Coated Fabrics Technology

VOLUME 5

Major Papers from the Journal of Coated Fabrics

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1

A Survey of Possible Approaches to Garment Warmth Evaluation

E. HAUSER

Abstract: The ultimate goal of garment warmth evaluation is to obtain a number or other designation that will reflect the in-use experiences by the customer. This paper takes a look at the problems involved and attempts to arrive at a useful system.

INTRODUCTION

BEFORE DISCUSSING METHODS FOR THE EVALUATION OF GARMENT warmth, there must be an agreement regarding basic definitions and concepts involved. For the purpose of today's discussion, warmth can be defined as being equivalent to the thermal resistance of the garment. Thermal resistance is the property of a material that impedes the flow of heat from a hot body to a cold environment. It is not a temperature and is only indirectly related to "comfortable ranges" or "lower use temperatures."

In the United States, the most common unit of thermal resistance for the evaluation of garments is the clo. It was originally derived from considerations of the clothing necessary to maintain comfort for an office worker, but is rigorously defined in terms of physical constants. For those who are interested, Appendix 1 goes into greater detail. For reference purposes, a nude person in still air has about .8 clo of thermal insulation, principally from the stagnant air layer next to his skin. A normal business suit would add about 1 clo to this, and an arctic explorer's outfit about 4.5 clo.

MEASURING THERMAL RESISTANCE

Having defined thermal resistance, we must now consider the usual methods of measuring it. Unfortunately, thermal resistance is a quantity much harder to measure than the usual physical parameters like time, temperature, or weight. The most reliable method is to measure the heat (usually electrical) required to maintain an object at a desired temperature over a period of time. Examples of this method are the guarded hot plate method and the "copper man." A similar experiment is to measure the rate of

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temperature change of a known weight of material. An example of this technique is a hot water calorimeter, or "water foot" which we have used in some footwear evaluations. A third method is to measure the very small temperature difference across a known and small thermal resistance. This is the so-called "heat flow meter." While such devices have been known for a long time, they have not been widely used due to difficulty in construction. Recently, commercial heat flow meters have become available in various configurations and are quite sensitive. When incorporated into a properly designed system, they are capable of excellent accuracy and precision.

With this background we can now turn our attention to the general sequence of events traditionally used in the scientific evaluation of clothing warmth. It is hoped that consideration of the complete analysis of a new material, Thinsulate Brand Thermal Insulation, will illustrate the various approaches that can be used to evaluate the warmth of garments.

EVALUATING MATERIALS

The first step in the evaluation of a new material is usually an attempt to measure the intrinsic thermal resistance of the material. A simple method is to wrap the test material around a can of hot water and record the loss of heat (temperature) as a function of time. If the water is stirred and the exterior temperature is constant, plots like those in Figure 1 can be obtained. To allow the calculation of the actual thermal resistance the calorimeter must be calibrated. The calibration is basically a two-step process. First, a theoretical analysis of the shape, end effects, and heat capacity must be made. Second, standard samples measured by another method must be run. From measurements on a guarded hot plate, the fiberfill was known to have a thermal resistance of .9 clo/cm and the Thinsulate insulation 1.9 clo/cm. A calculation of the theoretical slopes for this case predicted the fiberfill slope would be 72 percent of the Thinsulate insulation slope. The experimental result, shown in Figure 1, was 74 percent. This insensitivity to thermal resistance change was disappointing; therefore, we decided that we would require a more discriminating method.

The standard for the evaluation of thermal resistance is the guarded hot plate. This apparatus, as shown in Figure 2, consists of three electrically heated areas on a flat surface. Since the bottom guard, and the guard ring are carefully kept at exactly the same temperature as the center, all of the heat (electrical) that escapes from the central area must go straight out through the item being tested. This method gives excellent results, but is tedious to run. By replacing the center section with a heat flow meter, exactly the same information can be obtained much easier, since all of the controls can be made automatic. The one caution is that heat flow meters are subject to long term drift and must be periodically rechecked against standards.

If properly run, this type of equipment should show a straight line relationship between thermal resistance and thickness. Figure 3 shows such a plot for Type "M" Thinsulate Insulation. Note the intercept at .77 clo which is the thermal resistance of the stagnant air layer.

