Designation: F 1959/F 1959M – 99

Standard Test Method for Determining the Arc Thermal Performance Value of Materials for Clothing[1]

This standard is issued under the fixed designation F 1959/F 1959M; 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 thermal performance value of materials intended for use as flame resistant clothing for workers exposed to electric arcs that would generate heat flux rates from 2 to 600 cal/cm^{2}s.

1.2 This test method will measure the arc thermal performance value of materials which meet the following requirements: less than 6 in. char length and less than 2 s afterflame when tested in accordance with Federal Test Method 191A Method 5903.1.

1.2.1 It is not the intent of this procedure to evaluate non flame resistant materials except where used as under layers in multiple layer specimens.

1.3 The materials used in this test method are in the form of flat specimens.

1.4 This test method may be used to generate information for the development of smaller scale test methods.

1.5 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.

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.

1.7 *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 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:*

D 123 Terminology Relating to Textiles[2]

D 4391 Terminology Relating to the Burning Behavior of Textiles[3]

F 1494 Terminology Relating to Protective Clothing[4]

2.2 *ANSI/IEEE Standard:*[5]

Standard Dictionary of Electrical and Electronics Terms

2.3 *Federal Standard:*[6]

Federal Test Method Standard (FTMS) No. 191A Method 5903.1, Flame Resistance Cloth Vertical

3. Terminology

3.1 *Definitions:*

3.1.1 See also Terminology D 4391.

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

3.1.3 *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.

3.1.4 *arc gap*, *n*—distance between the arc electrodes, in.

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

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

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

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

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

3.1.10 *breakopen*, *n—in electric arc testing*, a material response evidenced by the formation of one or more holes in

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[1] This test method is under the jurisdiction of ASTM Committee F-18 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 07.01.

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

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

[5] Available from the Institute of Electrical and Electronics Engineers, Inc., 345 E. 47th St., New York, NY 10017.

[6] Available from Standardization Documents Order Desk, Bldg. 4, Section D, 700 Robbins Ave., Philadelphia, PA 19111-5094, Attn: NPODS.

the material which may allow thermal energy to pass through the material.

3.1.10.1 *Discussion*—The specimen is considered to exhibit breakopen when any hole is at least one-half square inch in area or at least one inch in any dimension. Single threads across the opening or hole do not reduce the size of the hole for the purposes of this test method. In multiple layer specimens of flame resistant material, all the layers must breakopen to meet the definition. In multiple layer specimens, if some of the layers are ignitable, breakopen occurs when these layers are exposed.

3.1.11 *breakopen threshold energy* (E_{BT}), *n*—the average of the five highest incident energy exposure values below the Stoll curve where the specimens do not exhibit breakopen.

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

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

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

3.1.15 *dripping*, *n—in testing flame-resistant clothing*, a material response evidenced by flowing of the fiber polymer.

3.1.16 *embrittlement*, *n*—the formation of a brittle residue as the result of pyrolysis or incomplete combustion.

3.1.17 *heat attenuation factor HAF*, *n*—in electric arc testing, the percent of the incident energy which is blocked by a material at an incident energy level equal to ATPV.

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

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

3.1.20 *ignitability*, *n (ignitable, adj)—in electric arc exposure*, the property of a material involving ignition accompanied by heat and light, and continued burning resulting in consumption of at least 25 % of the exposed area of the test specimen.

3.1.21 *ignition*, *n*—the initiation of combustion.

3.1.22 *incident energy monitoring sensors*, *n*—sensors mounted on each side of the panel, using the calorimeters described in 6.3, not covered by fabric, used to measure incident energy.

3.1.23 *incident energy* (E_i), *n—in electric arc testing*, the total heat energy received at a surface as a direct result of an electric arc.

3.1.23.1 *Discussion—In an arc test*, incident energy for a specimen is determined from the average temperature rise response of the two monitor sensors adjacent to the test specimen.

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

3.1.25 *melting*, *n*—in testing flame resistant clothing, a material response evidenced by softening of the fiber polymer.

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

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

3.1.28 *shrinkage*, *n—in testing flame resistant clothing*, a material response evidenced by reduction in specimen size.

3.1.29 *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).

