Designation: F 2178 – 02

Standard Test Method for Determining The Arc Rating Of Face Protective Products[1]

This standard is issued under the fixed designation F 2178; 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 test method is used to measure the arc rating of products intended for use as face protection for workers exposed to electric arcs.

1.2 This test method will measure the arc rating of face protective products. The faceshield or other applicable portions of the complete product must meet ANSI Z87.1. This excludes the textile or non ANSI Z87.1 testable parts of the hood assemblies or other tested products. This standard does not measure optical and impact properties (See ANSI Z87.1).

1.3 The materials used in this method are in the form of faceshields attached to the head by protective helmets (hard hats), headgear, or hood assemblies.

1.3.1 Fabric layers used in hood assemblies or other items tested under this standard meet flammability requirements of Specification F 1506.

1.4 This standard shall be used to measure and describe the properties of materials, products, or assemblies in response to convective and radiant energy generated by an electric arc under controlled laboratory conditions and does not purport to predict damage from light other than the thermal aspects measured.

1.5 *Units*—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.

1.6 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.

1.7 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 heat energy transmission due to these arc explosion phenomena is reduced by test specimens.

1.8 *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:*

C 177 Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded-Hot-Plate Apparatus[2]

D 123 Terminology Relating to Textiles[3]

D 4391 Terminology Relating to the Burning Behavior of Textiles[4]

E 457 Test Method for Measuring Heat-Transfer Rate Using a Thermal Capacitance (Slug) Calorimeter[5]

F 1494 Terminology Relating to Protective Clothing[6]

F 1506 Specification for Flame Resistant Textile Materials for Wearing Apparel for Use by Electrical Workers Exposed to Momentary Electric Arc and Related Thermal Hazards[7]

F 1958 Test Method for Determining the Ignitability of Non-Flame-Resistant Materials for Clothing by Electric Arc Exposure Method Using Mannequins[7]

F 1959 Test Method for Determining the Arc Thermal Performance Value of Materials for Clothing[7]

2.2 *ANSI/IEEE Standards:*

IEEE Standard Dictionary of Electrical and Electronics Terms[8]

ANSI Z87.1-1999 Practice for Occupational and Educational Eye and Face Protection[9]

3. Terminology

3.1 *Definitions*—For definitions of other textile terms used

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[1] This test method 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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[2] *Annual Book of ASTM Standards*, Vol 04.06.

[3] *Annual Book of ASTM Standards*, Vol 07.01.

[4] *Annual Book of ASTM Standards*, Vol 07.02.

[5] *Annual Book of ASTM Standards*, Vol 15.03.

[6] *Annual Book of ASTM Standards*, Vol 11.03.

[7] *Annual Book of ASTM Standards*, Vol 10.03.

[8] Available from Institute of Electrical and Electronics Engineers, Inc., 445 Hoes Ln., P.O. Box 1331, Piscataway, NJ 05584-1331.

[9] Available from American National Standards Institute, 25 W. 43rd St., 4th Floor, New York, NY 10036.

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in this method, refer to terminology in Terminology D 123, D 4391 and F 1494.

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, vi dt*, *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, in.

3.2.6 *arc rating*, *n*—a value which indicates the arc performance of a material or system of materials; either *ATPV* or E_{BT}.

3.2.6.1 *Discussion*—When the arc rating represents the *ATPV*, it shall be reported as Arc Rating (*ATPV*). When Arc Rating represents the E_{BT}, it shall be designated as Arc Rating (E_{BT}). E_{BT} is determined when the *ATPV* cannot be determined.

3.2.7 *arc thermal performance value (ATPV)*, *n*—in arc testing face protective products, the incident energy on a fabric or material that results in sufficient heat transfer through the fabric or material to cause the 50 % probability of the onset of a second-degree burn based on the Stoll curve.

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

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

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

3.2.11 *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.

3.2.11.1 *Discussion*—The specimen is considered to exhibit breakopen when any hole in the material or fabric is at least one-half square inch in area or at least one inch in any dimension. For textile materials, single threads across the opening or hole does not reduce the size of the hole for the purposes of this standard. In multiple layer specimens of flame resistant material, all the layers must breakopen to meet the definition.

3.2.12 *breakopen threshold energy* (E_{BT}), *n*—in arc testing face protective products, the incident energy on a fabric or material that represents the 50 % probability that a breakopen response will occur.

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

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

3.2.14 *closure*, *n*—point on supply current wave form where arc is initiated.

3.2.15 *deformation*, *n*—for electric arc testing of face protective products, the sagging of material greater than 3 in. or melting in any manner that the faceshield/window touches any part of the body.

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

3.2.17 *dripping*, *n*—in electric arc testing, a material response evidenced by flowing of the fiber polymer or the faceshield window polymer.

3.2.18 *electric arc ignition*, *n*—in electric arc testing of face protective products, the initiation of combustion as related to electric arc exposure, a response that causes the ignition of textile 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.

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

3.2.19 *faceshield*, *n*—a protective device commonly intended to shield the wearer's face, or portions thereof, in addition to the eyes, from certain hazards.

3.2.20 *heat attenuation factor, HAF*, *n*—in electric arc testing, the average of the percent of the incident energy which is blocked by a material.

3.2.20.1 *Discussion*—In Arc Testing of Face Protective Products, *HAF* (face) is based on the highest sensor reading among the four head sensors for each head exposure.

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

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

3.2.24 *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.

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

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

3.2.26 *melting*, *n*—in testing face protective products, a material response evidenced by softening of the fiber polymer or the faceshield window polymer.

3.2.27 *peak arc current*, *n*—maximum value of the AC arc current, A.

