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Protective clothing against heat and flame — Test method for complete garments — Prediction of burn injury using an instrumented manikin

Vêtements de protection contre la chaleur et la flamme — Méthode d'essai pour vêtements complets — Estimation de la probabilité de brûlure à l'aide d'un mannequin instrumenté

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Foreword

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The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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ISO 13506 was prepared by Technical Committee ISO/TC 94, *Personal safety — Protective clothing and equipment*, Subcommittee SC 13, *Protective clothing*.

Introduction

The purpose of heat- and flame-resistant protective clothing is to shield the wearer from hazards that can cause burn injury. The clothing can be made from one or more materials. The evaluation of materials for potential use in this type of clothing generally involves two steps. First, the materials are tested to gauge their ability to limit flame spread. They are then tested to determine the rate of heat transferred through them when exposed to a particular hazard. A variety of test methods are used in these two steps, depending on the intended end use of the materials.

The first test conducted is the one described in ISO 15025. In this test, a flame of prescribed size is applied to one or several vertically suspended fabric layer(s) for a prescribed time, and then removed. The location of the flame can be at the lower edge of the specimen or on the face of the material. The length of the flame spread on the material is observed and used as an indicator of the material's ability to support combustion.

The second test, that for heat transmission, can involve one or more tests, depending on the intended end use of the materials. For situations where the potential hazard is a contact with a flame, the method used is the one described in ISO 9151. If the hazard is exposure to thermal radiation only, then the method used is the one described in ISO 6942. Materials to be used in structural fire-fighting clothing can also be tested using ISO 17492. All these test methods use exposure heat flux density levels ranging from 20 kW/m^2 to 80 kW/m^2. The value depends on the test method and the potential hazard. These tests are transient and of short duration. The tests are terminated when a particular end point is reached, such as the temperature rise in a heat sensor located behind the material layer(s). Because these tests are transient, the endothermic and exothermic properties, the material density, the specific heat and the thermal conductivity of the material(s) are all important parameters in determining the outcome. The samples are conditioned before testing.

It is advisable that the specimens tested as outlined above be representative of the garment or ensemble material or component specimens. While these tests are able to allow a ranking of garment or ensemble materials and components, the tests do not allow a complete assessment of a garment or ensemble made of the materials.

All of the above test methods use small amounts of material, up to 150 mm x 150 mm in area, and hold the material initially flat, either in a vertical or in a horizontal plane. Multiple layers are used where appropriate (e.g. structural fire-fighting ensembles). In this case, the layer normally worn on the exterior is exposed directly to the energy source, while the layer normally worn on the inside is away from the energy source. With the planar orientation and alignment of materials, shrinkage has little effect on the outcome of the test, unless the shrinkage is so severe as to cause holes to form in the material during the exposure to the energy source. Sagging, however, does directly affect the results, as an air gap can form or grow in size, adding an insulating effect. While it is possible to test with the aforementioned test methods seams, zippers, pockets, buttons or other closures, metal and plastic clips or other features that can be included in a full garment like heraldry, company logos, etc., this is not frequently done because it is difficult to do. These aspects and the overall design features of a garment or ensemble that can affect the performance are best evaluated by testing full garments or ensembles on a manikin, and it is for this purpose that this International Standard was established.

In the test method in this International Standard, a stationary, full-sized male form (female forms are under development) is dressed in a complete garment and exposed for a prescribed short duration to a laboratory simulation of a flash fire. The average incident heat flux density to the exterior of the garment is 84 kW/m^2, a value similar to those used in ISO 9151, ISO 6942 and ISO 17492. The data-gathering period is 60 s for single-layer garments and 120 s for any other type of test specimen. Heat sensors fitted to the surface of the manikin are used to measure the heat flux density variation with time and location on the manikin and to determine the total energy absorbed over the data-gathering period. This information can be used to assist in evaluating the performance of the garment or protective clothing ensembles under the test conditions. It can also be used to estimate the extent and nature of skin damage that a person would suffer if wearing the test garment under similar exposure conditions.