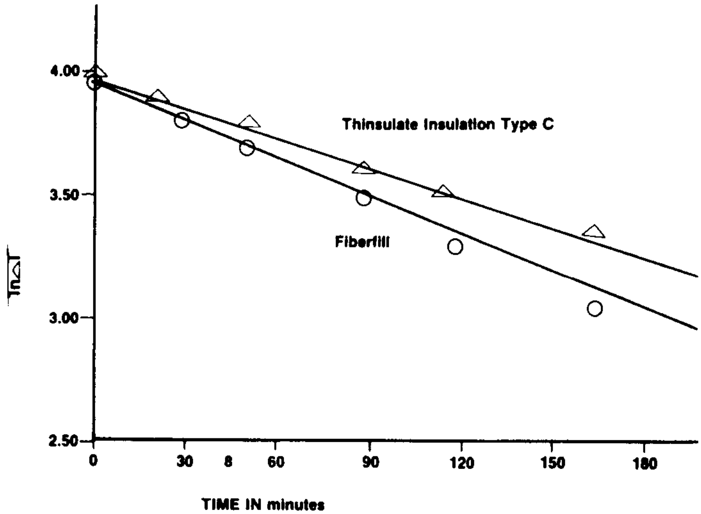

Figure 1. Hot water calorimeter experiment.

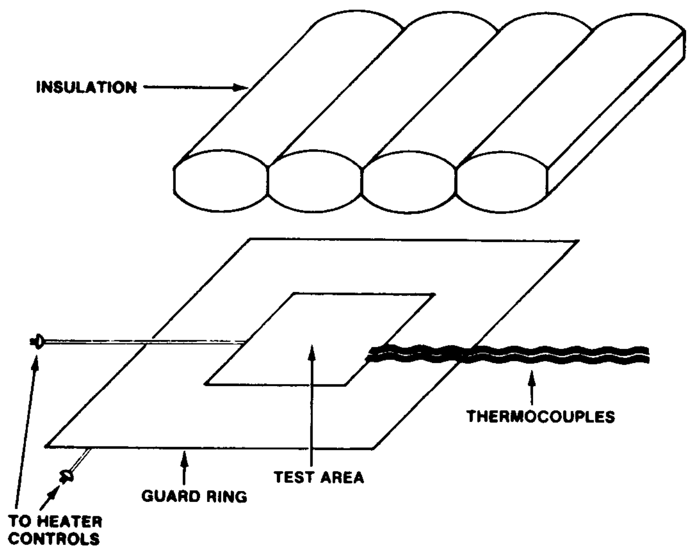

Figure 2. Thermal resistance by ASTM D 1518-64.

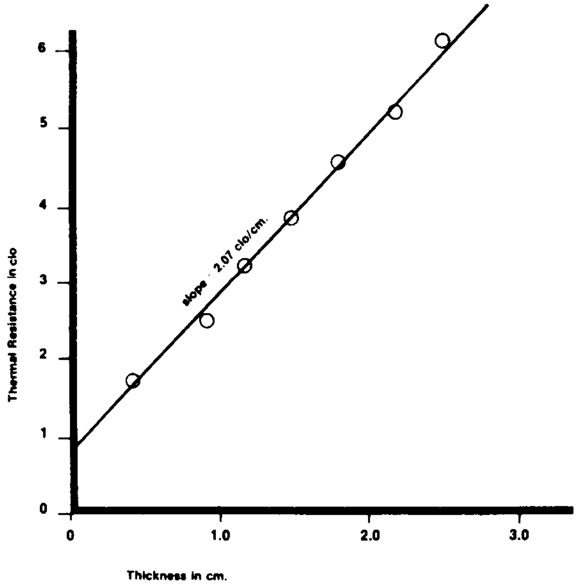

Figure 3. *Thermal resistance of Thinsulate M.*

The presence of wind may be simulated by adding fans to the test chamber. Heat transfer to moving air is very complicated, and the proper simulation of use conditions is beyond the scope of this paper, but some interesting results have been obtained. We have chosen to blow horizontally parallel to the surface of the sample. With a wind speed of .8 m/sec. (2 mph) the bare plate value is reduced to about .26 clo. Table 1 shows some representative effects as a function of insulation type and covering material. Note especially how much more warmth is retained when continuous filament polyester fiberfill is covered by a single layer of fabric.