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

3.2.29 *shrinkage*, *n*—in testing face protective products, a material response evidenced by reduction in specimen size of the fabric or the faceshield window.

3.2.30 *Stoll curve*, *n*—curve produced from data on human tissue tolerance to heat and used to predict the onset of second-degree burn injury (See Table 1).

3.2.31 *time to delta peak temperature*, *n*—the time from beginning of the initiation of the arc to the time the delta peak temperature is reached, s.

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

3.2.32.1 *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 Test Method

4.1 This test method determines the heat transport response across a material, fabric, or fabric system when exposed to the heat energy from an electric arc. This heat transport response is assessed versus the Stoll curve, an approximate human tissue tolerance predictive model that projects the onset of a second-degree burn injury (found in Table 1).

4.1.1 Products are mounted on the standard mannequin head containing copper slug calorimeters inserted in the eyes, mouth, and chin positions. During this procedure, the amount of heat energy transferred by the specimen face protective products is measured during and after exposure to an electric arc.

4.1.2 The thermal energy exposure and heat transport response of the test 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).

4.2 This procedure incorporates incident energy monitoring sensors.

TABLE 1 Human Tissue Tolerance To Heat—Second-degree Burn[A]

Exposure Time	Heat Flux		Total Heat	
s	kW/m^2	cal/cm^{2}s	kW/m^2	cal/cm^{2}s
1	50	1.2	50	1.20
2	31	0.73	61	1.46
3	23	0.55	69	1.65
4	19	0.45	75	1.80
5	16	0.38	80	1.90
6	14	0.34	85	2.04
7	13	0.30	88	2.10
8	11.5	0.274	92	2.19
9	10.6	0.252	95	2.27
10	9.8	0.233	98	2.33
11	9.2	0.219	101	2.41
12	8.6	0.205	103	2.46
13	8.1	0.194	106	2.52
14	7.7	0.184	108	2.58
15	7.4	0.177	111	2.66
16	7.0	0.168	113	2.69
17	6.7	0.160	114	2.72
18	6.4	0.154	116	2.77
19	6.2	0.148	118	2.81
20	6.0	0.143	120	2.86
25	5.1	0.122	128	3.05
30	4.5	0.107	134	3.21

[A] Derived from: Stoll, A.M. and Chianta, M.A., "Method and Rating System for Evaluations of Thermal Protection," Aerospace Medicine, Vol 40, 1969, pp. 1232-1238 and Stoll, A.M. and Chianta, M.A., Heat Transfer through Fabrics as Related to Thermal Injury, "Transactions-New York Academy of Sciences," Vol 33 (7), Nov. 1971, pp. 649-670.

4.3 Product and material performance for this procedure are determined by comparing the amount of heat energy generated by the arc flash on monitor sensors with the energy transferred by or through the test specimen(s) and measured by sensors on the mannequin head.

4.4 Product and material responses shall be further described by recording the observed effects of the electric arc exposure on the specimens using the terms in the Report section.

5. Significance and Use

5.1 This test method is intended for the determination of the arc rating of a product/design, intended for use as face protection for workers exposed to electric arcs.

5.1.1 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 test method maintains the specimen in a static, vertical position and does not involve movement except that resulting from the exposure.

5.3 This test method specifies a standard set of exposure conditions. Different exposure conditions may produce different results.

NOTE 1—In addition to the standard set of exposure conditions, other conditions representative of the expected hazard may be used and shall be reported should this data be cited.

6. Apparatus

6.1 *General Arrangement for Determining Rating Using Sensor Heads and Monitor Sensors*—The test apparatus shall consist of supply bus, arc controller, recorder, arc electrodes, two (or optionally three) four-sensor heads, and four (or optionally six) incident energy monitoring sensors. The arc exposure shall be monitored with two incident energy-monitoring sensors for each head.

6.1.1 *Arrangement of the Four-Sensor Heads*—The standard test set up is three four-sensor heads spaced at 120° around the arc (Fig. 1). If you only use one video camera to view the tests, place it so that the front of two of the heads can be viewed, and you may remove one of the heads to facilitate viewing. Locate each head vertically to the arc electrodes as

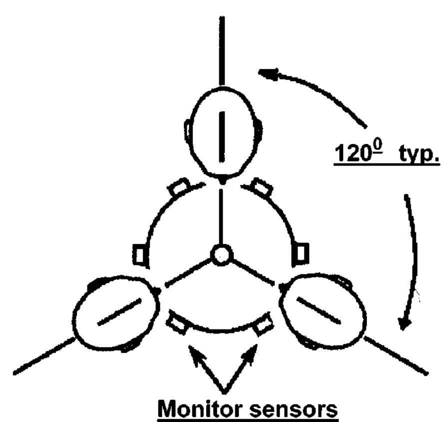

FIG. 1 Location of Mannequin Heads

shown in Fig. 2. You may use only calorimetry data from heads that are viewed from the front (must view minimum 50 % of the facial area) to record subjective data during the test. Each four-sensor head shall have two incident energy monitoring sensors. One monitoring sensor shall be positioned on each side of each four-sensor head as shown in Fig. 3.

6.1.2 *Head Construction*—Each four-sensor head and each monitor sensor holder shall be constructed from non-conductive heat resistant material as shown in Fig. 4. Use a mannequin head, size large, made from a non-conductive high temperature resin/fiberglass construction. (A mannequin head, such as Model 7001 D-H, Morgese Soriano or equivalent is acceptable.) It is recommended that the high-temperature resin used in the construction of the head be non-melting and flame resistant. Each four-sensor head and monitoring sensors shall be placed 12 in. (305 mm) from the centerline of the arc electrodes as shown in Fig. 2. Four-sensors shall be mounted in the head as shown in Fig. 4. The mouth sensor shall be forward of the eye sensor plane by ¼ in. (6 mm). The chin sensor shall be in the horizontal plane (perpendicular to the plane of the eye and mouth) under the chin as shown in Fig. 4. The chin sensor shall protrude below the lowest point of the chin by ⅛ in. (3 mm).

