Comparative Study of the Behavior of Seams in Fabrics that Retard the Flames, Subjected to Heat and Fire

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Abstract

The necessary attention given to the selection of base fabric for the protective clothing against heat and fire is, sometimes, neglected when manufacturing the product. Factors such as outsourcing of the sewing process by the companies and the quality inspection only at the end may raise difficulties not only to the supervision of the manufacturing process, as well as to the specification observation of the regulatory standards, enabling the production of ineffective clothing regarding its protective function. The seam flammability of a protective garment against heat and flames can be influenced by factors, independent or combined, such as, for instance, the chemical structure and the fiber geometry that compose the sewing threads, the thread structure, the thread lubrication, the tension in the stitch, the type of stitch and the base fabric flammability. This study aims to compare the behavior of seams made with different kinds of threads, on fabrics with flame-retardant characteristics, subjected to the vertical flammability test.

Keywords: seams, protective clothing, flammability and threads

1- Introduction

Documents from the New Stone age (c. 2,5 millions to 10 thousand A.D.) evidence that the human then already used a costume that would consist in an elementary protection, similar to the loincloth still used nowadays by some wild peoples; in the winter, animal furs were added to it. Therefore, the first protective clothes already appear in the pre-historic period of man. Over time, the costumes stopped serving only for protection and started being used as adornments and also as a way of distinguishing social classes.

The clothes have evolved over time and so have the protection needs. Sure enough, the evolution of certain scientific and technological activities expose the human being to new risks at work: nuclear contamination, chemical contamination, bacteriological contamination, among others. The advance of medicine points to dangers to man’s health, not considered until not so long ago: the ozone layer hole, the exposure to ultraviolet rays, the contaminant garbage and other malefactions of a highly technological, industrialized and consumerist society that can compromise the health and safety of any citizen.

Ergo, these characteristics mark the reality of the contemporary world and, because of this, they motivated the elaboration of this study that has as its specific objective to compare the behavior of seams made with threads of distinct structures and textile composition, made in fabrics that retard the flames when submitted to the flammability test with vertical flame. The health and safety of the workers are systematic concerns of the government, employers and employees, everything to contribute to the welfare and integrity of man. Thus, research in this field collaborates to prevent accidents at work, as well as to cutback expenses resulting from possible accidents.

The outsourcing of the sewing process in Brazil is a very common practice among the companies. According to the Studies and Industrial Marketing Institute (IEMI) data, about 70% of the Brazilian manufacturers have up to nineteen employees and, basically, provide services to bigger manufacturer companies.

In accordance, Silva (2002) asserts that, intending to solve difficulties and to maintain their place in the market, the medium and large enterprises transferred their productive deficiency, essentially the one regarding sewing, to the smaller ones through outsourcing. Under these circumstances, it can be concluded that important aspects related to the manufacturing of clothes are often neglected because of the lack of knowledge, negligence that can compromise the performance of the desired protection, putting the worker at risk. In accordance with Jakes (1974), many factors can contribute – independent or combined – to the seam flammability. Some examples: chemical structure of the fiber, fiber and sewing thread geometry, thread tension, thread lubrication, type of stitch, base fabric flammability, among others.

2- Literature Review

Statistics have been showing that 20% of the fires in residences are caused, in the first place, by textile material burning. As an aggravating, they also show that these fires cause over 50% of the deaths (HORROCKS; PRICE, 2001).

Every year the number of injured and fatal victims of domestic accidents with fire associated to the flammability of fabric rises.

After treatment, the same textile material seen by statistics as the responsible for the fire propagation is being used in the protection of man, with good results. New technologies, fiber blends, research on chemical finishes with fireproof properties allowed the development of several flame-retardant technical textiles. These textiles were conceived in order to reduce the risk of fire propagation in carpets, curtains, mattresses, etc. and to be used in the manufacturing of clothes to protect the man when exposed to risks inherent to certain industrial processes.

Factors That Affect the Flammability in Textile Products

When it comes to natural textile fibers with no chemical treatment, they burn continuously until the combustible material is consumed, even if the source of heat that generates the burning is eliminated. In the synthetic fibers cases, which are not resistant to the flame, they melt. In the flame-resistant fabrics, the burning stops almost instantly when the source of heat is removed (MIYADA et al., 2010).