3.1.30 *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.

3.1.31 *X/R ratio*—The ratio of system inductive reactance to resistance. 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.

3.2 For definitions of other textile terms used in this method, refer to Terminologies D 123 and F 1494.

4. Summary of Test Method

4.1 This test method determines the incident energy which would predict a second degree burn injury when the material(s) is exposed to heat energy from an electric arc.

4.1.1 During this procedure, the amount of heat energy transferred by the material(s) is measured during and after exposure to an electric arc.

4.1.1.1 The heat flux of the exposure and that transferred by the test specimen(s) are both measured with calorimeters. The rate at which the temperature of the calorimeters increases is a direct measure of the heat energy received.

4.2 Material performance for this procedure is determined from the amount of heat transferred by the specimen(s).

4.3 Heat transfer data is used to predict the onset of second degree burn using the Stoll curve.

4.4 This procedure incorporates incident energy monitoring sensors.

TABLE 1 Human Tissue Tolerance to Heat, Second Degree Burn[A]

Exposure Time	Heat Flux		Total Heat		Calorimeter[B] Equivalent		
s	kW/m^2	cal/cm^2s	kWs/m^2	cal/cm^2	ΔT °C	ΔT °F	ΔmV
1	50	1.2	50	1.20	8.9	16.0	0.46
2	31	0.73	61	1.46	10.8	19.5	0.57
3	23	0.55	69	1.65	12.2	22.0	0.63
4	19	0.45	75	1.80	13.3	24.0	0.69
5	16	0.38	80	1.90	14.1	25.3	0.72
6	14	0.34	85	2.04	15.1	27.2	0.78
7	13	0.30	88	2.10	15.5	28.0	0.80
8	11.5	0.274	92	2.19	16.2	29.2	0.83
9	10.6	0.252	95	2.27	16.8	30.2	0.86
10	9.8	0.233	98	2.33	17.3	31.1	0.89
11	9.2	0.219	101	2.41	17.8	32.1	0.92
12	8.6	0.205	103	2.46	18.2	32.8	0.94
13	8.1	0.194	106	2.52	18.7	33.6	0.97
14	7.7	0.184	108	2.58	19.1	34.3	0.99
15	7.4	0.177	111	2.66	19.7	35.4	1.02
16	7.0	0.168	113	2.69	19.8	35.8	1.03
17	6.7	0.160	114	2.72	20.2	36.3	1.04
18	6.4	0.154	116	2.77	20.6	37.0	1.06
19	6.2	0.148	118	2.81	20.8	37.5	1.08
20	6.0	0.143	120	2.86	21.2	38.1	1.10
25	5.1	0.122	128	3.05	22.6	40.7	1.17
30	4.5	0.107	134	3.21	23.8	42.8	1.23

[A] Stoll, A. M. And Chianta, M. A., "Method and Rating System for Evaluation of Thermal Protection," Aerospace Medicine, Vol 40, 1968, pp. 1232–1238.

[B] Iron/constantan thermocouple.

4.5 Material response shall be further described by recording the observed effects of the electric arc exposure on the specimens using the terms in 12.4.

5. Significance and Use

5.1 This test method is intended for the determination of the arc thermal performance value of a material, a combination of materials or a comparison of different materials will measure the arc thermal performance value of materials intended for use in flame resistant clothing for workers exposed to electric arcs.

5.1.1 This test method is intended for the determination of the arc thermal performance value of a material, a combination of materials, or a comparison of different materials.

5.1.2 Because of the variability of the arc exposure, different heat transmission values may result for individual sensors. Evaluate the results of each sensor 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. In addition to the standard set of exposure conditions, other conditions representative of the expected hazard may be used.

6. Apparatus

6.1 *General Arrangement For Determining Arc Thermal Performance Using Three Two-Sensor Panels and Monitor Sensors*—The test apparatus shall consist of supply bus, arc controller, recorder, arc electrodes, three two-sensor panels, and monitor sensors.

6.1.1 *Arrangement of the Two-Sensor Panels*—Three two-sensor panels shall be used for each test and spaced as 120 degrees as shown in Fig. 1. Each two-sensor panel shall have two monitoring sensors. One monitoring sensor shall be positioned on each side of the two-sensor panel as shown in Fig. 2.

