standard NR6 and is a legal requirement in several professional activities. However, adherence to the continuous use of this equipment is often compromised by feelings of discomfort reported by the workers themselves. In many cases, the discomfort generated by PPE is decisive for its rejection, even when its use is mandatory. Moura (2006) points out that workers tend to avoid the use of PPE mainly because of thermal discomfort and limited mobility. Similar results were obtained by Monquero et al. (2009), who identified excess heat, difficulty breathing and restricted movements during the use of clothing as the main reasons for refusal.

According to data from the AEAT 2023 (Statistical Yearbook of Occupational Accidents of Social Security), prepared by SEE-Fundacentro (Epidemiology and Statistics Service), 83.65 occupational accidents occur per hour in Brazil, and 2,007.54 per day, totaling 732,751 cases.

These alarming data show that the mere existence of standards is not enough: it is necessary to understand the factors that affect the acceptance and actual use of protective equipment in everyday life.

Traditionally, the main criterion for selecting materials in protective clothing has been technical performance, especially in terms of thermal and mechanical resistance. However, this isolated approach may be insufficient. Scott (2005) points out that PPE with high technical performance will be rejected by the user if it causes discomfort or compromises functional capacity, as occurs in the case of surgical gloves that, even though they offer excellent protection, can be discarded if they interfere with the professional's precision. Therefore, criteria such as comfort, ergonomics, durability, ease of maintenance, and suitability to the design of the task must be weighed in the selection of protective clothing.

In the context of protection against thermal hazards, such as electric arc, it is essential that the fabrics used in garments have effective flame retardant properties. There are currently two main technological approaches to this: the use of flame-retardant chemical finishes applied to natural and synthetic fibers, and the application of fibers with intrinsic resistance to combustion, such as aramid and modacrylic (BAJAJ, 2000; ERTEKIN; KIRTAY, 2014).

In view of this scenario, this article proposes a quantitative analysis of FR fabrics with different applied technologies, investigating how these variations impact the parameters of physical and thermophysiological comfort. The data obtained are correlated with the normative performance requirements, aiming to provide technical subsidies that help professionals in the textile and occupational safety areas in making more effective and humanized decisions in the selection of materials for protective clothing.

General objective:

This work aims to study fabrics with flame retardant technologies, and from this study, evaluate the performance parameters, such as resistance and durability, and compare them with the comfort parameters, such as: smoothness, fit, air permeability, moisture and vapor transport.

Specific objectives:

Obtain physiological and physical comfort quantitatively, through tests, as the feeling of discomfort can be decisive in the correct use of protective clothing.

Relate physiological and physical comfort to work safety, as the use of protective clothing is mandatory (NR 6).

THEORETICAL FRAMEWORK

Occupational safety, as a technical and scientific field, emerged as a response to the high accident rates and labor shortages during the Industrial Revolution. Currently, it is understood as a science aimed at anticipating, recognizing, evaluating and controlling occupational risks capable of compromising the health, well-being and productivity of workers. According to Chiavenato (2009), occupational safety is a set of technical, educational, medical and psychological measures used to prevent accidents and eliminate unsafe conditions in the work environment.

In this context, the use of Personal Protective Equipment (PPE), regulated by Regulatory Standard NR6, constitutes the last barrier between the worker and the risks present in the work environment. (CUNHA, 2006).

However, the practice reveals a persistent challenge: adherence to the use of this equipment is often compromised by discomforts reported by workers, such as restriction of movement, heat accumulation and tactile discomfort. Studies show that comfort is one of the main factors influencing the acceptance and continued use of PPE, and that the perception of protection does not always outweigh the feeling of discomfort, especially when the risks are not perceived as imminent. (LOPES NETO; BARRETO, 1996).

Thus, it is essential that PPE presents not only adequate technical performance, but also characteristics that favor its daily usability.

Among the occupational hazards, the electric arc stands out, which can reach temperatures above 20,000 °C and cause severe burns. To face this type of thermal threat, standards such as NR10 in Brazil and the American NFPA 70E establish strict criteria regarding flame resistance, heat dissipation, and structural integrity of garments.