The behavior of fibers towards fire is influenced – and often even determined – by a series of temperatures of thermal transition and thermodynamic parameters. The limiting oxygen index (LOI)[1] is an inherent measure to the material burning. Products with LOI values above 21% inflame and burn more slowly. In general, fibers and textile products with LOI values of, approximately, 26% - 28%, can be considered as flame-retardant (HORROCKS; PRICE, 2001).

Certain finishes can reduce the textile fibers flammability; they cannot, however, reach total incombustibility. In their studies on anti-flame treatment, Miyada et al. (2010) warn that the amount of heat in calories/gram discharged by the fiber combustion is one of the important factors to the fire propagation to other materials around. A flammable fabric acts as a fire diffuser, intensely liberating its calorific energy.

Fibers Resistant to Heat and Flame

Kadolph e Langford (1998), in the USA, studied the characteristics of these kinds of fabrics. They asserted the fibers can be submitted to temperatures over 200ºC, do not decompose and keep most part of their physical properties. Due to their characteristics, these fibers are produced for special applications, such as, for instance, protective textile material. In most of the cases, their costs are prohibitive for ordinary clothing, furniture and decoration. Some of these fibers cost sixty times more if compared to cotton and polyester, which are commonly found in clothing and decoration.

Table 1.Presents Some Fibers Resistant to Heat and Flame and Compares Their Respective Physical Characteristics of Resistance to Heat and Chemical Agents

[1] Signalizes the capability of the material to ignite on the limit condition of oxygen scarcity.

Table 1- Comparison among the Fiber Properties

Fiber	Tenacity g/d	Dry elongation %	Elasticity %	Regain %	Specific weight	Heat/chemical resistance
Aramid	23	4,0	100	4,3	1,44	Difficult to ignite; does not melt; decomposes at 900ºF, resistant to dilute acids and bases; degraded by strong mineral acids; excellent solvent resistance
Glass	15,3	4,8	100	0	2,48	Does not burn; softens af over 1350ºF, resists most of the acids and alkalis; unaffected by solvents
PBI	2,6-3,0	25-30	-	15	1,43	Does not ignite or melt; chars at 860ºF; unaffected by most acids, alkalis and solvents
Sulfar	3,0-3,5	35-45	100	0,6	1,37	Outstanding heat resistance; melts at 545ºF; outstanding resistance to most acids, alkalis and solvents
PTFE	0,9-2,0	19-140	-	0	2,1	Extremely heat resistance; melts at over 550ºF; most chemically resistant fiber known
Carbon	15,9	0,7	100	-	1,75-2,2	Does not melt, excellent resistance to hot, concentrated acids and alkalis, unaffected by solvents, degraded by strong oxidizers agents (chlorine bleach)

Source: Adapted from Kadolph; Langford, 1998

Heat-Resistant Fabrics

On his paper on the subject, Holmes (2000) says the required fabric properties for heat and flame protection are high level of flame retarding and no contribution to injuries to the wearer; fabric integrity, maintaining a barrier and avoiding direct risk exposure; low shrinking, maintaining a layer of air insulation; good thermal insulation so that it buys the wearer time to escape before the heat and/or fire causes health damage; easy to clean, without reducing or losing their flame-retardant characteristics; comfortable; oil-repelling, protecting against flammable contaminants such as oils and solvents.

Other authors add that the fire resistance of fabrics is also related to the kind of fiber used and to the use of some dyes that can make them more vulnerable to the flame (ARAÚJO; FANGUEIRO; HONG, 2000).

Textile Finishing and Heat Resistance

According to Kadolph e Langford (1998), the fabrics can be produced with flame resistant ability. Therefore, they say, one must use fibers that already have this property or use other fibers that start to have such properties by the addition of flame-retardant during their spinning, or by the application of flame-retardant to the fabric as finishing. These authors teach that the durable finishes are specific for each kind of fiber, taking into consideration its chemical structure and they are usually composed of phosphate or salts, halogenated organic compounds or inorganic salts.

Bajaj (2000) highlights the FR viscose inherent as an example of a fiber with a durable flameretardant property, produced through the incorporation of FR (Flame Retardant) additives in its production process, before extrusion. In this process, the limiting oxygen index (LOI) of the fiber goes from 18% to 27, 5%.

Flame-retardant finishes are also applied over cotton, viscose, polyamide and polyester fabrics. They last from fifty to a hundred washing; are not toxic or carcinogenic. They alter the tactile perception – in the textile area called “hand” –, the textile texture and present unpleasant odor (KADOLPH; LANGFORD, 1998).