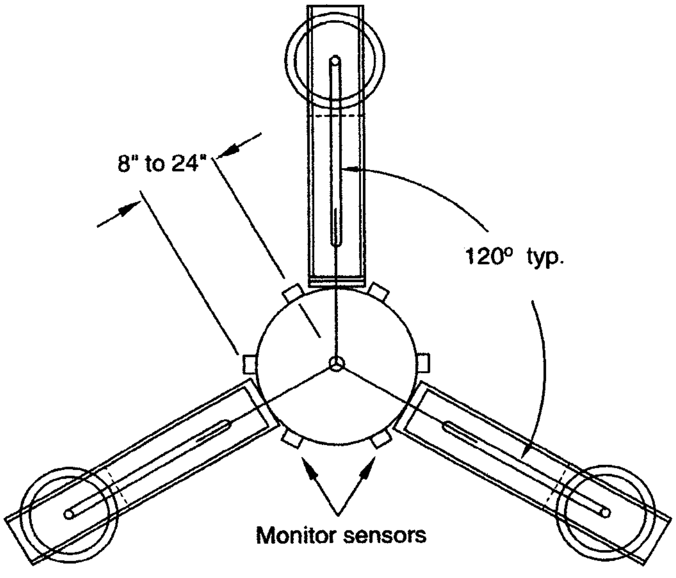


FIG. 1 Arrangement of Three Panel Sensors with Monitor Sensors

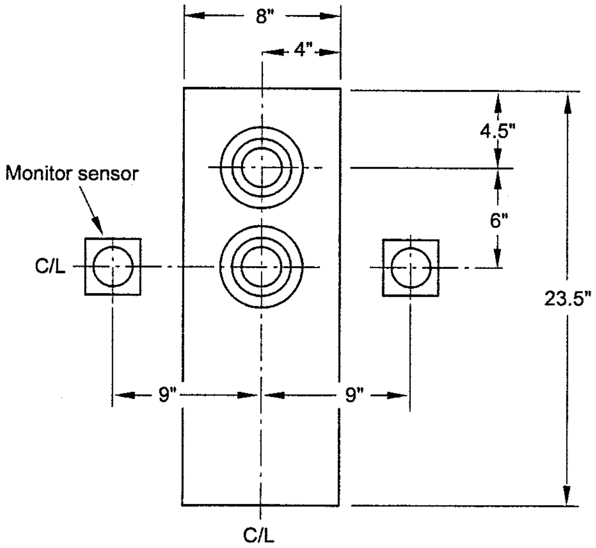


FIG. 2 Two Sensor Panel (Face View) with Monitor Sensors

6.1.2 *Panel Construction*—Each two sensor panel and each monitor sensor holder shall be constructed from non-conductive heat resistant material. Each two-sensor panel shall be 8 by 21.5 in. ± 0.5 in. as shown in Fig. 2. Each two sensor panel and monitoring sensors shall be adjustable from 8 in. (200 mm) to 24 in. [600 mm] from the centerline of the arc electrodes as shown in Figs. 1 and 3. Two sensors shall be mounted in the panel as shown in Fig. 2. Each sensor shall be mounted flush with the surface of the mounting board.

6.2 *Sensor Response*:

6.2.1 Panel sensor response shall be compared with the Stoll Curve.

6.2.2 Monitor sensor response is converted to incident energy in units of cal/cm^2 by multiplying the delta T C (ΔT) by the constant factor 0.135 cal/cm^2 C.

6.3 *Sensor Construction*—The sensor mount used to hold the calorimeter shall be constructed from non-conductive heat resistant material as shown in Fig. 4. The calorimeter shall be constructed from electrical grade copper with four thermocouple wires installed in the arrangement as shown in Fig. 5. The thermocouple wire shall be installed in the calorimeter as shown in Fig. 6. For test exposures above 40 cal/cm^2 only, alternate calorimeters for the monitor sensors may be used provided they are calibrated and have a similar response.