6.1.3 Each four-sensor head may be mounted on the mannequin body specified in Test Method F 1958 and the mannequin to simulate a human body. Any clothing on the mannequin (if used) shall be reported.

6.2 *Sensor Response*:

6.2.1 The copper slug calorimeter monitor sensor response is converted to incident energy of units cal/cm^2 by using the relationship:

$$\text{Total Heat Energy, } Q = \frac{\text{mass} \times \bar{C}_p \times (Temp_{final} - Temp_{initial})}{\text{area}} \quad (1)$$

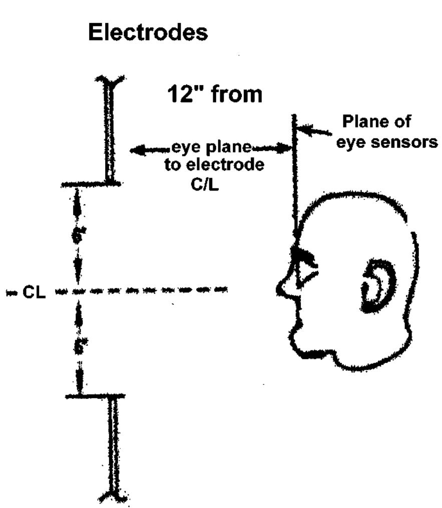

FIG. 2 Vertical Location of Heads to Arc Electrodes

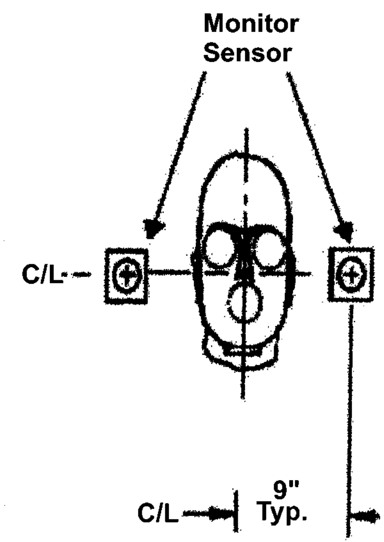

FIG. 3 Mannequin Head with Monitor Sensors

where:

Q = heat energy, cal/cm^2,
mass = mass of the copper disk/slug, g,
$\bar{C}_p$ = average heat capacity of copper during the temperature rise, cal/g°C,
$temp_{final}$ = final temperature of copper disk/slug at $time_{final}$, °C,
$temp_{initial}$ = initial temperature of copper disk/slug at $time_{initial}$, °C, and
area = area of the exposed copper disk/slug, cm^2.

The heat capacity of copper in cal/g°C at any temperature between 289 and 1358 K is determined via (Shomate Equation coefficients from NIST):

$$C_p = \frac{(A + B \times t + C \times t^2 + D \times t^3 + E/t^2}{63.546 \text{ g/mol}} \quad (2)$$

where:

t = (measured temperature °C + 273.15) / 1000,
A = 4.237312,
B = 6.715751,
C = -7.46962,
D = 3.339491, and
E = 0.016398.

The average heat capacity of copper during the temperature rise is then determined by calculating the C_p at $Temp_{initial}$ and C_p at $Temp_{final}$ and averaging the two results:

$$\bar{C}_p = \frac{C_p \mathbin{@} Temp_{initial} + C_p \mathbin{@} Temp_{final}}{2} \quad (3)$$

For a copper disk/slug that has a mass of 18.0 g and exposed area of 12.57 cm^2, the determination of heat flux reduces to:

$$\text{Total Heat Energy, } Q = 1.432 \times \bar{C}_p \times (Temp_{final} - Temp_{initial}) \quad (4)$$

If a copper disk/slug with a different mass or exposed area, or both, is used, the constant factor should be adjusted correspondingly.

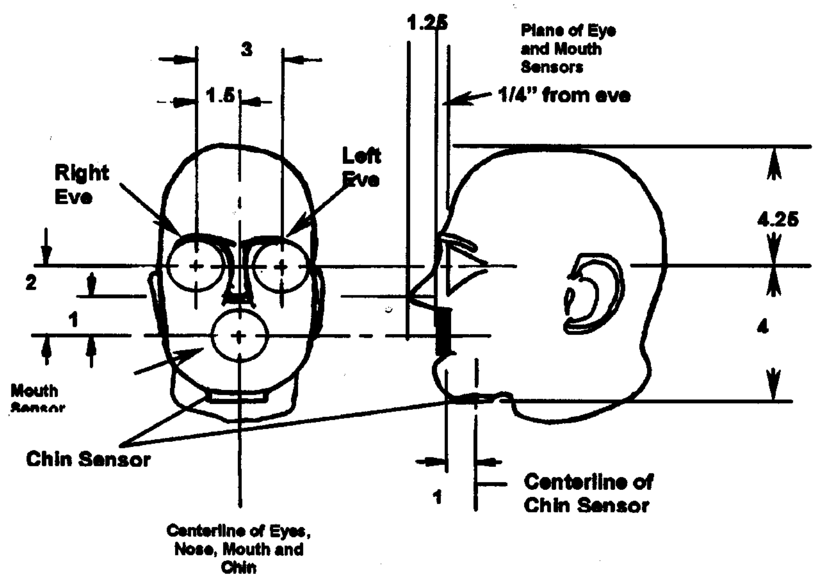

FIG. 4 Mannequin Head and Sensor Locations

6.2.2 Each head sensor response shall be converted to total heat energy using Eq 4 in 6.2.1 and compared with the Stoll Curve information in Table 1.