According to Montenegro and Santana (2012), the worker is able to be more receptive to the use of PPE as it is more comfortable, making its use more pleasant. For this, the equipment must be practical, have high protection, be easy to maintain, be strong and durable. In general, adherence to the use of PPE brings benefits to workers' health, such as greater productivity and a decrease in the number of leaves related to workers' health. Remembering that PPE must be appropriate to the needs of the procedure, and other factors such as comfort, size of the equipment and the type of risk involved are always evaluated in their acquisitions so as not to result in expenses for the company and compromise the execution of the procedure. On the other hand, non-adherence to equipment, when necessary, can result in damage affecting psychosocial, family and work relationships, contributing to the continued occurrence of occupational accidents (BALSAMO; FELLI, 2006; MARZIALE; NISHIMURA; FERREIRA, 2004; TAVARES; SALES, 2007).

The proper choice of fabrics is therefore crucial to ensure not only immediate protection but also the physical integrity of the worker in the event of an accident.

The way textile material behaves in relation to flame can be classified as: combustible, flammable, and non-combustible. The non-combustible ones are flame resistant, while the combustible ones do not maintain the flame because they are part of the fire tetrahedron and when the fuel extinguishes the flame goes out, and the flammable ones are modified and maintain the flame (SEITO, 2008).

The fabrics used in flame protection clothing can be classified into two main groups: those made with fibers that are intrinsically resistant to fire and those that receive chemical flame retardant treatments. In the first group, para-aramid fibers, such as Kevlar® and Twaron®, stand out, which have high resistance to traction, heat and thermal degradation, with a decomposition temperature of more than 500 °C. Meta-aramids, such as Nomex®, offer good thermal resistance and low flammability, and are self-extinguishing when removed from the heat source. Modacrylic fibers, such as those in the Kanecaron® line, have permanent flame retardant characteristics, high chemical resistance and good miscibility with other fibers, which makes them suitable for the manufacture of hybrid fabrics with good aesthetics and comfort (ERTEKİN; KIRTAY, 2014).

In the case of natural fibers, such as cotton, fire resistance is obtained through specific chemical treatments (MIYADA, 2010). FR finishes can be durable or non-durable, being the former preferred for industrial applications due to their stability after multiple washes. Chlorinated tetrahydroxymethylphosphonium (THPC) finishing is widely used in cellulose fabrics, promoting the formation of stable bonds with the fibers, especially when applied by the pad-dry-cure process. (SCHINDLER; HAUSER, 2004). Other techniques involve the use of gaseous ammonia for internal polymerization of the fiber (as in Proban®), or even surface application methods such as back-coating. Non-durable finishes, although effective in the short term, lose their properties after exposure to water or washing, being more suitable for disposable items or those for occasional use.

The structure of the fabric, the composition of the fibers and the finishes applied directly influence the thermal and moisture management properties of the garments. Among the most relevant properties for comfort and thermal performance, thermal resistance (Rct), resistance to water vapor (Ret), thermal conductivity, absorption capacity and capillarity stand out. Fibers with high regain, such as viscose, favor sweat absorption, but also tend to retain moisture, increasing the weight of the piece and promoting a feeling of cold in ventilated environments. Low-regain synthetic fibers, such as polyester, offer greater thermal resistance, but can make it difficult for sweat to evaporate. The porosity and density of the fabric also play a decisive role in ventilation and heat retention, in addition to the type of structure (mesh or flat fabric) and the weight (BORELLI, C.).

According to Slater, (1996), comfort, in the context of protective clothing, is a multifaceted quality that encompasses physical, physiological and psychological aspects. Physical comfort is related to the sensations caused by the direct contact of the fabric with the skin, covering variables such as touch, flexibility, fit and fit of the modeling. Physiological comfort, on the other hand, refers to the interference of clothing with the thermoregulatory mechanisms of the human body — such as conduction, convection, radiation, and evaporation — and depends on the fabric's ability to maintain an adequate thermal balance. The absence of good moisture management, for example, can cause sweat accumulation, adherence of the fabric to the skin and decreased thermal insulation, resulting in thermal discomfort and fatigue. Psychological comfort, in turn, is linked to appearance, style, fashion and social acceptance of clothing, and is also an important variable for adherence to use, especially in specific cultural and organizational contexts (SLATER, 1986).

The microclimate formed between the body and the garment also plays an essential role in thermal comfort. Air layers with a thickness of less than 12 mm favor conduction and radiation, while thicker layers promote natural convection, facilitating ventilation. The geometry of the garment, the fit to the body and the presence of pleats or gaps directly influence the efficiency of this microclimate. Thus, the design of the part must consider both the regulatory protection requirements and the ergonomic elements that favor thermal dissipation (BROEGA, 2010; BAJZIK, 2012).