6.4 *Supply Bus and Electrodes*—A typical arrangement of the supply bus and arc electrodes is shown in Fig. 7. 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 the chance of molten metal burns. 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

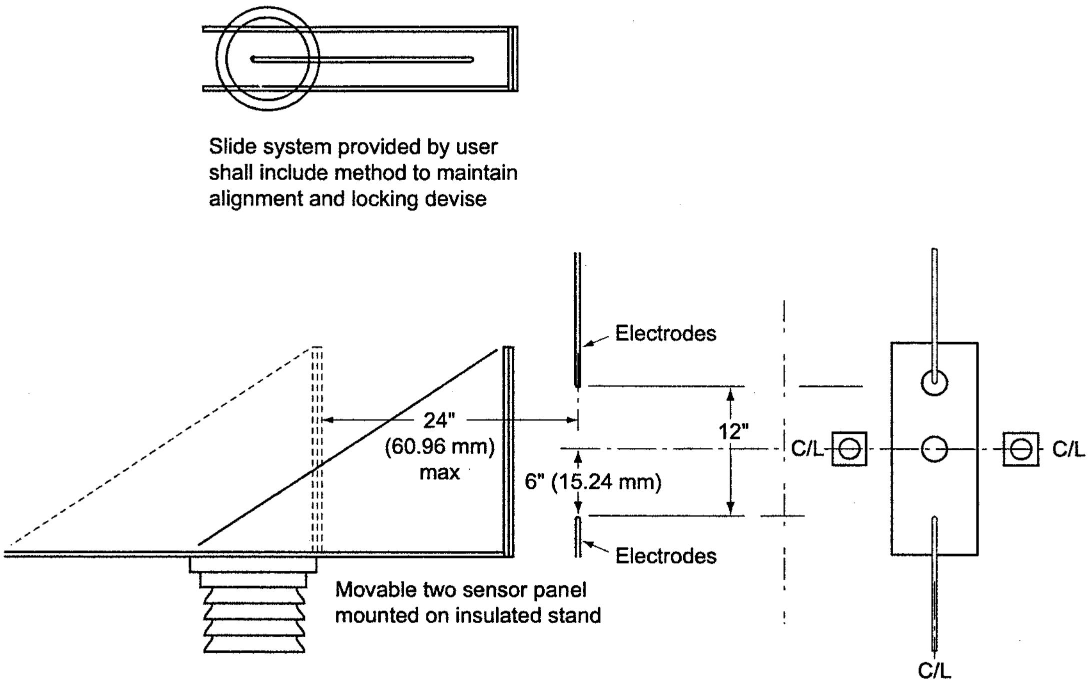


FIG. 3 Sliding Two Sensor Panel

up to 12 in. [305 mm] with alternating arc current from 4000 up to 25 000 amperes and with arc duration from 3 cycles [0.05 s] up to 90 cycles [1.5 s] from a 60 Hz supply. The X/R ratio of the test circuit shall be such that the test current contains a DC component resulting in the first peak of the test current having a magnitude of 2.3 times the symmetrical RMS value.

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 maximum asymmetrical current with an X/R ratio of the test circuit as stated in 6.5. 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 temperature data shall be acquired at a minimum sampling rate of 50 ms/channel for 30 s. The current and voltage data should be acquired at a minimum rate of 2 kHz. The acquisition system shall be able to record temperatures to 250 C with sufficient sensitivity to read sensor response to 1°C for a single layer system. For multiple layer systems, the system should be able to record temperatures to 400 C. The system should have a resolution of 0.1°C and an accuracy of 1.5°C.

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 heavily tinted glasses such as ANSI/ASC Filter Shade 12 welding glasses. If the test is conducted indoors there shall be a means to ventilate the area to carry away combustion products, smoke, and fumes. Air currents can disturb the arc reducing the heatflux 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 the ground for the appropriate test voltage.