3- Materials E Methods

Fabrics

Fabrics of distinct textile composition with flame-retardant characteristics were acquired in the national market. They were: fabrics with heat resistance fibers, fabrics with fiber blends and fabrics with traditional fibers that have flame-retardant finish over the final product.

Sewing Threads

Sewing threads with different structures and textile composition: spun and with continuous filaments; aramid, polyester, cotton or blended fibers were also purchased in the national market.

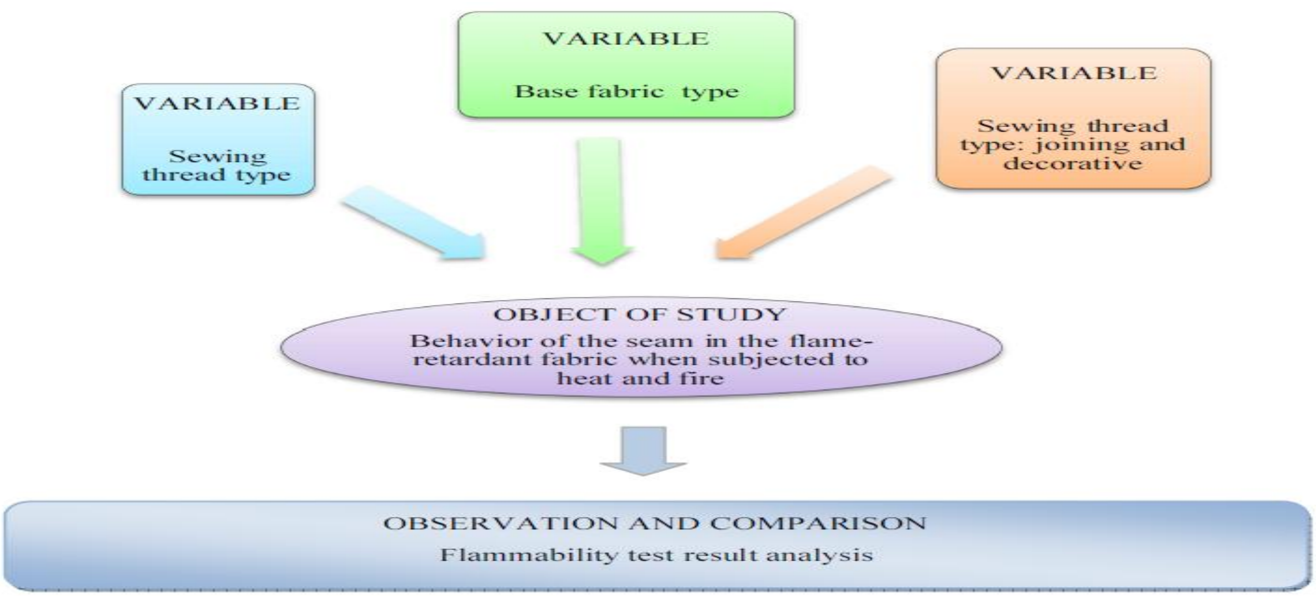
Methodology

The present study proposes the following question: do the heat and the fire interfere in the seam integrity in the protective garment, putting the wearer at risk? By this proposal, the following hypotheses were established which, on the other hand, led to the adopted methodology:

a) Does the thread used in the protective garment seam, according to its textile composition and structure, interfere in the function of joining the fabrics, directly exposing the wearer to the risk?
b) Can the seam, according to the textile composition and structure of the thread used in its formation, spread the fire, putting the wearer at risk?
c) Can the geometry of the stitch interfere in the propagating of flame and fire?
d) Are the textile composition and the fabric structure more relevant than the sewing thread for the mechanism of fire propagation, since their mass is much more significant as flammable material?

To confirm or question the established hypotheses, it was decided to research and, in an experimental way, to compare the behavior of seams, option that defined the methodology of the present study. The illustration on Picture 1 allows visualizing the methodological structure of the research made.