Comfort assessment can be performed by subjective methods, such as thermal sensation scales and user interviews, or by objective methods, such as tests with thermal mannequins and the application of ISO 11092, ASTM D737 and AATCC TM195 standards. In addition, predictive models studied by Wang (2019), such as Fanger's PMV/PPD or Fiala's segmented models, allow simulating the thermal response of the human body in the face of different environmental conditions and clothing configurations. Recently, digital simulations using software such as Theseus-FE and Modaris have been used to predict regions of heat accumulation, ventilation failures, and the impact of part adjustment on thermal performance.

Therefore, the development of FR protection clothing must go beyond technical fire resistance and consider comfort as a technical criterion of equal importance. The integration between textile engineering, human physiology, ergonomic design and user perception is essential to produce PPE that not only protects, but is used consistently, effectively contributing to safety and well-being in the workplace.

METHODOLOGY

The research was conducted with an experimental laboratory approach, with the objective of evaluating the performance and physical and thermophysiological comfort of three fabrics with flame-retardant properties. The study involved the physical-mechanical characterization of the fabrics, followed by the application of standardized tests to measure properties related to performance (mechanical durability) and comfort (thermal and tactile sensations).

Materials

Three fabrics with different compositions and flame retardant technologies were used:

Fabric 1: 100% cotton with a flame retardant chemical finish.

Fabric 2: 88% cotton and 12% polyamide with flame retardant finish.

Fabric 3: 48% modacrylic, 37% cotton and 15% aramid with flame-retardant properties inherent to the fibers.

All fabrics meet NFPA 2112, NFPA 70E, IEC 61482-2 and ABD 00031 (emission of toxic gases), and have the OEKO-TEX® Standard 100 seal, ensuring freedom of substances harmful to health.

Before the tests were carried out, the fabrics underwent standardized washing in the laboratory, with neutral soap and multiple rinses, with the objective of eliminating chemical residues that could interfere with the results.

Procedures

The trials were divided into three main blocks: physical characterization, performance tests, and comfort tests.

a) Physical characterization of tissues

These tests allow us to establish the comparative basis between the fabrics, isolating variables that influence both performance and comfort.

- Yarn density: performed according to ASTM D3775, with warp counting and weft by fraying on specimens of 5 × 5 cm, using magnifying glass and millimeter scale.
- Weight: determined according to ASTM D3776, from five samples cut with an area of 100 cm^2, weighed on an analytical scale.
- Yarn titer: measured according to ASTM D1059, with 50 cm samples, weighed with controlled pretension of 0.25 cN/tex.
- Twisting of the wires: performed in a torque meter according to ASTM D1422 and D1423, with pretension adjusted proportionally to the wire titer (0.5 cN/tex).

b) Performance tests

Focusing on mechanical resistance, the tests aimed to simulate the wear and tear resulting from prolonged use of the fabrics.

- Abrasion resistance: according to ASTM D4966 (Martindale method), with evaluation by number of cycles until yarn breakage and visual alteration (gray scale).
- Tear strength: according to ASTM D1424, using the Elmendorf device, with five specimens in the warp direction and five in the weft (10 × 7.5 cm).

c) Thermophysiological comfort tests

These tests evaluate the ability of the fabric to allow the dissipation of heat and moisture generated by the human body.

- Moisture transport (liquid): performed with the Moisture Management Tester (MMT) equipment, according to AATCC TM195 standard. Parameters such as absorption rate, wetting time and bidirectional transport capacity were analyzed.
- Steam transport: conducted in the SMTEX equipment, simulating body temperature (36.5 ºC), with collection of thermal data related to the breathability of the fabric.

d) Physical comfort tests

These tests address sensory and tactile aspects that influence the perception of comfort.

- Trim (malleability): evaluated by the cantilever method, according to the angular deformation of the tissue when suspended.
- Smoothness (friction): measured by means of a surface friction test with recording of the force of resistance to movement on the skin.
- Thickness: measured with a high-precision caliper at five different points per sample, according to the specifications of the fabric.

RESULTS

a) Characterization of the Tissues

The data in Table 1 refer to the basic physical characteristics of the tissues studied, before the application of the performance and comfort tests.