6.2.3 Monitor sensor response shall be converted to total heat energy observed using Eq 4 in 6.2.1.

6.3 *Sensor Construction*—The sensor mount used to hold the calorimeter shall be constructed from a thermally stable heat resistant material with a minimum thermal conductivity value as indicated in Table 2 (such as Fire-Resistant Structural Insulation or equivalent) and shown in Fig. 5 to prevent unwanted heat conduction. The calorimeter shall be constructed from electrical grade copper as shown in Fig. 4 of Test Method F 1959 with four thermocouple wires installed in the arrangement as shown in Fig. 5 of Test Method F 1959. The thermocouple wire shall be installed in the calorimeter as shown in Fig. 6 of Test Method F 1959. For test exposures above 40 cal/cm^2 only, existing monitoring sensors may be moved away from the arc center line, perpendicular to the arc, provided they are not blocked. A multiplier shall be determined to give an equivalent exposure value at 12 in. (for example, at 18 in., the multiplier is 2.25). Alternate calorimeters for the monitor sensors may be used provided they are calibrated and have a similar response at all levels.

6.3.1 The calorimeter shall be constructed from electrical grade copper with a single thermocouple wire installed in the position identified in Fig. 5. The thermocouple wire shall be installed in the calorimeter as shown in Fig. 5 of Test Method F 1959.

TABLE 2 Thermal Conductivity per Test Method C 177 at Various Mean Temperatures

Temperature	Thermal Conductivity Btu-in./ft^2, h, °F(W/m °K)
75°F (24°C)	1.15 (0.17)
400°F (205°C)	1.13 (0.16)
600°F (316°C)	1.15 (0.17)
800°F (425°C)	1.16 (0.17)
1000°F (538°C)	1.17 (0.17)

6.3.2 For test exposures which create a sensor temperature in excess of 300°C, alternate calorimeters for the monitor sensors shall be used. The alternate sensors shall be calibrated and shall have a similar response. An alternate approach for test exposures which create a sensor temperature in excess of 300°C is to increase the distance between the arc centerline and the monitor sensors from the standard distance of 12 to 18 in., and to apply a conversion factor to the incident energy measured at a distance of 18 in. in order to approximate the energy at a distance of 12 in. In this procedure, the specimen remains at a distance of 12 in. from the arc centerline. Copper calorimeter sensor data above 300°C shall be not be valid.

NOTE 2—At an ambient temperature of 25°C, the calorimeter temperature would reach 300°C (ΔT of 275°C) at approximately 36 cal/cm^2.

6.3.3 The exposed surface of the copper slug calorimeter shall be painted with a thin coating of flat black high temperature spray paint. An external heat source, for example, an external heat lamp, may be required to completely drive off any remaining organic carriers in the painted surface.

6.4 *Supply Bus and Electrodes*—A typical arrangement of the supply bus and arc electrodes is shown in Fig. 2. The arc shall be in a vertical position as shown.

6.4.1 *Electrodes*—Make the electrodes from stainless steel (Alloy Type 303 or Type 304) rod of a nominal ¾ in. (19 mm) diameter. Lengths of 18 in. (450 mm) long initially have been found to be adequate.

6.4.2 *Fuse Wire*—A fuse wire, connecting the ends of opposing electrodes tips, is used to initiate the arc. This wire is consumed during the test; therefore, its mass shall be very small to reduce any effects on the testing. The fuse wire shall be a copper wire with a diameter not greater than 0.02 in. (0.05 mm).

6.5 *Electric Supply*—The electric supply should be sufficient to allow for the discharge of an electric arc with a gap of up to 12 in. (305 mm), with alternating arc current from 4000 up to 25 000 amperes, and with arc duration from 3 cycles

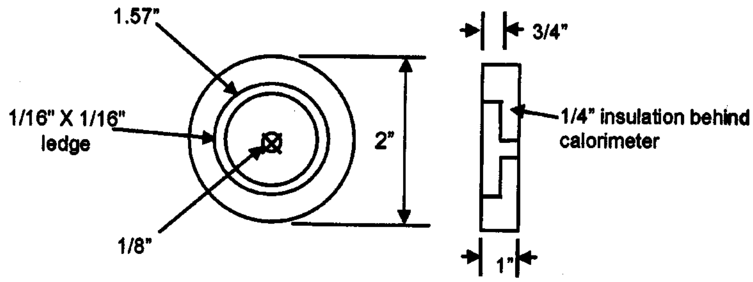

FIG. 5 Sensor Mount

(0.05 s) up to 200.0 cycles (3.3 s) (from a 60 Hz supply).

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 1°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 ±1°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.

7. Precautions

7.1 The test apparatus discharges large amounts of energy. In addition, the electric arc produces very intense light. Care should be taken to protect personnel working in the area. Workers should be behind protective barriers or at a safe distance to prevent electrocution and contact with molten metal. Workers wishing to directly view the test should use very heavy tinted glasses such as ANSI/ASC Filter Shade 12 welding glasses. If the test is conducted indoors, there should be a method to ventilate the area to carry away combustion products, smoke, and fumes. Air currents can disturb the arc reducing the heat flux at the surface of any of the calorimeters. The test apparatus should be shielded by non-combustible materials suitable for the test area. Outdoor tests shall be conducted in a manner appropriate to prevent exposure of the test specimen to moisture and wind (the elements). The leads to the test apparatus should be positioned to prevent blowout of the electric arc. The test apparatus should be insulated from ground for the appropriate test voltage.