The manikin is tested in a standing position in initially quiescent air. Controlled air motion for simulating wind effects or body movement is not presently possible, but it is possible to move the manikin through a stationary flame. Motion of this nature is not within the scope of this International Standard. Variations in the fit of the test garment that can occur when sitting or bending are not evaluated.

The fire simulations are dynamic. As such, the exposure is more representative of an actual industrial accident or structural fire than the exposures used in the bench scale tests mentioned above. The heat flux density resulting from the exposure is neither constant nor uniform over the surface of the manikin/garment. Under these conditions, the results are expected to have more variability than carefully controlled bench scale tests. In addition, the garment is not constrained to be a flat surface, but is allowed to have a natural drape on the manikin. The effect these variables have on a garment can be seen in several ways: ignition and burning of the garment and heraldry, shrinkage or sagging in all directions after flaming, hole generation, smoke generation and structural failure of seams. Many of these failures rarely appear in the bench scale testing of the materials because they are a result of garment design variables, interaction between material properties and design variables, construction techniques and localized exposure conditions that are more severe.

Fit of the garment on the manikin is important. A standard garment is specified to minimize the effect of this variable. Experience suggests that testing a garment one size larger than the standard will reduce the total energy transferred and percentage body burn by about 5 %.

This International Standard is not designed to measure material properties directly, but to evaluate the interaction of material behaviour and garment design. One can compare relative material behaviour by making a series of test garments out of different materials using a common pattern. The performance of the full garments will not necessarily be ranked in the same order as might be obtained when the materials are tested using ISO 9151, for example. Correlations between small scale tests and results from single-layer garments have been examined (see Reference [9]). The best correlation was obtained when three-dimensional shrinkage effects were allowed to occur with the fabric, just as occurs with garments on the manikin.

The hands and feet of the manikin do not contain sensors, but it is possible to assess some aspects of hand protection depending upon the specific design of the hands. The head, however, does contain heat sensors. The reason for this is that many outer garments include an integral hood, but not gloves or footwear. Tests for gloves and footwear are covered by other ISO documents for specific end uses.

The protection offered by the test specimens is evaluated through quantitative measurements and observations. Heat sensors fitted to the manikin are used to measure the energy transferred to the manikin surface during the data-gathering period. This information can be reported directly or used to calculate the nature and extent of the damage that would occur to human skin from the exposure. The latter information is reported as time to pain, first-, second- or third-degree burn injury (see Clause 3 and Annex C). Unlike skin on a human, the model used for evaluating damage to the skin assumes it to be the same at all locations. The reason for this is the limited amount of thermo-physical data on human skin and how skin responds to thermal insult. The published data is specific to the skin samples tested and is not intended to apply to significantly different thicknesses such as occur on a human.

Documents listed in the Bibliography give full details of manikin and sensor construction, data acquisition, computer software requirements, flame exposure chamber and fuel and delivery system. They also suggest numerical techniques that can be used to carry out the calculations required.

The European Committee for Standardization (CEN) specifies the test method described in this International Standard as an optional part of EN 469:2005. This test method is also specified in ISO 11612:1998 as an optional test.

The National Fire Protection Association (NFPA) specifies a test method similar to the one described in this International Standard as part of a certification process for garments (see Reference [10]).

Protective clothing against heat and flame — Test method for complete garments — Prediction of burn injury using an instrumented manikin

1 Scope

This International Standard provides the general principles of a test method for evaluating the performance of complete garments or protective clothing ensembles in a flash fire or other short duration exposures. This test method characterizes the thermal protection provided by garments, based on the measurement of heat transfer to a full-size manikin exposed to a laboratory simulation of a fire with controlled heat flux density, duration and flame distribution. The heat transfer measurements can also be used to calculate the predicted skin burn injury resulting from the exposure. In addition, observations are recorded on the overall behaviour of the test specimen during and after the exposure.

This method is useful for three types of evaluation:

a) comparison of garment or ensemble materials;

b) comparison of garment or ensemble design; and

c) evaluation of any garment or ensemble prototype for a particular application or to a specification.