Table 1. Characterization of tissues

	100% cotton fabric		**Fabric 88% cotton 12% polyamide**		**Fabric 48% Modacrylic 37% Cotton 15% Aramid**	
	WEFT	**WARP**	**WEFT**	**WARP**	**WEFT**	**WARP**
Density (wires/cm)	22	42	22	41	18	36
Title (Tex)	12,5	13,2	12,4	16,7	11,3	16,9
Twist (twists/m)	528	681	189	294	321	456
Gramatura (g/m²)	309,8		283,9		255,3	

Source: Authors

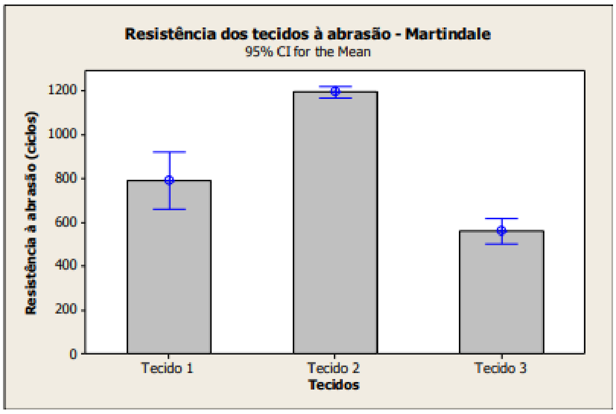
b) Performance Tests

Focusing on mechanical resistance, the tests aimed to simulate the wear and tear resulting from prolonged use of the fabrics.

- **Abrasion resistance**

The cycles in the abrasion resistance table refer to the number of cycles until the rupture of 2 or more threads.

Graph 1 Resistance of fabrics to abrasion – Martindale



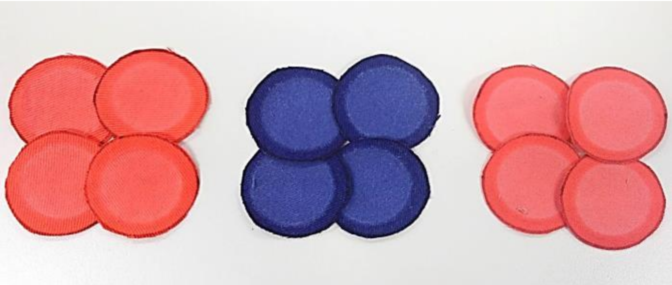
Source: Authors

As can be seen in graph 1, the three fabrics obtained very different results (p=0.000) where fabric 2 was the one that performed best in the abrasion resistance test, this may have occurred because it has polyamide in its composition. Polyamides have a good performance against abrasion due to their micellar structure with chain folding, molecular flexibility and intramolecular bonds, favoring the dissipation of energy transferred by friction.

Fabric 3, even though it is a fabric that has inherent flame retardant fibers, did not do well as expected, this must have occurred due to the low density of threads, excessive twists promoting shear or even the fact that it has a percentage of cotton fibers in its composition, where in an attempt to increase comfort it ended up causing damage to the abrasion resistance of the fabric.

An analysis of the appearance of the tissues after 400 cycles was also performed. The three tissues obtained a score of 2 with the use of the gray scale. (In figure 2, there are tissues 1, 3 and 2, respectively).

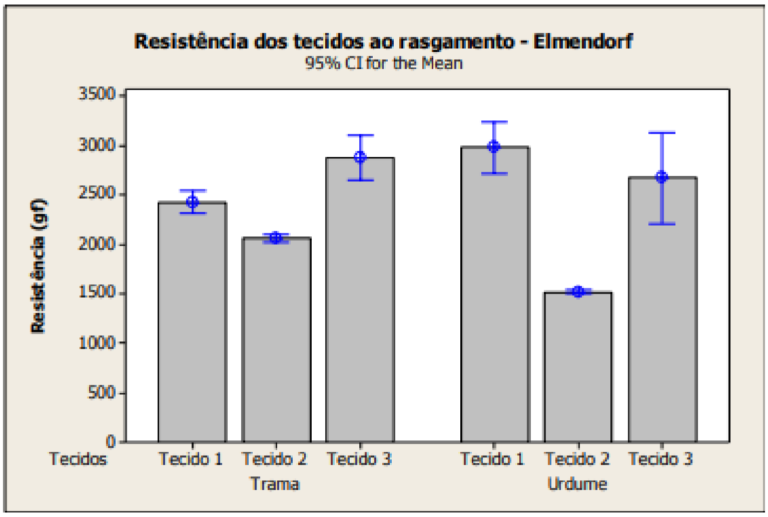
Figure 2. Analysis of the appearance of the fabrics in the abrasion test