7.2 The test apparatus, electrodes, and calorimeter assemblies become hot during testing. Use protective gloves when handling these hot objects.

7.3 Use care when the specimen ignites or releases combustible gases. An appropriate fire extinguisher should be readily available. Ensure the materials are fully extinguished.

7.4 Immediately after each test, the electric supply shall be shut off from the test apparatus and all other laboratory equipment used to generate the arc, and the apparatus and other laboratory equipment shall be isolated and grounded. After data acquisition has been completed, appropriate methods shall be used to ventilate the test area before it is entered by personnel. No one should enter the test area prior to exhausting all smoke and fumes.

8. Sampling and Specimen Preparation

8.1 Test specimens for four-sensor head test shall be representative of the product, as it will be sold.

8.2 Test specimens shall be mounted as they are normally intended to be worn.

9. Calibration and Standardization

9.1 *Data Collection System Precalibration*—The data collection system shall be calibrated by using a thermocouple calibrator/simulator. This will allow calibrations to be made at multiple points and at levels above 100°C. The data collection system shall be calibrated. Due to the nature of the tests, frequent calibration checks are recommended.

9.2 *Calorimeter Calibration Check*—Calorimeters shall be checked to verify their operation. Measure and graph the temperature rise of each calorimeter and system response. At 30 s, no one calorimeter response shall vary by more than 4°C from the average of all calorimeters. Any calorimeter not meeting this requirement shall be suspected of faulty connections and shall be replaced.

NOTE 3—One accepted method follows: After final placement within the test cell of all test head sensors and monitor sensors, expose each calorimeter to a known fixed radiant energy source for 30 s. For example, place the front surface of a calibrated 500-watt spot light 10.5 in. from the calorimeter. The spot shall be centered on and perpendicular to the calorimeter. A 500-watt light source is available from the Strand Electric and Eng. Co. Ltd. as Part #83 (500 W, 120 V light source).

9.3 *Arc Exposure Calibration*—Prior to each calibration, position the electrodes of the test apparatus to produce a 12-in.

(305-mm) gap. The face of the monitor sensors shall be parallel and normal to the centerline of the electrodes. The midpoint of the electrode gap shall be at the same elevation as the center point of the monitor sensors. (See Fig. 2.) Connect the fuse wire to the end of one electrode by making several wraps and twists and then to the end of the other electrode by the same method. The fuse wire shall be pulled tight and the excess trimmed. Adjust the test controller to produce the desired arc current and duration.

9.4 *Apparatus Calibration for the Four-Sensor Head and Monitor Sensors*—Position each four-sensor head so that the surface of each head is 12 in. [305 mm] from, parallel and normal to, the centerline of the electrodes. Set the symmetrical arc exposure current to 8000 ± 500 A and the arc duration at 10 cycles [0.167 s]. Discharge the arc. Determine the maximum temperature rise for each of the sensors, and multiply by the appropriate factor, determined in 6.2.1, to obtain the total incident energy (in cal/cm^2) measured by each sensor. Compare the highest sensor reading and the average value obtained for all sensors, (excluding the chin sensor), for example, with the theoretical result of 10.1 cal/cm^2 for the calibration exposure given in 9.4.1. Compare the total heat value determined by the sensors to the value shown. The average total heat calculated for the sensors shall be at least 60 % of the value determined by calculation or that shown. The highest measured total heat of any one sensor shall be within 10 % of the calculated value. If these values are not obtained, inspect the test setup and correct any possible problems that could produce less than desired results. An arc exposure calibration test should be conducted at the desired test level after each adjustment, and prior to the start and end of each day's testing and after any equipment adjustment or failure.

9.4.1 Because the arc does not follow a path equidistant from each sensor, the results will vary. At 8000A, the highest total heat measured with a single sensor shall be between 9 and 11 cal/cm^2 and the average total heat for all sensors (excluding the chin sensor) shall be at least 6 cal/cm^2. If these values are not achieved, check the calibration of the sensor system, electrical conditions, and the physical setup of the apparatus and repeat the calibration exposure until the required results are obtained.

9.5 *Confirmation of Test Apparatus Setting*—Confirm the test apparatus setting for each test from the controller equipment. Values reported should be peak arc current, RMS arc current, arc duration, arc energy, and arc voltage. A graph of the arc current should be plotted to ensure proper wave form. In addition, the ambient temperature and relative humidity shall be recorded.

10. Apparatus Care and Maintenance

10.1 *Initial Temperature*—Cool the sensors after exposure with a jet of air or by contact with a cold surface. Confirm that the sensors are at a temperature of 25 to 35°C.

10.2 *Surface Reconditioning*—While the sensor is hot, wipe the sensor face immediately after each test to remove any decomposition products that condense and could be a source of future measurement error. If a deposit collects and appears to be thicker than a thin layer of paint or the surface appears irregular, the sensor surface requires reconditioning. Carefully clean the cooled sensor with acetone or petroleum solvent, making certain to follow safe handling practices. Repaint the surface as noted in 6.3.3. Ensure the paint is dry before running the next test.

10.3 *Monitor Sensor Care*—The sensors shall be kept dry. For outdoor tests, the mannequin heads and monitor sensors shall be covered during long periods between tests to prevent excess temperature rise resulting from exposure to the sun. Due to the destructive nature of the electric arc, the mannequin and head should be covered with the same paint as the sensors. The heads should be re-coated periodically to reduce mannequin deterioration.