Each type of evaluation has different garment or ensemble requirements because the test results are dependent on the test material performance, on the garment size, on the garment design and on the use of ensemble components.

The results obtained apply only to the particular garments or ensembles, as tested, and for the specified conditions of each test, particularly with respect to the heat flux density, duration and flame distribution. For the purposes of this test method, the incident heat flux density is limited to a nominal level of 84 kW/m^2.

This International Standard is intended to be used to measure and describe the behaviour of complete garments or protective clothing ensembles in response to convective and radiant energy under controlled laboratory conditions, with the results used to optimize garment combinations and designs. This International Standard is not intended to be used to compare the properties of garment materials or combinations of materials unless the test specimens are absolutely identical in size and design. Furthermore, this International Standard is not intended to be used to describe or appraise the fire hazard or fire risk under actual fire conditions. However, the results of this test can be used as elements of a fire risk assessment which takes into account all of the factors that are pertinent to an assessment of the fire hazard of a particular end use. Considerations for the use of this test method are provided in Annex A. Inter-laboratory data for the test method are provided in Annex B.

NOTE 1 This test method provides information on material behaviour and a measurement of garment performance on a stationary upright manikin. The effects of body position and movement are not addressed in this test method.

NOTE 2 This test method does not apply to the evaluation of protection for the hands or the feet.

NOTE 3 This test method is complex and requires a high degree of technical expertise in both the test setup and operation.

NOTE 4 Deviations from the instructions in this test method can lead to significantly different test results. Technical knowledge concerning fabric behaviour and the theory of heat transfer and testing practices is needed in order to evaluate which deviations are significant with respect to the instructions given in this test method. Standardization of the test method reduces, but does not eliminate, the need for such technical knowledge. Any deviations from this test method are reported with the results.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 6330, *Textiles — Domestic washing and drying procedures for textile testing*

ISO 7941, *Commercial propane and butane — Analysis by gas chromatography*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
burn injury
burn damage which occurs at various levels of depth within human tissue due to elevated temperatures resulting from heat transfer to the surface

NOTE Burn injury in human tissue occurs when the tissue is heated and kept at an elevated temperature (> 44 °C) for a critical period of time. For the purposes of this International Standard, it is assumed that skin has three layers: the epidermis, which is the tough outer layer, the dermis, which is the layer below the epidermis, and the subcutaneous tissue, which is the fatty layer of skin deeper than the dermis. This tissue varies in thickness in different parts of the body, from person to person and with age. The severity of damage, referred to as first-, second-, or third-degree (or partial thickness or full thickness) burn injury, depends upon the level of the elevated temperature above 44 °C and the time during which it remains above 44 °C. Annex C gives details of the model and criteria used in calculating the damage.

3.1.1
first-degree burn injury
first-degree burn
burn in which only the superficial part of the epidermis has been injured

NOTE The skin turns red, but does not blister or actually burn through. First-degree burn damage is reversible.

3.1.1.1
first-degree burn injury area
first-degree burn area
sum of the areas represented by heat flux sensors for which only a calculated first-degree burn injury occurs

3.1.2
second-degree burn injury
second-degree burn
partial thickness burn
burn in which the epidermis and a varying extent of the dermis are burned, but the entire thickness of the dermis is not destroyed and the subcutaneous layer is not injured

NOTE Second-degree burn damage is more serious than first-degree burn damage, but is reversible.

3.1.2.1
second-degree burn injury area
second-degree burn area
sum of the areas represented by heat flux sensors for which only a calculated second-degree burn injury occurs

3.1.3
third-degree burn injury
third-degree burn
full thickness burn
burn which extends through the dermis, into or beyond the subcutaneous fat

NOTE Third-degree burn damage is irreversible.