The horizontal orientation, the flat shape, and the difficulty of evaluating garment construction details, argue for the use of a simulation method close to an actual person. To fill this gap, various antropomorphic devices have been used. The simplest of these is the "water foot," the most complicated is a fully instrumented "copper man."

In our initial investigations of the use of Thinsulate Brand Thermal Insulation in footwear, we constructed a waterproof rubber sock which could be used in the evaluation of various boot constructions. Table 2 gives the comparison of the relative warmth of the various pac boots using this method. Two things should be noted. First, no attempt has been made to eliminate the effects of heat loss out the top of the boot. Second, it is most useful in evaluating boots of similar warmth and construction. In the given example, the two boots are shown to be as warm as the standard even though they are considerably thinner.

Table 1. The Effect of a .8 m/s Wind on Thermal Resistance.

	No Covering		Covered with Nylon Tafeta	
Material	**No Wind**	**Wind**	**No Wind**	**Wind**
Thinsulate C 150 Insulation	1.82 clo/cm (2.36 clo)	1.41 clo/cm (1.9 clo)	1.98 clo/cm (3.07 clo)	2.13 clo/cm (2.73 clo)
Continuous Filament Polyester Fiberfill	.82 clo/cm (2.57 clo)	.25 clo/cm (.86 clo)	.97 clo/cm (3.12 clo)	1.05 clo/cm (2.82 clo)

The values in parentheses are the total thermal resistance of the tested batt.

The next step up in sophistication is an electrically heated manikin or manikin part. Since most of these devices are made from copper, it is usual to refer to the "copper man" or the "copper foot." These devices are very useful but often present significant problems. At one time we were very interested in getting an evaluation of an insulated leather boot on one of the copper feet. We found that it is impossible to put a size 10 copper foot into that particular size 10 boot. Eventually, the test was completed with size 12 boots, but the results are questionable because of the loose fit.

We have had much more success with an electrically heated hand. Table 3 summarizes one study of the warmth of mittens and gloves. Note that the Thinsulate mitten is virtually the same warmth as the fiberfill mitten even though it is about half the thickness. Also note that gloves are about 42 percent as warm as mittens.

In sleeping bag evaluation, the rigid posture of a manikin presents an interesting problem. It is well known that humans tend to curl up when they get cold. Presumably, this will tend to limit the heat loss and raise the apparent thermal resistance of the bag, but it is also not unreasonable to postulate that some designs would lose efficiency due to contact with zippers and compression of insulation. It would be interesting to build flexible manikins for this type of study.

Table 2. Boot Warmth by Water Calorimeter Methods.

Boot	Thickness	Relative Warmth*
Felt Pac Boot	11.9 mm	0.27
M-530 Thinsulate Insulation	9.5 mm	0.25
M-520 Thinsulate Insulation (better Sock Design)	9.5 mm	0.30

*Warmth = 1/S.W.
Where W = weight of water input
S = slope of the plot, in ΔT = a-s (time)
This is proportional to the thermal resistance.

Table 3. Mittens.

Insulation	Relative Warmth
9 oz./yd. continuous filament polyester	16.1°/watt
Thinsulate M-400 Insulation	16.0°/watt
GLOVES	
Sherpa Pile	6.8°/watt
Thinsulate M-200 Insulation	6.5°/watt

HUMAN TESTING

As an alternative or extension of thermal resistance measurements, physiological testing is an attractive approach. Volunteers or subjects are suitably instrumented, dressed in the garments to be evaluated, and placed in a cold environment. The principle problems now become human instead of machine related. Due to the variability of human response, either a large number of replicate tests must be made or the subjects must be constant and "calibrated." By calibrated, I mean that the same subjects are used often enough and with enough standard uniforms so that their response is known. Dr. Bill Kaufman, of the University of Wisconsin, Green Bay, has produced some interesting results testing sleeping bags in this manner. The applicability to individual garments as opposed to complete outfits is somewhat less clear.

Experimental design is critical to the success of this type of study and should be done in consort with an experimental physiologist.

Next on the scale of difficulty and closer to reality, is testing in the field under actual use conditions. This can be roughly divided into two approaches. The first is the use of large groups in double blind evaluation. The other is the use of small numbers of trained experienced observers. Each has its advantages and each its own set of problems.