11. Procedure

11.1 *Face Protective Products*:

11.1.1 Test specimens shall be exposed to an electric arc. Record the readings of the eye, mouth, and chin sensors.

11.2 Test parameters shall be 8000 ± 500 A arc current, 12-in. (305 mm) electrode gap, ¾ in. diameter stainless steel electrodes, 12-in. (305 mm) distance between the arc center line and the facial plane. In addition to the standard set of exposure conditions, other conditions representative of the expected hazard may be used and shall be reported should this data be cited, but may not be used in determination and reporting of a standard arc rating.

11.3 *Order of Tests*:

11.3.1 Each test shall consist of at least two specimens of the same material, one for each of the four-sensor heads.

11.3.2 To evaluate a single sample of a material, a series of at least ten tests shall be run over a range of incident energies so that the average transmitted heat energy response of at least 20 % of the four-sensor heads are equal to or above and at least 20 % below the Stoll curve criteria. At least 50 % of the data points should be within 20 % of the *ATPV* (see Discussion).

11.3.3 If more than the minimum number of tests are performed, for whatever reason, all valid data points shall be used (see Discussion).

11.3.4 A minimum of 20 data points, the average of four-sensor heads for each of 20 specimens, will be required for data analysis. If breakopen occurs, more than 20 data points may be required so that the breakopen response can be evaluated (above or below the Stoll curve criteria, see 12.2 for treatment of breakopen).

11.3.5 *Discussion*—An iterative process will be needed for achieving the requirement that 50 % of the data points are within 20 % of the *ATPV*. After the first two tests (six specimens) are completed, assuming response above and below the Stoll curve criteria, an estimated *ATPV* value can be determined. Using this estimation, the remaining tests can be selected so that the four-sensor head data fall within 20 % of the *ATPV*, for example, if the approximated *ATPV* is 6.5 cal/cm^2, then test parameters are selected so that the incident energies on the three panels will fall within the range of 5.2 to 7.8 cal/cm^2. As each successive test is performed, the accuracy of the *ATPV* estimation will improve so that the incident energy target range of *ATPV* ±20 % can also be more accurately established. The goal is to achieve 50 % of the data within 20 % of *ATPV* by the time the required 20 data points are complete. Generally, assuming all data points are valid, this would mean that 11 of the 21 data points would need to have incident energy values within 20 % of the *ATPV*. In the example above, 11 of the data points would need to have incident energy values within the range of 5.2 to 7.8 cal/cm^2 for a material with an *ATPV* of 6.5 cal/cm^2. If less than 11 data points fall in this range, additional tests may be needed until about 50 % of the total data points have incident energy values within 20 % of the *ATPV*. All data points are valid unless the copper calorimeter temperature is outside the valid temperature range of the setup, there is a malfunction of the test equipment, or the specimen mounting fails.

11.4 *Heat Transfer Determination with the Four-Sensor Head Test*:

11.4.1 Adjust the temperature of the sensors to between 25 to 35°C.

11.4.2 *Specimen Mounting*—The specimen shall be placed on the test head in the manner in which the product is to be worn.

11.5 *Specimen Data*—Record specimen data including: (*1*) identification number, (*2*) the order of layering (for layered systems) with outer layer listed first, (*3*) material type, (*4*) faceshield/window specimen thickness before testing, (*5*) weave/knit type of hood material(s), (*6*) color, and (*7*) number of specimens tested.

11.6 Mount the fuse wire on electrodes.

11.7 Exercise all safety precautions and ensure all persons are in a safe area.

11.8 Expose test specimens to the electric arc.

11.9 Shut off the electric supply, ventilate the test area at the completion of the data acquisition period, and apply the protective grounds. (Refer to Section 7).

11.10 Extinguish any flames or fires unless it was predetermined to let the specimen(s) burn until consumed.

11.11 Record the thermal and electrical data and material response as required in Section 13.

11.12 Inspect and recondition the sensors if required and adjust the electrodes to proper position and gap.

12. Interpretation of Results

12.1 *Heat Transfer*

12.1.1 *Face Protective Products*:

12.1.1.1 Use only the data from the calorimeter (sensor) with the highest average transmitted heat energy response rise from either the right eye, left eye, mouth, or chin position.

12.1.2 *Plotting Sensor Response*—Once the initiation point is determined, the temperature data collected from any of the calorimeters up to the initiation point can be averaged to obtain the starting calorimeter temperature, $T_{initial}$ (°C). The heat capacity of the copper slug at this temperature is then calculated using Eq 2 in 6.2.1. From this point on, the total incident energy versus time can be determined and plotted for both the head and incident energy sensors. This is accomplished at each time step by calculating the heat capacity of the copper slug from the measured temperature and applying Eq 3 and 4 in 6.2.1 to obtain the total incident energy. These procedures can easily be automated in a spreadsheet.

12.1.3 *Sensor Response versus Stoll Curve*—The Stoll curve prediction information shown in Table 1 can be fit to a model equation that specifies the incident energy for a burn injury at a given value of exposure time:

$$\text{Stoll Response, cal/cm}^2 = 1.1991 \times t(i)^{0.2901} \quad (5)$$

where:

$t(i)$ = elapsed time since the initiation of the exposure, s.

This value can be overlaid on the plot versus time of the sensor responses. A determination can then be made whether a particular head's sensor response did or did not cross the Stoll curve criteria.

12.1.3.1 Calculate the measured heat energy for each of the highest head-sensors at each time increment. Compare this value to the Stoll Response (from Eq 5).

12.1.3.2 At the completion of the data acquisition period, assess each of the highest head heat energy responses versus the Stoll curve. Record a value of 1 for the respective head sensor that at any time exceeds the Stoll criteria, and a value of 0 for those that do not.

