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Standard Practice for Determining Response Characteristics and Design Integrity of Arc Rated Finished Products in an Electric Arc Exposure[1]

This standard is issued under the fixed designation F2621; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice provides procedural guidelines for conducting arc testing on finished products intended for use as thermal protection by workers who may be exposed to electric arcs.

1.1.1 This practice is intended to provide procedural guidelines to improve consistency across testing groups. This practice is not intended to define the end points, parameters, or measures to be studied by the tester.

1.1.2 This practice is supplemental to Test Methods F1959/F1959M and F2178. Protective materials used to manufacture arc rated finished products shall be tested according to Test Method F1959/F1959M prior to being tested according to this practice, and face protective products shall be tested according to Test Method F2178 prior to being tested according to this practice. Test Methods F1959/F1959M and F2178 provide definitive numeric arc ratings for materials intended for use in finished products worn by workers exposed to electric arcs.

1.1.2.1 *Discussion*—Face protective products such as face shields and hoods are tested as finished products using Test Method F2178. These items may be subsequently tested using this practice in order to determine the performance of the interface area between the face protective product and the arc flash PPE worn on the torso.

1.1.3 The test specimens used in this practice shall be in the form of arc-rated finished products. These arc-rated finished products may include, but are not limited to, single layer garments, multi-layer garments or ensembles, cooling vests, gloves, chaps, rainwear, balaclavas, faceshields, and hood assemblies with hood shield windows. Non-arc rated finished products shall not be used except that flammable under-layers may be included when part of a flame resistant system or for detecting heat transmission level through the finished product and flammable finished products may in some cases be appropriate for incident reenactment.

1.1.4 The arc rated finished product specimens are new products as sold or products which have been used for the intended purpose for a designated time period.

1.1.5 Fabrics, fabric layered systems, sewing thread, findings and closures used in arc rated finished products tested under this practice shall meet the requirements of Specification F1506.

1.1.6 Rainwear materials, findings and closures tested under this practice shall meet the requirements of Specification F1891.

1.2 This practice shall be used to measure and describe the response characteristics or design integrity of arc-rated materials, products, or assemblies in the form of finished products when exposed to radiant and convective energy generated by an electric arc under controlled laboratory conditions.

1.3 This practice can be used to determine the integrity of closures and seams, the protective performance of arc-rated products in areas where garment overlap occurs or where heraldry is used, and response characteristics such as afterflame time, melting, dripping, deformation, shrinkage, electric arc ignition, or other damage, or combination thereof, of fabrics, systems of fabrics, flammable undergarments when included as part of a system, sewing thread, findings and closures.

1.4 This practice can be used to identify the effectiveness of finished product specimens in attenuating heat, sound or pressure waves, or combination thereof.

1.5 This practice can be used for incident reenactment, training demonstrations and material/design comparisons.

1.6 The values stated in either SI units or in other units shall be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system must be used independently of the other, without combining values in any way.

[1] This practice is under the jurisdiction of ASTM Committee F18 on Electrical Protective Equipment for Workers and is the direct responsibility of Subcommittee F18.65 on Wearing Apparel.

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1.7 This standard shall not be used to describe or appraise the fire hazard or fire risk of materials, products, or assemblies under actual fire conditions. However, results of this test may be used as elements of a fire assessment, which takes into account all of the factors, which are pertinent to an assessment of the fire hazard of a particular end use.

1.8 This standard does not purport to describe or appraise the effect of the electric arc fragmentation explosion and subsequent molten metal splatter, which involves the pressure wave containing molten metals and possible fragments of other materials except to the extent that evidence of projectile damage is assessed and reported, and an optional determination of the attenuation of sound or pressure wave, or both, due to the presence of the finished product specimen may be reported.

1.9 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* For specific precautions, see Section 7.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D123 Terminology Relating to Textiles
D4391 Terminology Relating to The Burning Behavior of Textiles
F1494 Terminology Relating to Protective Clothing
F1506 Performance Specification for Flame Resistant and Arc Rated Textile Materials for Wearing Apparel for Use by Electrical Workers Exposed to Momentary Electric Arc and Related Thermal Hazards
F1891 Specification for Arc and Flame Resistant Rainwear
F1958/F1958M Test Method for Determining the Ignitability of Non-flame-Resistant Materials for Clothing by Electric Arc Exposure Method Using Mannequins
F1959/F1959M Test Method for Determining the Arc Rating of Materials for Clothing
F2178 Test Method for Determining the Arc Rating and Standard Specification for Eye or Face Protective Products

3. Terminology

3.1 For definitions of other textile terms used in this practice, refer to Terminologies D123, D4391 and F1494.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *afterflame, n*—persistent flaming of a material after the ignition source has been removed.