Large scale double blind field testing can give much information on consumer preferences, durability, and warmth if it is carefully done. In our initial evaluations of Thinsulate Brand Thermal Insulation in gloves and mittens, we attempted to use approximately 100 testers for each design. Each participant was given two pair of gloves identified only by a neutral letter. At the end of a specified time, one pair was returned and a questionnaire filled out. A typical question and results are shown on Table 4. The greatest problem with this type of evaluation, aside from cost, was the cross talk between fit, comfort, and forcing function. For example during warm weather, 15 percent of respondents picked the fiberfill insulated mitten as being as warm or warmer than the Thinsulate "M" insulated mitten, but during cold (below °F) weather, 100 percent picked the Thinsulate insulated mitten as being warm or warmer than the fiberfill insulated mitten.

Small groups of experienced evaluaters can be extremely valuable if proper allowance is made for their prejudices. For example, we had one respondent say "my 12 years in the arctic tell me that the thicker one is warmer; therefore, *I did not wear* the other one."

On the other hand, expert field evaluation has been very informative during the development of Thinsulate Brand Thermal Insulation. Information about the durability and esthetics of a product are available much quicker than from more elaborate field tests.

THERMOGRAPHY

Thermography has received much attention recently as a method of evaluating the thermal efficiency of everything from coats to houses. Basically it is a method of visualizing the surface temperature of an object. Since under identical conditions, a better insulated area has a lower surface temperature, it is possible to make comparisons of thermal resistance. Unfortunately, it is difficult to quantify the meaning of color or brightness differences in a photograph. Also because the electronics are very adjustable, side by side comparisons on the same film are the only valid use of the method. Figure 4 shows a ski jacket with Thinsulate Insulation on the left side and polyester needle punch on the other. The dark indicates that the Thinsulate side is coooler and therefore, is retaining more heat.

A comparison on a hot plate shows that the total thermal resistance of the needle punch side was about 1.6 clo and the total thermal resistance of the Thinsulate side about 2.2 clo. Because it can look at small areas, thermography is an excellent way to evaluate the effects of garment details. For example, the quilt lines in a down sample stand out quite vividly in Figure 4.

The double quilted Thinsulate Insulation in Figure 5 shows the increased uniformity obtainable with this type of construction. These thermographs were made by gluing panels to containers of hot water illustrating one way it is possible to get true comparisons.

Having described a complete evaluation scheme for a new thermal insulation material and by implication of a complete scheme for an evaluation of a new garment, it is time to consider what practically could be done to evaluate

Table 4. Warmth of Ski Mittens: Question: How Warm Was Your Mitten? All Responses (20 Responses).

	Relative Warmth		
	Cold	**Adequate**	**Warm**
Thinsulate Insulation	(2.7) 0	5%	95%
Fiberfill	(2.5) 5	10%	85%
Testers who were out below zero (5 responses)			
Thinsulate Insulation	0	0	100
Fiberfill	20	20	60

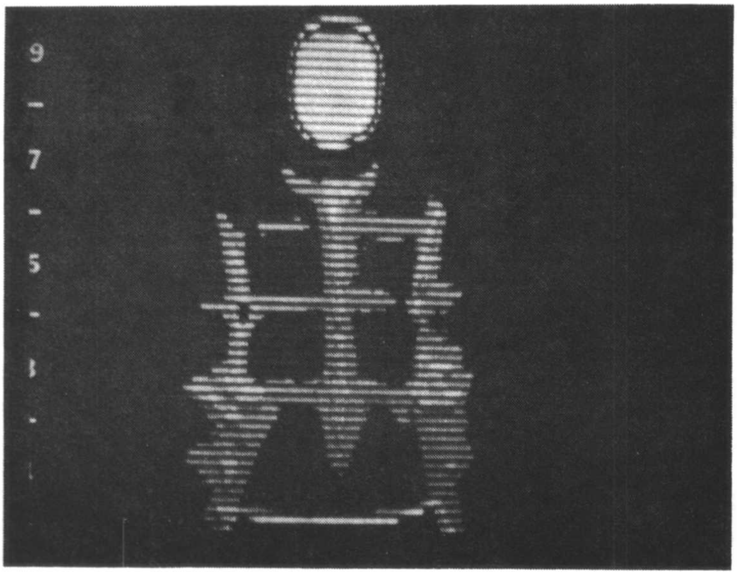

Figure 4. *Thermogram of a down jacket.*

Figure 5. *Thermogram comparing down (rt. side) with Thinsulate insulation (left side).*