Source: Authors

- **Tear Strength**

Graph 2 – Tear resistance of fabrics – Elmendorf



Source: Authors

As can be seen in graph 2, fabric 3 had a good performance, this must have occurred because it has a lower weight among the three fabrics and lower thread density, causing fewer shear points. From the tear strength graph, it can be seen that there were significant differences in the strength of the three fabrics ($p=0.000$), where fabric 2 obtained lower resistance in both directions (warp and weft).

- **Moisture Transport - MMT**

For a better analysis of the results, Table 2 was elaborated, with the means of wetting time, maximum wet radius and diffusion velocity, as these are the main points for evaluating the physiological comfort provided by each tissue, that is, in this way, the evaluation was simpler and more objective.

Table 2 - Summary of the data obtained from the MMT device

Index			**100% cotton fabric**	**Fabric 88% cotton 12% polyamide**	**Fabric 48% Modacrylic 37% Cotton 15% Aramid**
Wetting time(s)	Top surface	Wtt	10,56	11,96	5,27
	Bottom Surface	Wtb	40,63	20,79	5,96
	Top surface	Mwrt	12,00	10,00	15,00

Max. Wet Radius (mm)	Bottom Surface	Mwtb	11,00	12,00	15,00
Diffusion speed (mm/s)	Top surface	SST	0,59	0,55	2,36
	Bottom Surface	Ssb	0,32	0,43	2,25

Source: Authors

The upper surface of the tissue is positioned in the direction of the upper sensor of the MMT device and simulates the behavior of the side of the tissue in contact with the skin, i.e., it is the inner part of the tissue. The lower surface is positioned in the direction of the lower sensor of the MMT device and simulates the behavior of the external side of the fabric in contact with the environment.

Fabric 3 has a lower percentage of cotton fibers, that is, its liquid transport is done entirely by capillarity since aramid and modacrylic fibers do not have the capacity to absorb moisture.

As can be seen in table 2 of the results of the MMT device, this fact affects the internal and external diffusion velocities and the internal and external wetting times, because the cotton fiber has a great affinity with water, promoting the formation of hydrogen bonds, so the water is not transported uniformly, causing longer delays in dissemination. Therefore, the wetting time and the diffusion speed are consistent with the percentage of cotton found in the composition of each fabric.

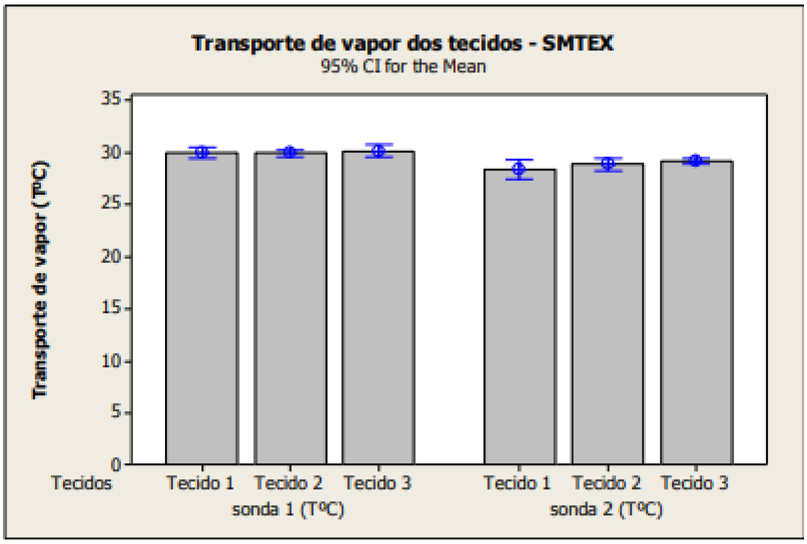
It can be observed that fabric 3 transports a greater amount of liquid per second, providing a greater feeling of comfort, because the transport is quite fast, it gives enough time for the skin to dry itself, promoting a greater feeling of comfort (dry skin), while the fabrics that contain a higher percentage of cotton (1 and 2) can provide a lower feeling of comfort due to the slower transport of moisture.