12.1.4 *Incident Energy (E_i) Monitor Sensor Responses*—Calculate an average value of the measured heat energy for the respective incident energy monitor sensors at each time increment. At the completion of the data acquisition period, record the maximum measured heat energy response for each respective panel.

12.1.5 *Determining the Arc Rating (ATPV or E_{BT})*—Utilize a minimum of 20 measured head responses (see 11.3) to calculate an *ATPV*. If more than 20 points are collected during a specific test exposure sequence, all valid results shall all be used in determining *ATPV*.

12.1.5.1 Perform a nominal logistic regression on the resulting test data. The maximum average incident energy monitor sensor response is used as the continuous variable, *X*. The corresponding nominal binary *Y* value response is the respective highest head sensor response, exceeding = 1/not exceeding = 0, the Stoll criteria. See Appendix X1 for discussion of the logistic regression technique.

12.1.5.2 Use the logistic regression determined values of slope and intercept to calculate (inverse prediction) the 50 % probability value of exceeding the Stoll curve criteria. This is the *ATPV* value, or the incident energy value that would just intersect the Stoll curve criteria. The value is determined as:

$$ATPV = \left|\frac{\text{Intercept}}{\text{Slope}}\right| \quad (6)$$

12.1.5.3 *Determination of Heat Attenuation Factor (HAF)*—Determine the maximum heat energy response for each of the four head units, from 12.1.3.1, and divide these responses by their respective maximum incident energy monitor sensor responses, from 12.1.4. Identify each of these values as *Et* (fraction of the incident energy which is transmitted through the specimen) for each panel. A *HAF* data point (*haf*) for each four-head unit is calculated according to the formula: $haf = 100 \times (1 - Et)$. The *HAF* factor is then determined by calculating the average of all the *haf* values. At least 20 data points representing 20 respective maximum head sensor values shall be used. Also calculate the standard deviation of the points (Std), the standard error of the average (given by the ratio of the standard deviation to the square root of the number of panels used), and the 95 % confidence interval using:

$$\text{Upper Confidence Limit} = HAF\text{value} + \frac{t_{95\,\%} \times Std}{\sqrt{N}} \quad (7)$$

$$\text{Lower Confidence Limit} = HAF\text{value} - \frac{t_{95\,\%} \times Std}{\sqrt{N}}$$

where $t_{95\,\%}$ referenced in this section only is the Student's *t* value confidence interval value for $N-1$ degrees of freedom and *N* is the number of panel values used (for $N = 20$, $t_{95\,\%} = 2.093$).

12.2 *Determination of Breakopen Energy*—If breakopen is observed on any four-sensor head unit at an energy level at or below the Stoll criteria (from the *ATPV* analysis in 12.1), a determination of the breakopen energy response of material under test shall be determined. This can be done using the existing test four-sensor head information if the respective maximum head sensor values are distributed such that about 20+ % of lower incident energy values indicate no breakopen, 10 to 20 % of higher incident energy values indicate breakopen, and 50 to 70 % of the incident energy values show mixed results (sometimes breakopen occurs, sometimes it does not). If there is not enough data in these ranges, perform additional specimen tests at the respective incident energy range and record the material response.

NOTE 4—The following technique can be used to determine a material systems breakopen response irrespective of the resulting incident energy and its relationship to Stoll.

12.2.1 Record a value of 1 for each four-sensor head that at any time exhibits breakopen, and a value of 0 for those that do not.

12.2.2 Perform a nominal logistic regression on the resulting test data. The maximum average incident energy monitor sensor response is used as the continuous variable, *X*. The corresponding nominal binary *Y* value response is the four-sensor head material breakopen response, breakopen = 1/no breakopen = 0.

12.2.3 Use the logistic regression determined values of slope and intercept to calculate (inverse prediction) the 50 % probability value of material breakopen. This is the E_{BT} value, or the incident energy value that would just predict breakopen. The value is determined as:

$$E_{BT} = \left|\frac{\text{Intercept}}{\text{Slope}}\right| \quad (8)$$

12.2.4 If the E_{BT} value is above the previously determined *ATPV* (if it can be determined), then the *ATPV* value stands without modification and is the value reported as the arc rating (*ATPV*).

12.2.5 If the E_{BT} value is equal to or below the previously determined *ATPV* (if it can be determined), then the E_{BT} value shall be reported as the arc rating (E_{BT}) and this is noted in the test report.

12.2.6 If the *ATPV* value cannot be determined due to breakopen, perform sufficient panel tests, as identified in 12.2 to allow determination of the E_{BT} value. Report the resultant E_{BT} value and the E_{BT} value shall be reported as the arc rating (E_{BT}) and note this in the test report.

12.3 *Electrical Data*—Consistency in maintaining the arc voltage, arc current, arc duration, and closing may vary from test laboratory to test laboratory. Section 6.6 requires no more than 2 % variation from test to test, given identical test parameters. Tests that exceed this 2 % variation shall be investigated.

12.4 *Subjective Data*—Observe the effect of the exposure on the product and, after the exposed specimens have cooled, carefully remove the product from the head noting any additional effects from the exposure. This may be described by one or more of the following terms which are defined in Section 3: (*1*) breakopen, (*2*) melting, (*3*) dripping, (*4*) deformation, (*5*) afterflame time, (*6*) shrinkage, and/or (*7*) electric arc ignition.