garments prior to sale. Any practical scheme will have to fulfill a number of relatively rigid requirements. First, the cost of testing will have to be reasonable. This obviously eliminates the large scale field testing of all styles. Limited cold room physiological testing may be possible. Surely simple thermal conductivity measurements are not out of the question. One commercial lab was charging $50/test a few years ago. Secondly, the results should be relatively easily interpreted. The clo scale is probably suitable here. With a minimum of education, most people should be able to come to a personal assessment of how much thermal resistance they require of garments for their customary activities. The use of a clo scale should help eliminate the tendency of unthinking people to say "but the tag said it was good to 20 below and I got a cold at . . . " without thinking that they require more or less clothing than average. The system should be relatively hard to fool. There will always be some fringe suppliers who will try to sell inferior goods if they can. Personal testimony and Thermography both can be easily manipulated and thus I would not recommend either as a basis for a rating system.

My suggestion for an evaluation system is to investigate the possibility of using a modification of the copper manikin to simulate the heat loss through the main body panels of the item. This would then be used to develop an approximate thermal resistance value for the whole garment. Coupled with consumer education, this would give the buyers much more information than they now have.

Specifically, we are intending to construct a model shaped somewhat like a torso with a 4 inch square heat flow meter in the center. This would be electrically heated and placed upright in a controlled environment. By making measurements on both front and back, an average thermal resistance could be calculated. Since the temperature control can be completely automatic, the cost per test should be relatively reasonable. By not attempting to completely simulate the complicated shape of the human body, the equipment should be within reach of many laboratories.

In developing the standard test sequence for garments cross comparison between full manikins, physiological cold room testing, and field evaluations will have to be made to assess the accuracy and precision of the testing. It would be hoped that this type of testing could achieve a coefficient variation of about 10 percent and a correlation coefficient with other methods of about 90 percent.

APPENDIX I

The clo is formally defined by the following equation:

$$I = [c(T_h - T_c)\,(A)\,(t)]/H$$

where:

I = Thermal resistance
T_h = The temperature of the hot side
T_c = The temperature of the cold side

A = The area
H = The heat transferred
t = The time
c = A proportionality constant to adjust the units to those desired.

If T_h and T_c are in °C, A in m², H in kcal, the $c = 5.55$ and I is in clo. If T_h and T_c are in °F, A in ft², t in hrs., H in BTU, then $c = 1.136$. I is still in clo. By the way, this also defines the conversion factor from the engineers "R" value to the clo.

The above formal definition of the clo was originally derived by A. P. Gagge, et al.*, from consideration of human comfort and clothing requirements. They assumed that a normal, average human seated quietly in a 21 °C (70 °F) room would be comfortable if he were in thermal equilibrium with his surroundings and would be wearing 1 clo of clothing. Knowing the surface area of the average man (1.8m²), the metabolism rate (50 kcal/hr m²), the skin temperature (32 °C) and that 76 percent of the heat loss occurs through the clothing, it was possible to calculate the total thermal resistance. From other experiments it was known that with little air movement the still air layer next to the skin has a thermal resistance of about (.14 °C) (hr) (m²)/kcal. Subtracting this from the measured value of .324 °C hr. m²/kcal leaves a thermal resistance of .18 °C hr. m²/kcal for the clo of clothing the person was assumed to be wearing.

APPENDIX II. CONVERSION FACTORS FOR THERMAL RESISTANCE AND TRANSMISSION UNITS

Resistance Units

From:	Multiply By	To Get
L I_{clo}	.648	r_c(°C sec. m²)/cal.
I_{clo}	.88	R(°F hr. ft²)/BTU
I_{clo}	.18	r_m(°C hr. m²)/Kcal.
r_m(°C hr. m²)/Kcal	5.56	I_{clo}
R(°F hr. ft²)/BTU	1.136	I_{clo}

Transmission Units

From:	Do	To Get
I_{clo}	$1.54/I_{clo}$	$t_c$cal/(°C sec m²)
I_{clo}	$1.136/I_{clo}$	U BTU/(°F hr. ft²)
I_{clo}	$5.56/I_{clo}$	t_m Kcal/(°C hr. m²)
I_{clo}	$6.45/I_{clo}$	t_w watt/°C m²
U BTU/(°F hr. ft²)	1.136/U	I_{clo}
T t_w watt/(°C m²)	$6.45/t_w$	I_{clo}
t_m K cal/(°C hr. m²)	$6.56/t_m$	I_{clo}
t_c cal/(°C sec m²)	1.54 t_c	I_{clo}

*A. P. Gagge, A. C. Barton, and H. C. Bazett, *Science*, *94*, 128 (1941).