3.1.3.1
third-degree burn injury area
third-degree burn area
sum of the areas represented by the heat flux sensors for which only a calculated third-degree burn injury occurs

3.2
complete garments
any single garment or combination of garments designed to protect the torso, arms and legs of the wearer

NOTE Both a single garment and a combination of garments can include protection for the head of the wearer by means of a hood (integral or separate) or balaclava. A combination of garments can include undergarments and outer garments.

3.3
flame distribution
spatial distribution of incident flames from test facility burners which provides a controlled heat flux density over the manikin surface.

3.4
flash fire
fire that spreads rapidly through a diffuse fuel-air mixture without the production of damaging pressure

NOTE The fuel can be a dust, a gas or vapours of an ignitable liquid. The duration is typically less than 3 s.

3.5
garment ease
difference between body (manikin) dimensions and garment dimensions

3.6
heat flux sensor
device capable of directly measuring the heat flux density to the manikin's surface under test conditions, or of providing data that can be used to calculate the heat flux density

NOTE In either case, the created data needs to be in a form that can be processed by a computer program to assess the total energy transferred over the recording period and the potential burn injury.

3.7
instrumented manikin
model representing an adult-sized human and fitted with heat flux sensors on the surface for use in testing

3.8
predicted total area of burn injury
total area of predicted burn injury
sum of the areas represented by the heat flux sensors which calculate at least a second-degree burn injury

3.9
protective clothing ensemble
any combination of complete protective garments.

NOTE Although this International Standard does not require sensors in the hands of the manikin, gloves can be included in the protective clothing ensemble to be tested. This will allow representation of a realistic interface between arm and hand protective items.

3.10
thermal protection
overall protective performance of a garment or protective clothing ensemble relative to how it limits the transfer of heat to the manikin over the data-gathering period

NOTE In fire testing of clothing, thermal protection of a garment or ensemble and the consequential predicted burn injury (first-, second- or third-degree) can be quantified by the measured heat flux sensor response which indicates how well the garment or protective clothing ensemble limits heat transfer to the manikin surface. In addition to the measured sensor response, the physical response and degradation of the garment or ensemble are observable phenomena which are associated with the heat flux sensor calculation and are useful in understanding garment or protective clothing ensemble thermal protection.

3.11
time to pain
time taken for the interface of the epidermis and dermis layers to reach 43,2 °C

4 General

The method evaluates the protective performance of the test specimen, which is either a garment or an ensemble. The performance is a function of both the materials of construction and design. The test specimen is placed on an adult-size manikin at ambient atmospheric conditions and exposed to a laboratory simulation of a fire with controlled heat flux, duration and flame distribution. The test procedure, data acquisition, result calculations and preparation of the test report are performed with computer hardware and software programs.

Heat which is transferred through the test specimen during and after the exposure is measured by heat flux sensors. These measurements shall be used to calculate the second- and third-degree and total burn injury areas resulting from the exposure. They may also be used to calculate the time to pain and first-degree burn injury. Identification of the test garment, test conditions, comments and remarks about the test purpose and response of the test specimen to the exposure are recorded and are included as part of the test report. The performance of the test specimen is indicated by the calculated total energy transferred, the burn injury area and the way the test specimen responds to the test exposure.

5 Apparatus

5.1 Instrumented manikin

An upright manikin the shape and size of an adult human form shall be used (see Figure 1). The manikin shall be constructed to simulate the body of a human being and shall consist of a head, a chest/back, an abdomen/buttocks, arms, hands, legs and feet. The manikin should be constructed of flame-resistant, thermally stable materials, such as ceramics or glass-reinforced vinyl ester resin. The shell thickness should be at least 3 mm.

A reproducible positioning system is required for the manikin. It may consist of pin locators in the floor, a portable rigid positioning frame and light or laser beams for setting vertical orientation and arm position.

The instrumented manikin[1)] shall match the dimensions indicated in Table 1.

1) A manikin meeting these requirements is available from Composites USA, 1 Peninsula Drive, Northeast, Maryland, USA. Ph. +1 302 834 7712. This information is given for the convenience of users of this International Standard and does not constitute an endorsement by ISO of the product named. Equivalent products may be used if they can be shown to lead to the same results.