13. Report

13.1 State that the test has been performed as directed in this test method, and report the following information:

13.1.1 Specimen data as indicated in 11.5.

13.1.2 Conditions of each test, including: (*1*) test number, (*2*) RMS arc current, (*3*) peak arc current, (*4*) arc gap, (*5*) arc duration, (*6*) arc energy, (*7*) plot of arc current, and (*8*) any clothing on mannequin.

13.1.3 Test data including; (*1*) test number, (*2*) RMS arc current, (*3*) full specimen(s) description, (*4*) order and weight of layers and the total weight of all layers (in the case of multi-layer systems), (*5*) distance from the arc center line to facial plane, (*6*) subjective evaluation as outlined in 12.5, (*7*) plot of the response of the monitor sensors and the four-sensor heads for each head test, (*8*) plot of the maximum response from each of the four-sensor heads and from the monitor sensors for each head test, (*9*) Arc Rating (*ATPV* or E_{BT}), (*10*) heat attenuation factor (*HAF*), (*11*) plot of *HAF* on E_i, and (*12*) plot of the incident energy distribution E_i (bare) from the bare shot analysis.

13.2 Report any abnormalities relating to the test apparatus and test controller.

14. Test Specimen Disposition

14.1 Return the exposed specimens, plots, test data, and unused specimens to the person requesting the test, in accordance with any prior arrangement. All test specimens shall be marked with a reference to a unique identifier.

15. Precision and Bias

15.1 *Statement of Precision*—The precision of the procedure in Test Method F 2178 for measuring the *ATPV* and E_{BT}, is being determined and will be available by June, 2003 or within six months of the publication of this standard. It is not feasible to specify the precision of the procedure at this time since no comparative data is available.

15.2 *Statement of Bias*—No information can be presented on the bias of the procedure in Test Method F 2178 for measuring the *ATPV* or E_{BT}, because no material having an accepted reference value is available.

16. Keywords

16.1 arc rating; electric arc; faceshield; hood

APPENDIX

(Nonmandatory Information)

X1. LOGISTIC REGRESSION TECHNIQUE[10]

X1.1 Binomial logistic regression is a form of regression used when the dependent variable is limited to two states (dichotomy) and the independent variable is continuous (it can also be applied to multiple continuous independent variables). The logistic regression technique applies maximum likelihood estimation after transforming the dependent variable into a probability variable, the natural log of the odds of the dependent occurring or not. It thus generates an estimate of the probability of a certain event occurring by solving the following:

$$ln\left[\frac{p}{1-p}\right] = a + bx + error \quad \text{(X1.1)}$$

or

$$\left[\frac{p}{1-p}\right] = e^{a} \times e^{bx} \times e^{error} \quad \text{(X1.2)}$$

where:

ln	=	natural logarithm,
p	=	probability that the event *Y* occurs, *p* (*Y* = 1),
[p/(1−p)]	=	odds ratio; (1−*p*) is the probability that event *Y* does not occur,
ln[p/(1−p)]	=	log odds ratio, and
right hand side of the equation	=	standard linear regression form.

X1.2 The logistic regression model is simply a non-linear transformation of the linear regression model. The logistic distribution is an S-shaped distribution function which is somewhat similar to the standard normal distribution. The logit distribution estimated probabilities lie between 0 and 1. This can be seen by rearranging the equation above solving for *p*:

$$p = \left[\frac{e^{(a+bx)}}{1 + e^{(a+bx)}}\right] \quad \text{(X1.3)}$$

or

$$p = \left[\frac{1}{1 + e^{(-a-bx)}}\right] \quad \text{(X1.4)}$$

X1.2.1 If (*a*+*bx*) becomes large, *p* tends to 1, when (*a*+*bx*) becomes small, *p* tends to 0, and when (*a*+*bx*) = 0, *p* = 0.5 (the value used for *ATPV* and E_{BT} in the methods above). The 50 % probability value is the point where the probability of occurring / not occurring is identical and would represent, in the case of the *ATPV* measurement, the point at which you just crossed the Stoll curve.

X1.3 The analysis technique makes no assumptions about linearity of the relationship between the independent variable and the dependent, does not require normally distributed variables, does not assume the error terms are homoskedastic (the variance of the dependent variable is the same with different values of the independent variable—a criteria for ordinary least squares regression), and in general has less stringent requirements.

X1.4 Operationally, a dummy variable of 1 or 0 is utilized to represent the particular state of the dependent item measured. In the *ATPV* example above, the coding of the dependent variable corresponds to:

$Y = 1$ if the heat response of the calorimeter exceeded the Stoll curve

$Y = 0$ if the heat response of the calorimeter did not exceed Stoll

X1.4.1 The independent, continuous variable in this case is the incident energy from the thermal arc exposure.

X1.5 A logistic regression is performed from a series of measurements and the values for *a* and *b* are determined (plus a host of other descriptive features; see the particular documentation for the software package used). The Stoll criteria (or breakopen response) is then determined by calculating *x* at the *p* = 0.5 or 50 % probability value, which from above is simply where (*a* + *bx*) = 0 or:

$$x = \left|\frac{a}{b}\right| \quad \text{(X1.5)}$$

X1.5.1 The absolute value has been used here since some packages express their model calculation in the reverse manner (*p* = probability not occurring, etc.) which flips the S-shaped distribution. This can introduce a negative sign on the value of *a* or *b*, however the value at the 50 % probability point is the same.

X1.6 There are several commercial and free software packages that will perform this analysis. The University of Minnesota School of Statistics offers a free and quite powerful statistical analysis package called MacAnova, which can be used to perform the analysis (http://leech.stat.umn.edu/macanova/).

[10] See also D.W. Hosmer and S. Lemeshow, “Applied Logistic Regression,” 1989, John Wiley & Sons, New York.

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