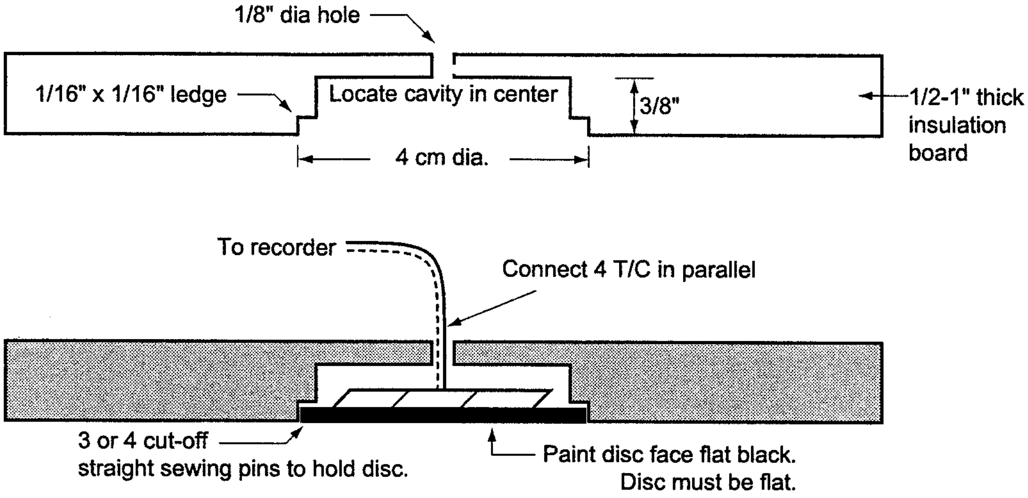
7.2 The test apparatus, electrodes and calorimeter assemblies become hot during testing. Use protective gloves when handling these hot objects.

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

7.4 Immediately after each test, the electric supply shall be shut off from the test apparatus and all other lab equipment used to generate the arc. The apparatus and other lab 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 Two-Sensor Panel Test*—From the material to be tested, make the post-laundered specimen size at least 26 in. [610 mm] long and at least 12 in. [305 mm] wide.



Heat flux (q):

$$q = \frac{\text{mass} \times \text{heat capacity copper} \times \text{temperature rise}}{\text{area of disc} \times \text{time}}$$

$$= \frac{mC_p \, \Delta T}{A \, \Delta\theta}$$

$$C_p = 0.0942 \text{ cal/g °C}$$
$$= 0.0523 \text{ cal/g °F}$$

If disc weighs 18 g:

$$q = 0.0135 \, \Delta T/10 \text{ s °C}$$
$$q = 0.0075 \, \Delta T/10 \text{ s °F}$$

Heat Flux (g):

$$\text{g} = \frac{\text{mass} \times \text{heat capacity copper} \times \text{temperature rise}}{\text{area of disc} \times \text{time}}$$

$$= \frac{mC_p\Delta T}{A\Delta\theta} \qquad C_p = 0.0942 \text{ cal/g °C}$$
$$= 0.0523 \text{ cal/g °F}$$

If disc weighs 18 g:

$$q = 0.0075 \, \Delta T/10 \text{ s °F}$$
$$= 0.0135 \, \Delta T/10 \text{ s °C}$$

FIG. 4 Calorimeter and Thermocouple Detail

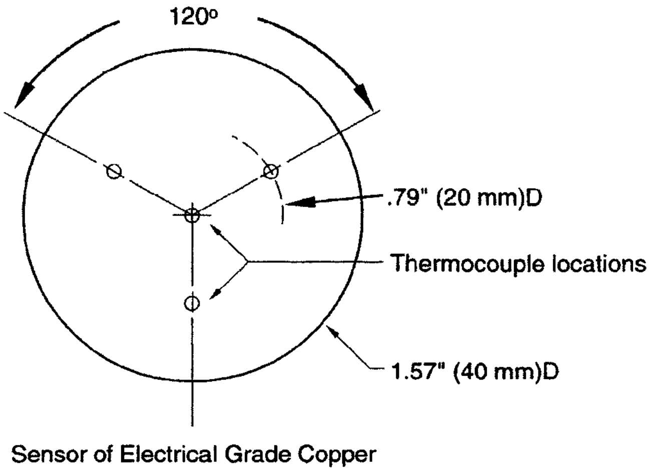


FIG. 5 Calorimeter

Refer to Section 10, to determine number of samples.