3.2.2 *afterflame time, n*—the length of time for which a material continues to flame after the ignition source has been removed.

3.2.3 *arc duration, n*—time duration of the arc, s.

3.2.4 *arc energy, n*—sum of the instantaneous arc voltage values multiplied by the instantaneous arc current values multiplied by the incremental time values during the arc, J.

3.2.5 *arc gap, n*—distance between the arc electrodes, cm (in.).

3.2.6 *arc rated finished product, n*—a commercial product used for arc flash protection in the form as it is sold and used.

3.2.7 *arc rating, n*—value attributed to materials that describes their performance to an exposure to an electric arc discharge.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

3.2.7.1 *Discussion*—

The arc rating is expressed in cal/cm^2 and is derived from the determined value of ATPV or E_{BT} (should a material system exhibit a breakopen response below the ATPV value).

3.2.8 *arc thermal performance value (ATPV), n*—~~in arc testing,~~the incident energy on a material or multilayer system of materials that results in a 50 % probability that sufficient heat transfer through the tested specimen is predicted to cause the onset of a second-degree skin burn injury based on the Stoll curve, ~~cal/cm~~kW/m^2.~~–~~[cal/cm^2].

3.2.8.1 *Discussion*—

The ATPV is determined using Test Method F1959/F1959M.

3.2.9 *arc voltage, n*—voltage across the gap caused by the current flowing through the resistance created by the arc gap (V).

3.2.10 *asymmetrical arc current, n*—the total arc current produced during closure; it includes a direct component and a symmetrical component, A.

3.2.11 *blowout, n*—the extinguishing of the arc caused by a magnetic field.

3.2.12 *breakopen, n—in electric arc testing* , a material response evidenced by the formation of one or more holes in the material which may allow thermal energy to pass through material.

3.2.12.1 *Discussion—*

The specimen is considered to exhibit breakopen when any hole is at least 1.6 cm^2(0.5 $in.^2$) in area or at least 2.5 cm (1.0 in.) in any dimension. Single threads across the opening or hole do not reduce the size of the hole for the purpose of this practice. In multiple layer finished product specimens of flame resistant materials, all the layers must exhibit breakopen in order to meet the definition.

3.2.13 *breakopen threshold energy (E_{BT}) , n*—the incident energy on a material or system of materials that results in a 50 % probability of breakopen.

3.2.13.1 *Discussion—*

The E_{BT} is determined using Test Method F1959/F1959M.

3.2.14 *calorimeter, n*—a device used in which the heat measured causes a change in state.

3.2.14.1 *Discussion—*

The determination of heat energy, as a consequence of an electrical arc exposure, is made in this procedure by measuring the change in temperature of an exposed copper slug of specific geometry and mass during finite time intervals.

3.2.15 *charring, n*—formation of carbonaceous residue as the result of pyrolysis or incomplete combustion.

3.2.16 *closure, n—~~in initiating the arc current with an electrical switch,~~*the ~~the~~ point on supply current wave from where arc is initiated.

3.2.17 *deformation, n—for electric arc testing of finished products*, the sagging of material greater than 3 in. or melting in any manner that the faceshield, hood window or other melted material touches any part of the body.

~~3.2.18 *delta peak temperature, n*—difference between the maximum temperatures and the initial temperature of the sensor during the test, °C.~~

3.2.18 *dripping, n—in electric arc testing* , a material response evidenced by flowing of a polymer and droplets separating from the material.

3.2.18.1 *Discussion—*

For finished product protective clothing and equipment, dripping can involve the fiber polymer, coatings, findings, the faceshield window material or any other component of the finished product.

3.2.19 *electric arc ignition, n—in electric arc testing of arc rated finished products*, the initiation of combustion as related to electric arc exposure, a response that causes the ignition of the test specimen material which is accompanied by heat and light, and then subsequent burning for at least 5 s, and consumption of at least 25 % of the test specimen area.