From the results obtained, it can be seen that again because fabric 3 has its moisture transport by capillarity, its wetness radii are uniform and larger since the water does not have enough affinity with the aramid and modacrylic fibers to the point of making hydrogen bonds, that is, the moisture transport capacity of fabric 3 will be greater because there are no affinity barriers along the course of the water.

- **Steam Transport - SMTEX**

The tests were carried out in an environment with 24.3ºC temperature and 75% relative humidity. This data should be used as a reference to evaluate the results obtained by the SMTEX device.

Graph 3 – Steam transport of fabrics – SMTEX



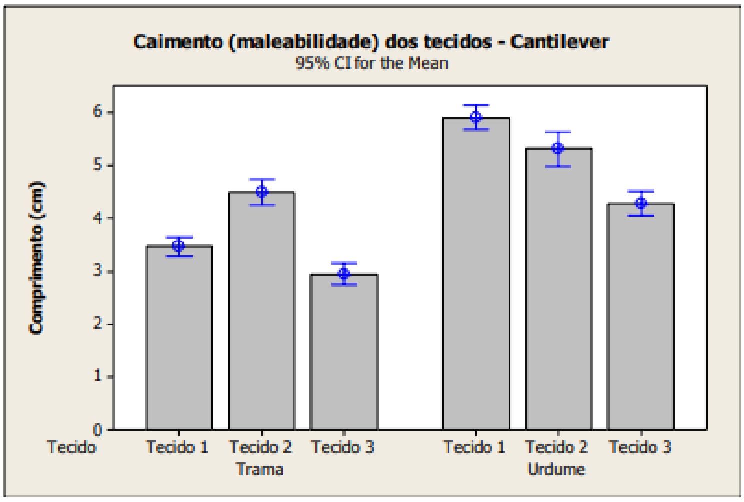
Source: Authors

Probe 1 represents the temperature between the skin and the tissue and probe 2 represents the temperature between the tissue and the environment. As can be seen in graph 3 of the SMTEX results, fabric 1 has the capacity for greater heat exchange with the environment because the temperature differences from probe 1 to probe 2 were 1.6ºC, therefore, it has greater breathability (porosity) causing a greater feeling of comfort (freshness). The porosity of the fabric is the factor with the greatest influence on the water vapor permeability property.

Another factor that may also have influenced the results is the fact that fabrics 1 and 2 receive flame retardant treatment by impregnation. However, in general, these variations are imperceptible in practice, making the fabrics equivalent in this regard. According to ANOVA, probe 1 obtained p= 0.414 (indifferent) and probe 2 obtained p= 0.026 (different).

- **Trim**

Graph 4 - Fit (malleability) of the fabrics – Cantilever



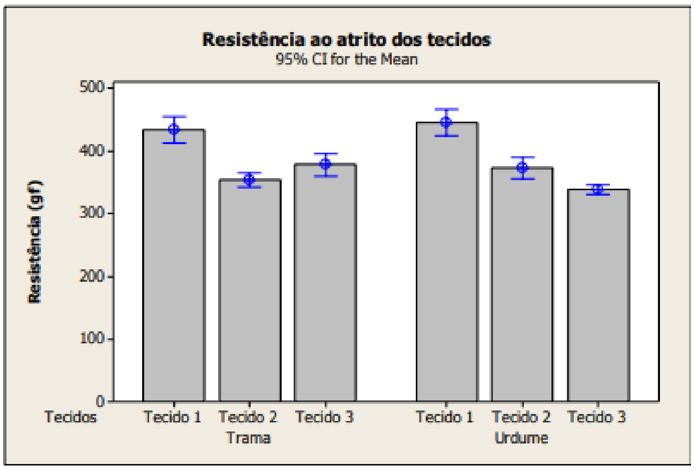
Source: Authors

Graph 4 illustrates the differences that the fabrics present in terms of fit and, consequently, in malleability (p=0.000). Where the malleability of the fabric is the flexural force required for the flexion of the fabric on an inclined plane, which is the same test used for the determination of the fit of the fabrics (cantilever method).

Fabric 3 is the fabric that has the least rigidity, that is, it has a better fit (malleability). This must have occurred because it has a lower density of threads and does not need to carry out flame retardant treatments by impregnation or the use of *wash and wear* resins that stiffen the fabric, unlike the other two fabrics.