8.1.1 The length direction should be cut in the warp or wale direction of the material.

8.2 *Laundry Conditioning of Test Specimens*:

8.2.1 Launder the required amount of material for the test specimens.

8.2.1.1 Launder three times in a washing machine using a commercially available detergent without chlorine bleach and with a warm 120°F [50°C] water setting.

NOTE 1—Drying is not required following the first two launderings.

8.2.1.2 Following the three laundry cycles, tumble dry in a dryer on a setting appropriate for the fabric. Remove specimens when dry.

8.2.1.3 Samples may be restored to a flat condition by pressing.

8.2.2 For those materials that require cleaning other than laundering, follow the manufacturer's recommended practice and note the procedure used in the test reports.

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 proper operation. Measure and graph the temperature rise of each calorimeter and system response. At

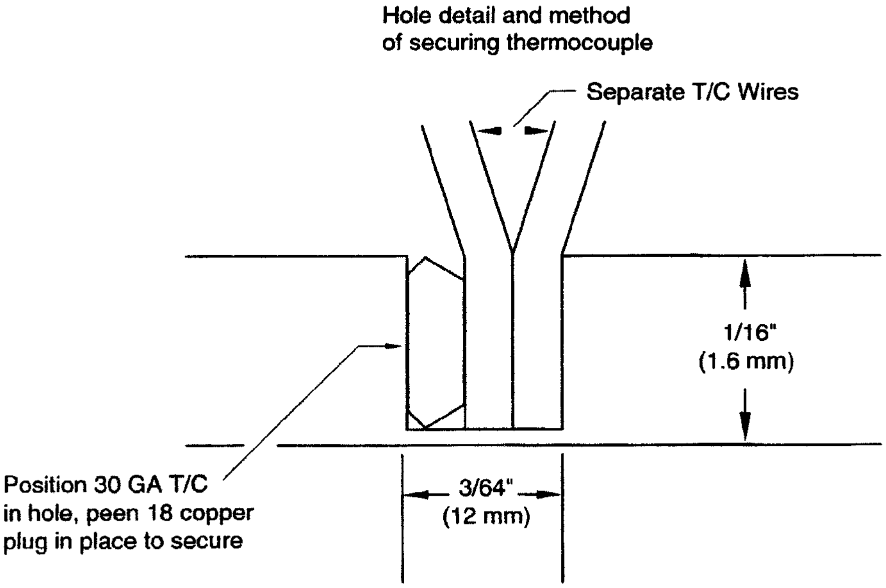


FIG. 6 Thermocouple Wire Installation

30 seconds 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 or repaired.

NOTE 2—One acceptable method is to expose each calorimeter to a fixed radiant energy source for thirty seconds. For example, place the front surface of a 500 watt spot light[7] 10.5 in. from the calorimeter. The spot shall be centered on and perpendicular to the calorimeter.

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. 1). 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. The test controller should be adjusted to produce the desired arc current and duration.

9.4 *Apparatus Calibration for the Two-Sensor Panels and Monitor Sensors*—Position each two-sensor panel so that the surface of each panel is 12 in. [305 mm] from, parallel and normal to the centerline of the electrodes. Set the symmetrical arc exposure current to the test amperage level 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 sensor constant 0.135 [cal/cm^2 C] to obtain the incident energy (total heat) (cal/cm^2) measured by each sensor. Compare the highest sensor reading and the average value obtained for all sensors. For example, with the measured result of 10.1 cal/cm^2 for the calibration exposure of 8000 A for 0.167 s. Compare the total heat value determined by the sensors to the value shown. The average total heat calculated for the