3.2.19.1 *Discussion—*

For multilayer specimens, consumption of the innermost FR layer must be at least 25 %.

3.2.20 *garment closure, n—in a finished product or garment*, the area in which two parts are joined with a mechanical device.

3.2.20.1 *Discussion—*

Examples of closures are zippers, snaps, buttons or hook & loop fasteners on the front of a coat, a shirt or a pair of pants.

3.2.21 *heat flux, n*—the thermal intensity indicated by the amount of energy transmitted per area and time, cal/cm ^{2}s (W/m^2).

3.2.22 i^2t,*n*—sum of the instantaneous arc current values squared multiplied by the incremental time values during the arc, A^2/s.

3.2.23 *helaldry, n—relating to finished products*, an informational symbol or logo on a finished product.

3.2.23.1 *Discussion—*

The logo or symbol is embroidered onto the finished product, or the logo or symbol is on a label which is affixed to the finished product.

3.2.24 *incident energy monitoring sensors, n—* sensors mounted on each side of the torso and on each side of the head, using calorimeters, not covered by specimens, used to measure incident energy.

3.2.25 *incident exposure energy (E_i), n—in arc testing*, the total incident energy delivered to monitor calorimeter sensors as a result of the arc exposure, cal/cm^2.

3.2.25.1 *Discussion—*

In an arc test exposure, incident exposure energy for a specimen is determined from the average of the measured incident energy from all the respective monitor sensors adjacent to the test specimen.

3.2.26 *indicator undergarment, n—in finished product arc exposure*, a very light weight longjohn turtle neck shirt with optional balaclava and pants that is used to subjectively detect heat transfer through a finished product and heat leakage through closures or interface areas of a finished product garment.

3.2.26.1 *Discussion—*

A white 100% untreated cotton fabric with an areal density of 48 to 116 g/m^2 (1.4 to 3.4 oz/yd^2) has been found to be an effective indicator of heat transmitted through the FR garment test specimen. The areal density of the indicator undergarment fabric shall not exceed 153 g/m^2 (4.5 oz/yd^2). The onset of discoloration of the cotton fabric due to scorching or charring, or both, is an indication of heat exposure. Arc testing has indicated that an untreated cotton fabric with an areal density of 48 to 116 g/m^2 (1.4 to 3.4 oz/yd ^{2}) when receiving a heat exposure as an under layer, exhibits scorching or charring, or both, at approximately 2 cal/cm^2. When evaluating the discoloration of the cotton indicator undergarment, care must be used to ensure that the source of discoloration is, in fact, scorching or charring, or both, as discoloration may in some cases be due to staining caused by off-gases or dye sublimation of the flame-resistant materials used in the test specimen.

3.2.27 *interface area, n—in arc testing* , the areas of the body at which finished product specimens overlap but are discontinuous.

3.2.27.1 *Discussion—*

The waist and mid-torso area of the body at which a coat overlaps a bib overall is an example of an interface area, and the neck and upper torso area of the body is an example of an interface area.

3.2.28 *material response, n*—material response to an electric arc is indicated by the following terms: breakopen, charring, melting, dripping, deformation, afterflame time, shrinkage, and electric arc ignition.

3.2.29 *melting, n—in testing finished products*, a material response evidenced by softening of the fiber polymer, findings, closures, the faceshield window polymer or any other component of the finished product.

3.2.30 *peak arc current, n*—maximum value of the ac arc current, A.

3.2.31 *RMS arc current, n*—root mean square of the AC arc current, A.

3.2.32 *shrinkage, n—in testing finished products*, a material response evidenced by reduction in specimen size of the fabric, finding, closure or the faceshield window.

3.2.33 *Stoll curve, n*—curve produced from data on human tissue tolerance to heat and used to predict the onset of second-degree burn injury.

~~3.2.35 *time to delta peak temperature, n—* the time from beginning of the initiation of the arc to the time the delta peak temperature in reached, s.~~

3.2.34 *X/R ratio, n*—the ratio of system inductive reactance to resistance.

3.2.34.1 *Discussion—*

It is proportional to the L/R ratio of time constant, and is, therefore, indicative of the rate of decay of any dc offset. A large X/R ratio corresponds to a large time constant and a slow rate of decay.