- **Smoothness**

Graph 5 - Frictional resistance of the fabrics

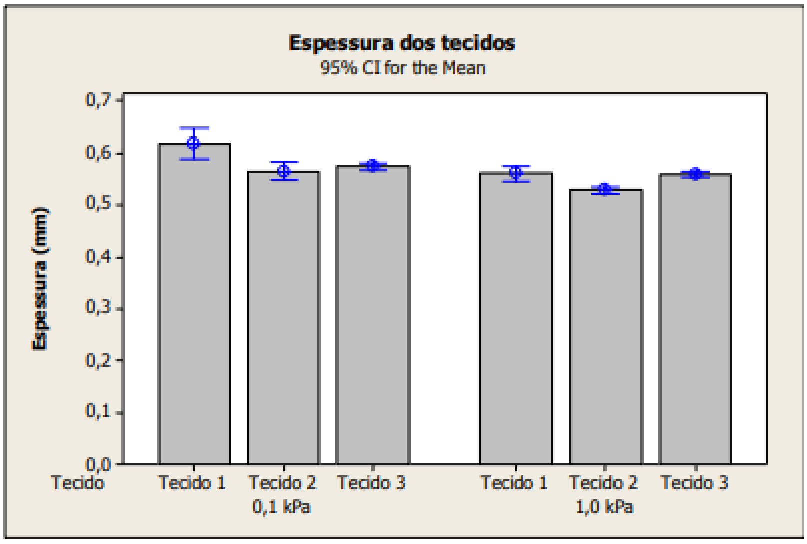


Source: Authors

The fabric that contains the lowest resistance to friction, that is, greater smoothness on the surface, is fabric 3, as shown in graph 5. Fabric 1, on the other hand, had a worse performance in this regard, this must have occurred because fabric 1 had a greater number of twists in the warp and weft directions, which generates greater friction on the surface of the fabric. By ANOVA, weft and warp obtained p=0.000.

- **Thickness**

Graph 6 - Thickness of the fabrics



Source: Authors

As can be seen in graph 6, there is a minimal difference in thickness between the tissues (p=0.000), however, in practice, these variations are irrelevant. It can be said that there is no significant compressibility (softness) between the fabrics, even if mathematically they are different, from a tactical point of view they are indifferent.

DISCUSSION

The comparative analysis of the fabrics used in protective clothing revealed significant differences between the materials in terms of their physical properties, mechanical performance, and physical and physiological comfort. The results obtained confirm that fabric 3 — composed of fibers with intrinsic flame resistance (modacrylic, cotton and aramid) — has superior performance in terms of comfort, especially with regard to malleability (better fit), lower thickness, less surface friction and greater capacity to transport moisture and vapor. These attributes contribute to a greater feeling of freshness and freedom of movement, fundamental aspects for the adhesion and usability of PPE in thermal risk environments.

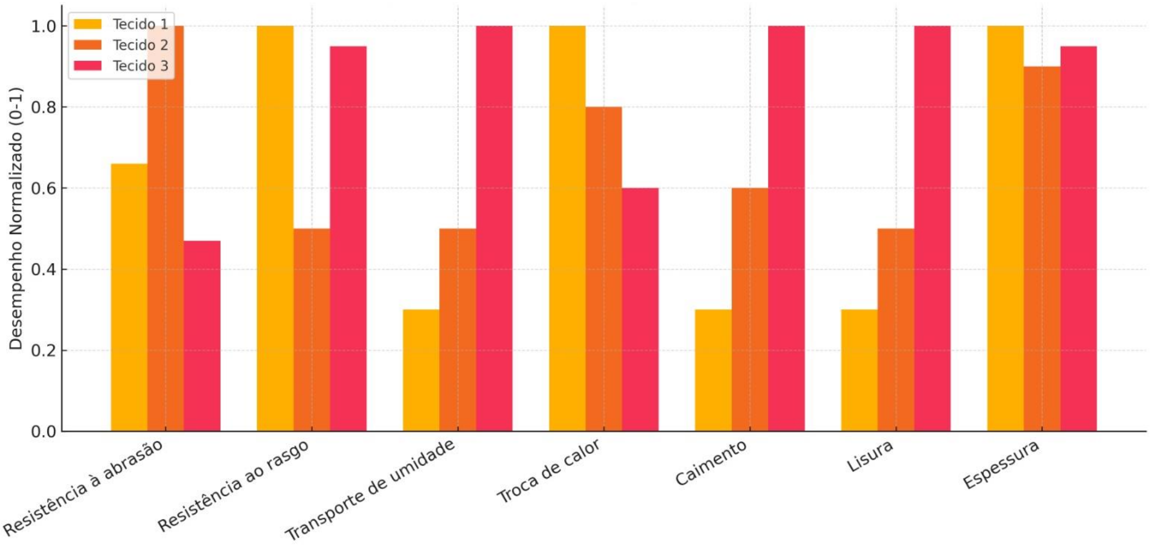
Such results are in line with the theoretical foundations on thermophysiological and physical comfort, which point to the decisive influence of factors such as yarn density, fiber composition, fabric structure and absence of aggressive chemical finishes. As demonstrated in the tests with the MMT and SMTEX devices, fabric 3 promoted greater efficiency in the transfer of heat and moisture from the skin to the environment, which is reflected in greater thermal stability and lower risk of physiological overload under working conditions.