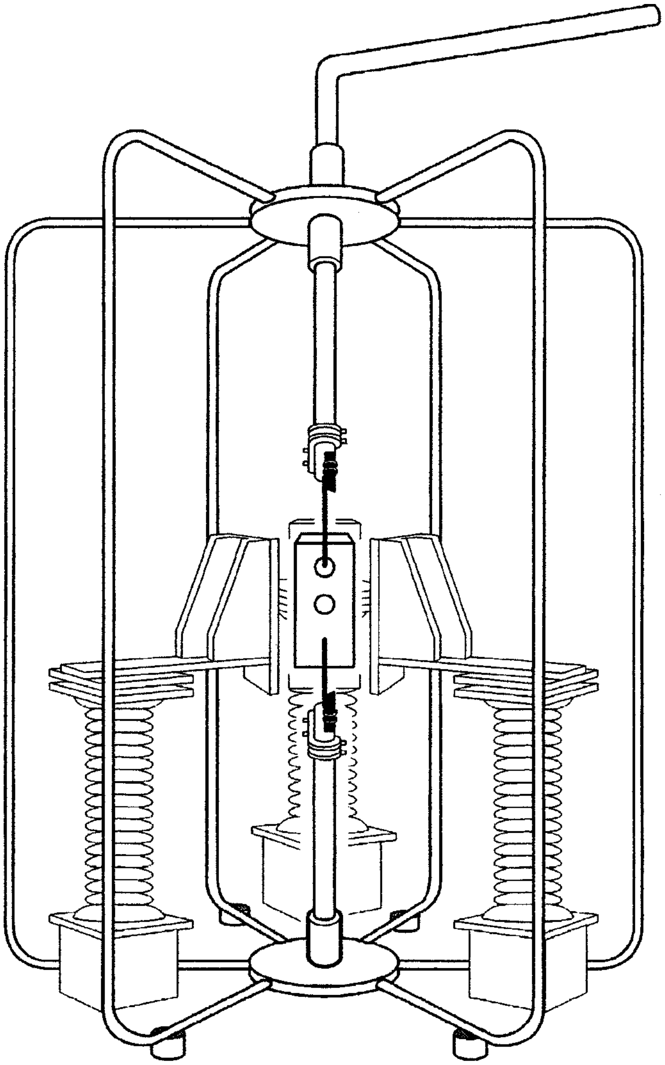


FIG. 7 Supply Bus and Arc Electrodes for Panels

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[7] A 500W light source is available from the Strand Electric and Engineering Co. Ltd. as Part No. 83 (500W, 120V light source).

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 which is equidistant from each sensor, the results will vary. At 8000 A, 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 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.

9.4.2 If during testing the exposure values specified in 9.4 are not achieved in three consecutive tests, then suspend testing and re-calibrate the system. If a change is made as a result of the re-calibration, then the data from the last three tests shall be rejected.

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 which condense and could be a source of future error. If a deposit collects and appears to be thicker than a thin layer of paint, or the surface is 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 with a thin layer of flat black high temperature spray paint. Use the same paint on all sensors and ensure that the paint is dry before running the next test.

10.3 *Panel and Incident Energy Monitoring Sensor Care*—The boards shall be kept dry. For outdoor tests the panels and monitoring 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 monitoring sensor holders should be covered with the same paint as the sensors. The holders should be re-coated periodically to reduce deterioration.

11. Procedure

11.1 Test parameters shall be 8 ± 1 kA arc current, 12-in. electrode gap, stainless steel electrodes, 12-in. distance between the arc center line and the test specimen surface. Additional test parameters may also be used and the results reported on an optional basis.

11.2 *Order of Tests*—Each test shall consist of three specimens of the same material, one for each of the three two-sensor panels. To evaluate a single sample of a material, a series of at least seven tests shall be run over a range of incident energies so that the average temperature rise of at least 20 % of the two-sensor panels are equal to or above and at least 20 % below the Stoll curve. If more than the minimum number of tests are performed, for whatever reason, all data points shall be used. Not more than 10 percent of the data points shall be greater than 10°C above or below the Stoll curve. A minimum of 20 data points, the average of two sensor results for each of 20 panels, will be required for data analysis. If breakopen occurs, more than seven tests may be required (see 3.1.8). The incident energy range shall be achieved by increasing or decreasing the arc duration (cycles). The intent of these tests is to achieve an average temperature rise for each panel which is in the same range as the Stoll curve.

11.3 *Heat Transfer Determination with the Three Two-Sensor Panel Test*:

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

11.3.2 *Specimen Mounting*—The specimen shall be fixed to the panel without stretching the material and in a manner that permits the specimen to shrink during arc exposure. This has been achieved with a material clamping system (see Fig. 8). The clamping system consists of four clamps that hold the specimen to the panel and allow the specimen to shrink during arc exposure. Each clamp within the clamping system applies between 1 and 1½ lb of force to secure the material to the panel. Other means of mounting, which meet the above objectives, may also be employed. If multiple layer specimens are used, they shall be mounted in a manner that represents normal layering of wearing apparel.