4. Summary of Practice

4.1 This practice provides a procedure for determining the response characteristics and design integrity of materials, products, or assemblies in the form of finished garments or other finished products when exposed to convective and radiant energy generated by an electric arc under controlled laboratory conditions.

4.1.1 When evaluating the design integrity or protective performance of arc rated finished products, the electric arc heat exposure level should be set to be at least equivalent to the arc rating of the finished product being evaluated in cal/cm^2.

4.1.2 When using this practice for incident reenactment, the test specimen shall be subjected to an electric arc heat exposure level similar to that determined from the incident criteria.

4.2 Finished product specimens are mounted on the standard mannequin including torso and head utilized for Test Methods F1958/F1958M and F2178. Mannequin legs can be added if exposures to the lower torso and legs are of interest. The mannequin is in a standing position with arms down to the sides of the torso. The mannequin is equipped with copper slug calorimeters in the torso, neck and head positions as specified in Test Methods F1958/F1958M and F2178. During this procedure, the amount of heat energy transmitted through the finished product specimens is measured during and after exposure to an electric arc.

4.2.1 Finished product test specimens which cover the mannequin body shall be designated size “Large” or designated with a chest measurement of 44 in. (112 cm) and a waist measurement of 36 in. (91 cm).

4.2.2 The mannequin can be positioned in other positions, for example, in incident reenactment the mannequin can be in a sitting position or with the arms extending horizontally toward the arc exposure to simulate the conditions of the incident. Any additional modification to the mannequin position shall be indicated in the test report.

4.2.3 The mannequin can also be equipped with additional calorimeter sensors in other parts of the body, for example, the legs, groin, and arms. Any additional sensors used shall be indicated in the test report.

4.2.3.1 *Discussion*—When additional sensors are used, the sensor responses relative to the monitor sensor responses will not provide a valid determination of burn injury unless the additional sensors are positioned at the same distance and orientation as the monitor sensors.

4.2.4 A light-weight “indicator undergarment” utilizing a size “large” long-sleeved underwear turtleneck shirt and optional balaclava or pant design, or both, can be mounted on the mannequin to provide a heat-sensitive surface which can indicate heat exposure transmitted through the finished product specimens or heat leakage through garment closures or interface areas of the finished product specimens.

4.2.4.1 If other heat indicator approaches are used such as selective placement of panels of 100% untreated cotton fabric or PVC sheets, these should be described in detail and included in the test report.

4.2.4.2 When an indicator undergarment or indicator material panels are used to indicate heat transfer, sensor data for sensors covered by the indicator garment or panels shall not be used due to the reduction of exposure energy on the sensors caused by the presence of the indicator undergarment.

4.3 The thermal energy exposure and heat transfer response of the finished product specimen(s) are measured with copper slug calorimeters. The change in temperature versus time is used, along with the known thermo-physical properties of copper to determine the respective heat energies delivered to and through the specimen(s).

4.3.1 The heat transfer response and heat leakage of the finished product specimen(s) are also estimated by evidence of thermal changes to the “indicator” undergarment fabric.

4.4 This practice incorporates incident energy monitoring sensors used to determine the heat exposure on the finished product specimen.

4.5 The standard mannequin can be equipped with microphones or pressure transducers, or both, in the left ear and on the front surface of the upper torso to measure sound or pressure wave intensity, or both, under the finished product specimens.

4.5.1 When the mannequin is equipped with optional microphones or optional pressure transducers, or both, this procedure also incorporates monitor microphones or monitor pressure transducers, or both, which are not covered by the finished product specimen(s).

4.5.2 When the mannequin is equipped with additional microphones or pressure transducers, or both, the location and orientation of all microphones or pressure transducers, or both, shall be documented in the test report.

4.6 Finished product specimen response characteristics shall be further described by recording the observed effects of the electric arc exposure on the specimens using the terms in the Report (see 12.4 and 13.1.3).

5. Significance and Use

5.1 This practice can be used for a range of purposes including incident replication, development of improved arc rated protective products, and the determination of the response characteristics and design integrity of new or used arc rated finished products intended for use as protection for workers exposed to electric arcs.