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Fibres, Fabrics and Finishes for FR Workwear in Europe

A. C. CHAPMAN AND G. MILLER

INTRODUCTION

THE REQUIREMENTS FOR FR WORKWEAR IN EUROPE ARE CONSIDERED IN terms of:

—Hazards in the working environment;
—The function of workwear in protecting against various hazards;
—The performance of various fibres, fabric weights and construction, and finishes in meeting these requirements;
—Relevant performance standards;
—Pressures favouring the wider use of FR workwear;
—How current practice relates to the ideal.

The European market is a very diverse one in respect to many of these factors. This is a reflection of the different patterns which apply among the member countries in respect of historical development, political pressures, traditional suppliers, national temperaments, climatical differences, legislative approaches, and test methods, but whatever the causes, a wider approach to what are essentially similar problems is taken than is the case for example in the U.S.A. which is a market of comparable size. These differences are only slowly being resolved with the increase in safety awareness in Europe and moves towards the harmonization of approach within the European Economic Community.

HAZARDS IN THE WORKING ENVIRONMENT

Every day people work in environments in which there is a hazard of fire, either direct or indirect. These include steel manufacture, metal casting, forging, welding, cutting and fire fighting and also many occupations such as the oil, gas and chemical industries, munitions and pyrotechnics where the hazard of fire is always present in accident situations. Every year injuries and death arising from burns add to industrial costs whether the origin of these burns be direct flame, spilled inflammable liquid, radiant heat or molten metal.

Presented at the Fire Retardant Chemicals Association Conference, in New Orleans, LA, in March 1979.

The approach taken towards these hazards in so far as they have been recognized and any corrective action taken at all has depended very much on the degree of obviousness of the hazard. In the case of direct flame, for example in fire fighting, the potential for injury to the worker both directly and by ignition of his clothing is obvious and the hazard has been recognized if not always acted upon. Throughout the metal manufacture and the foundry industries where molten metal is being poured or handled and there is an ever present danger of workers being hit by splashes of molten metal, large or small, there has been at least some recognition of this hazard which carries a very severe potential for injury or death to the worker. Molten metal splashes have severe potential for injury; with a high thermal capacity and momentum and fluidity producing very high thermal contact with the skin or clothing of the victim, and a relatively small quantity of molten metal can produce extensive third-degree burns unless the clothing worn provides suitable protection. This is normally recognized and some kind of protective clothing provided; what is not always appreciated is the likelihood of secondary ignition of the clothing by the molten metal with resultant injury from direct flame.

The case of inflammable liquids or gases is very different. Here we have a situation where the primary hazard, the burning of the inflammable liquid or gas, is only activated by ignition of the fuel by a spark or some other incident. Measures will invariably be taken to prevent such ignition; smoking will be prohibited and spark-proof electrical equipment may be specified. However, little attention has hitherto been paid to the fact that there are further measures which can and should be taken by way of protective clothing to protect workers from injury from direct flame and heat in the event that ignition *does* take place (and as we all know this does indeed happen occasionally despite all precautions which are taken). This sort of situation applies quite widely in oil refineries, natural gas installation engineering and maintenance operations, chemical plants, petrol (gasolene) stations and the like and is becoming recognized in some of these areas.

THE FUNCTION OF WORKWEAR IN PROTECTING AGAINST HAZARDS

The Workwear worn by an operative may have several functions to fulfill depending on the situation in the work-place:

—It must not itself contribute to the hazard;
—It must not ignite or sustain combustion from exposure to direct flame or molten metal splash;
—It must not melt away from the flame leaving a hole which exposes the flame directly to the skin of the wearer;
—It must not melt to produce hot sticky residues which can and do stick to the skin to produce severe burns.

Molten thermoplastic is both a very effective heat transfer medium and a very tenacious adhesive and on human skin produces very severe burns indeed.