Figure 1: Representation of the Experimental Research Structure

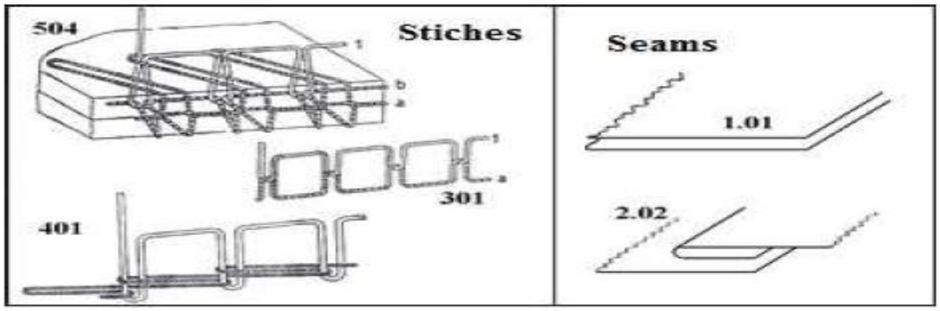


Source: Author

4- Comparative Study

The fabrics were sewn with threads of different textile compositions. There were selected the stitch combination and the types of seams most used in the manufacturing of the protective garments. The representation of the stitches and the sewing classes is in Figure 2.

Figure 2 – Stitches and Seams Used in the Experiment



Source: Adapted from NBR 9397 e NBR 13483

No kind of lubricant was added to the tested threads, as the sewing threads were used with the lubrication from the manufacturer.

Decoration Seam – Embroidery

Embroidery was used as decoration seam, for it is an ornamentation resource very adopted in professional uniforms. There was made an embroidery of, approximately, 2, 500 stitches.

Trial Method

The ASTM 6413 trial method of flammability was adopted. In this method, the bodies of proof are subjected to a heat source for twelve seconds. Finished that period, the heat source is withdrawn, and the self-extinguishing time of the flame in the fabric is timed. It is necessary, then, to observe if there was material melting and dropping.

5-Results

The results obtained with the comparative study made a series of considerations possible, which will be shown in the following sub-items.

Joining Seams

On the vertical flammability trial, the burner is placed in the center of the boy of proof. It was, then, possible to observe that on the inside out, where there is a greater concentration of thread; there was a higher effect of heat and fire in all the tested combinations. For this reason, it was preferable to illustrate this work mainly with pictures from the inside out. The results of the flammability trials on the seams will be presented individually by type of threads, as it follows.

Thread 1: 100% Straight Polyester Filament

The non-extinction of the flame after its removal was observed on the thread 1 (100% straight polyester filament) and fabric B (92% meta-aramid) combination. In this case, the flame only extinguished after consuming all the sewing thread. In Figure 3 picture, it can be observed that the flame kept inflaming, using the thread as fuel.

Figure 3 – Bodies of Proof with Thread 1 after the Flammability Test

Source: Author

Thread 2: Minimum of 80% of Meta-Aramid

Thread 2 (minimum of 80% of meta-aramid) presented the best result of all tested combinations. Such fact was expected, since the meta-aramid fiber is resistant to heat and fire.

The bodies of proof with thread 2 are shown in Figure 4.

Figure 4 – Bodies of Proof with Thread 2 after the Flammability Test

Source: Author

Thread 3: 65% Polyester and 35% Cotton

Thread 3 (65% polyester and 35% cotton) and fabric B (92% meta-aramid) presented unsatisfactory results once the flame only extinguishes after consuming part of the sewing thread. In Figure 5 it is possible to observe that the flame kept flaming for longer than in the other fabrics.

Figure 5 – Bodies of Proof with Thread 3 after the Flammability Test

Source: Author

Thread 4: 100% Spun Polyester and Thread 5: 100% Textured Filament Polyester Yarn Combination

Thread 4 was used in needles and thread 5 in loopers of the 504 stitch. The use of textured filament yarn in loopers and of thread in needles is a very common practice in clothing manufacturing.

The case of non-extinction of the flame was observer in the combination with the fabric B (92% meta-aramid), in which the flame only extinguished after consuming all the sewing thread. In Figure 6 it can be observed that the flame kept flaming, using the thread as fuel.

Figure 6 – Bodies of Proof with Thread 4 and Thread 5 (Textured Filament) After the Trial