5.1.1 In-service garments can have very different wash and wear histories. Caution must be used when applying test results from a particular used garment to other used garments. Factors to consider include the garments’ wear histories, work environments, and tasks for which the garments were worn; the methods and facilities for garment maintenance; the number of launderings or

processings the garments have been subjected to; and other factors that could impact the protective performance of different garments. Test results from specific used garments should be considered only an approximation of results that might be obtained from other used garments of the same type.

5.1.2 Because of the variability of the arc exposure, different heat transmission values may result for individual sensors. The results of each sensor are evaluated in accordance with Section 12.

5.2 This practice maintains the specimen in a static, vertical position and does not involve movement except that resulting from the exposure.

6. Apparatus

6.1 *General Arrangement for Using Mannequin Torso and Head Sensors and Monitor Sensors*—The test apparatus shall consist of supply bus, arc controller, recorder, arc electrodes as described in Test Methods F1958/F1958M and F2178, at least one four-sensor mannequin torso as specified in Test Method F1958/F1958M or at least one four-sensor head as specified in Test Method F2178, or both, and at least one set of incident energy monitoring sensors as specified in F1958/F1958M or F2178, or both.

6.1.1 Additional sensors can be added to the mannequin on an optional basis.

6.1.2 A lower torso with legs can be added to the mannequin on an optional basis.

6.1.3 Modify the vertical position of the electrodes and the electrode gap on an optional basis in order to create an arc exposure on any area of the mannequin of particular interest.

6.1.3.1 For finished products that provide protection to the torso, arms and legs but not the head, an area of interest is the closure area on the mannequin torso.

6.1.3.2 For finished products that provide face protection and protection to the torso, arms and legs, areas of interest are the interface area between the face protection and upper torso protection, the torso closure areas, and the interface area between the coat and pant finished products.

NOTE 1—If additional sensors are used, specify the locations and types of these additional sensors in the report. If a lower torso with legs is added to the mannequin, specify this in the report. If the position of the monitor sensors, the electrodes or the electrode gap is modified relative to Test Methods F1958/F1958M or F2178, specify this in the report.

6.1.4 *Video Cameras*—One or more video cameras shall be used to view the tests. One video camera shall be placed so that the front of mannequin can be viewed.

6.1.5 *Mannequin Construction*—The mannequin torso and head shall be constructed as specified in Test Methods F1958/F1958M and F2178. If a lower torso and legs are added to the mannequin, this shall be constructed from the same non-conductive, heat-resistant material as is described for the mannequin torso in Test Method F1958/F1958M.

6.2 *Sensor Response:*

6.2.1 The copper slug calorimeter sensor response is converted to incident energy of units cal/cm^2 as described in Test Method F1959/F1959M.

6.3 *Sensor Construction*—The sensors, sensor mounts and sensor surface conditioning shall be as described in Test Method F1959/F1959M.

6.4 *Electrodes*—The electrode shall be as specified in Test Method F2178.

6.4.1 *Fuse Wire*—The wire shall be as specified in Test Method F2178.

6.5 *Electric Supply*— The electric supply shall be as specified in Test Method F2178.

6.6 *Test Circuit Control*—Repeat exposures of the arc currents shall not deviate more than 2 % per test from the selected test level. The make switch shall be capable of point on wave closing within 0.2 cycles from test to test such that the closing angle will produce a symmetrical current wave repeatable from test to test. The arc current, duration, and voltage shall be measured. The arc current, duration, voltage, and energy shall be displayed in graph form and stored in digital format.

6.7 *Data Acquisition System*—The system shall be capable of recording voltage, current, and sufficient calorimeter outputs as required by the test. The data acquisition system shall be capable of reporting the voltage and current to within 1 % and the calorimetry measurements to within 0.75°C.

6.7.1 The temperature data (calorimeter outputs) shall be acquired at a minimum sampling rate of 20 samples per second per calorimeter. The acquisition system shall be able to record temperatures to 400°C. The temperature acquisition system shall have at least a resolution of 0.1°C and an accuracy of ±0.75°C.

6.7.2 The system current and voltage data shall be acquired at a minimum rate of 2000 samples per second. The current and voltage acquisition system shall be able to report voltage and amperage to within 1 %.

6.8 *Data Acquisition System Protection*— Due to the nature of this type of testing, the use of isolating devices on the calorimeter outputs to protect the acquisition system is recommended.