On the other hand, fabrics with flame retardant treatment by chemical impregnation (fabrics 1 and 2) showed greater structural rigidity, greater thickness and lower efficiency in heat and moisture dissipation. In the case of fabric 1 (100% treated cotton), the higher weight, density and torsion confer greater thermal insulation capacity, but compromise physical comfort and abrasion resistance. Fabric 2 (88% cotton and 12% polyamide) stood out for its better abrasion resistance, possibly due to the presence of polyamide, known for its high mechanical resilience and resistance to frictional wear. However, this same fabric performed the worst in tear strength, suggesting that polyamide may have limited the elasticity needed to resist the propagation of stress failures.

In general, the SMTEX results indicated slight variations in the thermal exchange between the fabrics, with a slight advantage for fabric 1 in heat dissipation, possibly due to its greater porosity and grammage. Even so, the results of physical comfort, especially in fit and smoothness, largely favored the fabric 3, which reinforces its ergonomic suitability in conditions of prolonged use.

Compiling all the experimental data, the graph shows this comparative analysis of the evaluative parameters.

Graph 7 – General comparison of tissue properties



Source: Authors

The absence of subjective evaluations in this study represents a methodological limitation. However, the data obtained provide relevant subsidies for future investigations that integrate physiological measurements (such as skin temperature and heart rate) and thermal perception scales, as proposed by authors such as Islam et al. (2023) and Awais et al. (2019). Such approaches could more comprehensively validate the impact of textile properties on the real user experience and assist in the development of protective garments that more effectively reconcile safety and comfort.

Table 2 – ANOVA Analysis

Variable	Statistic F	p-value	Significant difference?
Thickness (mm)	686,59	4.23×10^{-13}	Yes
Tear (gf)	1815,07	1.28×10^{-15}	Yes
Abrasion (cycles)	12283,54	1.35×10^{-20}	Yes
Moisture Transport (%)	998	4.56×10^{-14}	Yes

Source: Authors

The statistical analysis, whose data are shown in Table 3, was conducted using One-Way ANOVA, considering three types of fabric and four variables: thickness, tear strength, abrasion, and moisture transport. The results showed statistically significant differences between the tissues in all parameters analyzed: thickness ($F = 686.59$; $p < 0.001$), tear ($F = 1815.07$; $p < 0.001$), abrasion ($F = 12283.54$; $p < 0.001$) and moisture transport ($F = 998.00$; $p < 0.001$). These results indicate that the flame retardant technologies used confer distinct characteristics to the fabrics, directly affecting both mechanical performance and comfort.

CONCLUSIONS

The results of this study indicate that fabric 3, with inherent flame retardant fibers, presents the best overall performance, especially in terms of physical and physiological comfort, such as fit, smoothness, thickness and moisture transport. In addition, it obtained good results in tear resistance, which reinforces its viability for industrial environments with high thermal exposure.

On the other hand, fabric 2 (with polyamide) excelled in abrasion resistance, but performed the worst in tear resistance. Fabric 1 (100% treated cotton) showed greater stiffness and lower comfort, even with good performance in heat dissipation.

In this way, fabric 3 is the most balanced option for applications that require thermal protection without compromising comfort. However, its lower abrasion resistance limits its use in harsher environments.

It is recommended that occupational safety and ergonomics professionals consider comfort criteria in the PPE selection processes, expanding worker adherence and ensuring effective protection. Future research with real users will be able to validate the laboratory data obtained and contribute to the development of more efficient and comfortable garments.

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