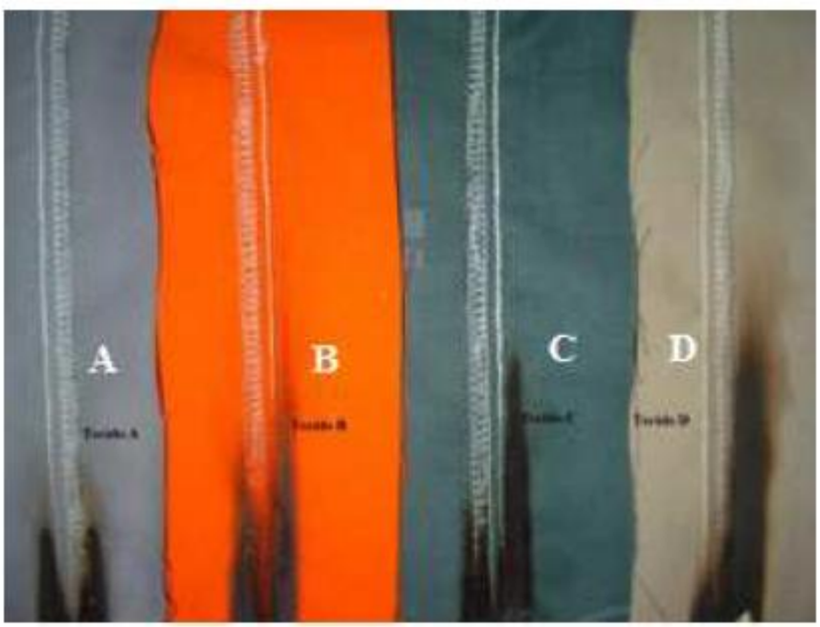
Source: Author

Thread 2: Minimum Of 80% Meta-Aramid and Thread 4: 100% Spun Polyester Combination

This combination of thread was tested because it is common in manufacturing the practice of blending threads, to cutback the production costs, as well as for stock improvement.

In Figure 7 it can be observed that the charred area in the fabric D was bigger compared to the others.

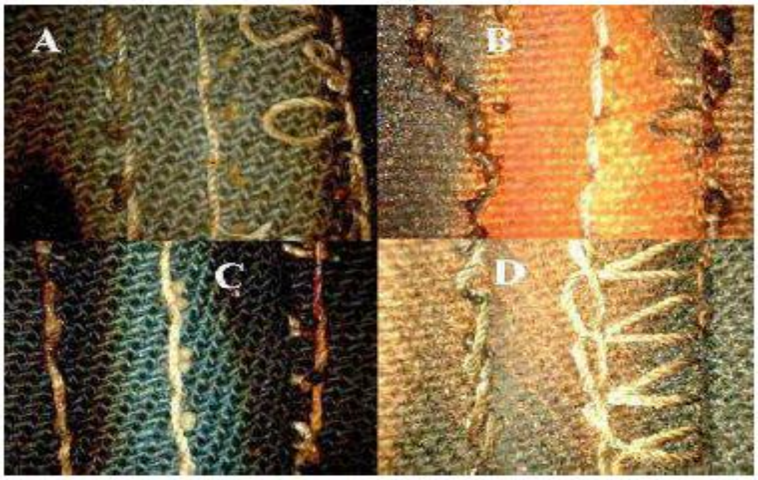
Figure 7 – Bodies of Proof with Thread 2 in Loopers and Thread 4 in Needles after the Flammability Trial



Source: Author

It can be observed in Figure 8 that one of the threads melt and undo the seam stitch.

Figure 8 – Pictures of the Seams Made with Thread 2 in Loopers and Thread 4 in Needles



Source: Author

Embroidery

Thread 6: 100% Trilobal Polyester Filament

After withdrawing the heat source, thread 6 keeps burning until it is totally consumed, as it is shown in Figure 9.

Figure 2 – Embroidery Before and After the Flammability Trial

Source: Author

Result Summary

The specifications of NFPA 2112 were used as a base: flame self-extinction yes means the flame meets the specification and self-extinguishes up to two seconds after the heat source withdrawal, and flame self-extinction no when the self-extinction time exceeds two seconds and does not meet the specification. Table 2 summarizes the flammability trial results.

Table 2 – Results Summary

		Flame self-extinction up to two seconds after the heat source removal				The thread melts
		Fabric A 100% cotton	Fabric B 92% meta-aramid	Fabric C 100% cotton	Fabric D 50% modacrylic and 50% cellulosic and para-aramid	
Joining seam	Thread 1 100% straight PES filament	Meets	Does not meet	Meets	Meets	Yes
	Thread 2 minimum of 80% of meta-aramid	Meets	Meets	Meets	Meets	No
	Linha 3 65% PES 35% CO	Meets	Does not meet	Meets	Meets	Yes
	Thread 4 Thread 5 100% PES staple fiber + textured filament PES yarn	Meets	Does not meet	Meets	Meets	Yes
	Thread 2 80% of meta-aramid in looper + Thread 4 100% PES staple fiber in needle	Meets	Meets	Meets	Meets	Yes
Embroidery	Thread 6 100% trilobal PES filament	Not tested	Not tested	Does not meet	Not tested	Yes

Source: Author

6- Conclusions

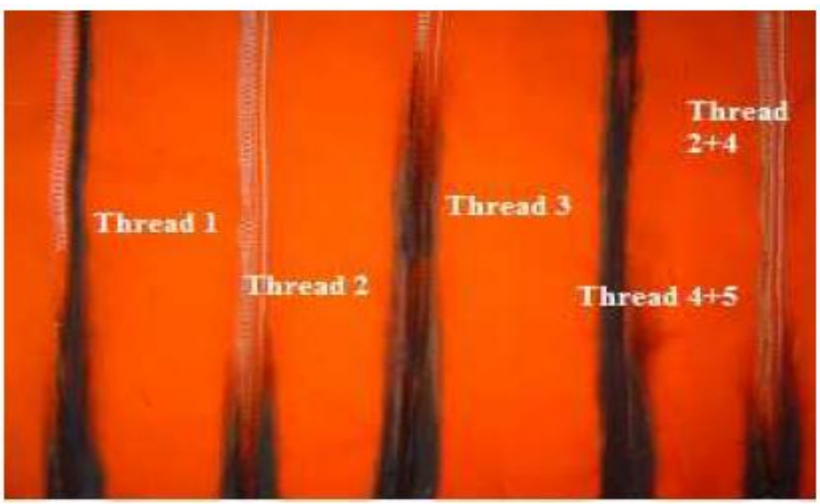
The comparative study showed that the seams made with thread 2 with a minimum of 80% meta-aramid fiber were the ones which met the specifications in the flame self-extinction enquiry up to two seconds after the heat source withdrawal, as well as in not presenting melting or dropping.

The seams with threads that contained polyester in their composition (threads 1, 3, 4 and 5) over the fabrics with 100% cotton fibers (fabric A and C) and fabric with cellulosic and synthetic fiber blends (fabric D) met the flame self-extinction enquiry, in the maximum time of two seconds; however, the thread melted and undid the seam stitch.

A similar observation was mentioned in Jakes's study (1974), regarding the factors that act upon flammability. In the present trial, the FR cotton fabric was less sensitive to the sewing thread flammability than the FR thermoplastic fabrics, obtaining acceptable seams in all tested combinations.

The combination of threads that contain polyester in their composition (threads 1, 3, 4 and 5) with fabric B (91,6% meta-aramid and 8,4% para-aramid) presented the worst combination of results in flame self-extinction and material melting. Such result can be verified in Figure 10.

Figure 3 – Fabric B Bodies of Proof with all the Threads



Source: Author

The retardant mechanism of the aramid fiber that composes fabric B explains the behavior of the polyester thread. In this case, the temperature of fiber pyrolysis rises, and this temperature increase is transferred to the sewing thread which continues to burn even after the heat source withdrawal.

The embroidery seam concentrates a much greater amount of thread than the joining seam. Such concentration, therefore, favors the flame continuity, even after the heat source withdrawal. It can be observed in the trial that the flame only extinguished after consuming all the embroidery thread, i. e. 23,87 seconds in average, after the heat source withdrawal. The amount of embroidery thread ranges according to the number of embroidery stitches. Ergo, larger embroidery must burn for longer.

It can also be observed that the most damaged are the seam stitches that consume a greater amount of thread and that expose more material to the flame. This relation between seam flammability, type of stitch and sewing thread dtex had already been presented in the The Influence of Thread Mass and Fabric Mass on Seam Flammability study, by Jakes, Smith e Spivak (1975).

Final Considerations

As previously mentioned, many factors can contribute – independent or combined – to the seam flammability. For instance: chemical structure of the fiber, fiber and sewing thread geometry, type of seam, base fabric flammability, etc. The present research, as exposed, merely tested some of these combinations, not having, therefore, the pretension of wearing a subject of such unarguable importance.

Another consideration refers to the fact that it was possible to notice that the lack of interaction between the fabric and the sewing thread may result in the failure of heat and fire protection the garment should meet. Only the flame retarding of the fabric itself cannot be used to ensure the garment results as a whole. Neglecting other manufacturing variables endangers the garment safety.

Figure 11 shows a shirt purposely folded, with the inside out exposed, where it can be observed that the shoulder seam was made with a synthetic textured thread, different from the other seams in which the flame retardant thread was used.

Figure 11 – Inside Out of a Shirt in Flame-Retardant Fabric Sewn with Two Different Kinds of Threads: Thread Flameretardant Fiber and Synthetic Textured Filament Thread

Source: Author

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