11.4 *Specimen Data*—Record specimen data including: (*1*) identification number, (*2*) the order of layering with outer layer listed first, (*3*) material type, (*4*) actual basis weight after laundering and before testing, (*5*) weave/knit type, (*6*) color, and (*7*) number of specimens tested.

11.5 Mount the fuse wire on electrodes.

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

11.7 Expose test specimens to the electric arc.

11.8 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)

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

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

11.11 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 *Determining Time Zero*—Due to the electrical noise typically associated with conducting tests of this type, it is difficult to get a reliable trigger signal at the initiation of the arc. The starting time of the arc can be reliably determined

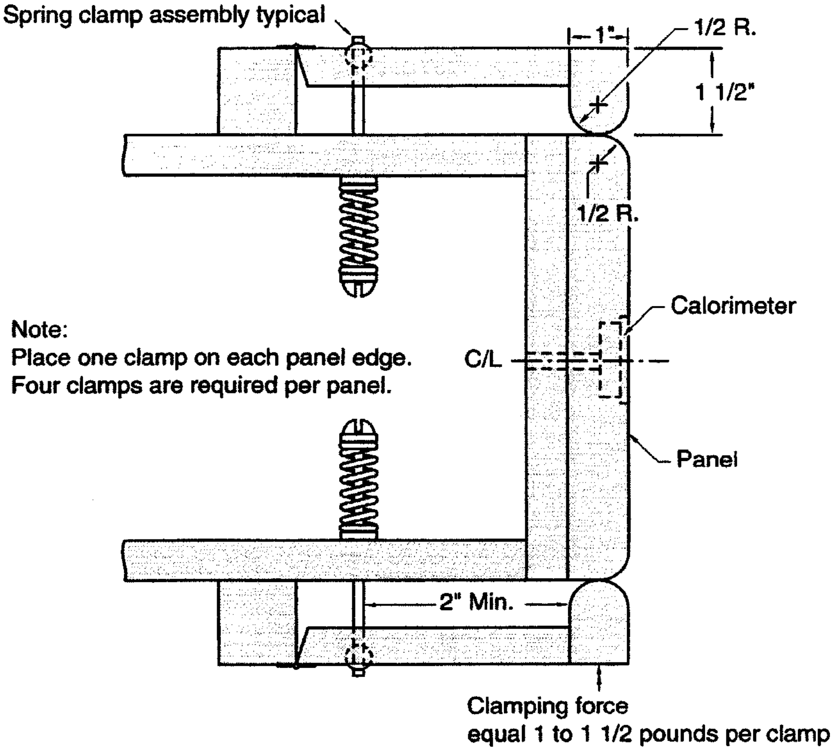


FIG. 8 Material Clamping Assembly

however, for each test through the following analysis. For each sensor's curve, plot the difference between the curve and a line drawn from the start of the data stream to some point on the rising temperature region of the curve. Find the maximum of this difference plot. The point at which this maximum occurs is the best estimate of the arc initiation time for that sensor. These arc initiation points are usually very consistent within a test, but the median of these points or all sensors should be used as the initiation point for all of the sensors.

NOTE 3—Other satisfactory methods are available to determine time zero and may be utilized.

12.1.2 *Plotting Sensor Response*—Once the initiation point is determined, the data collected up to the initiation point can be averaged to obtain a baseline for each sensor curve. The baseline of each individual curve is then subtracted from each of the data points to yield a zero based temperature rise curve. With the initialization point determined, and the sampling time known the temperature rise curve can now be plotted with the correct time scale, Fig. 9. These procedures can easily be automated in a spreadsheet.

12.1.3 *Sensor Response versus Stoll Curve*—The Stoll Curve is defined by the values in Table 1. Overlay the Stoll Curve on the plot of the sensor responses. Also create a data file which interpolates between the Stoll Curve data points in Table 1 so that Stoll Curve data is available at each time interval at which temperature rise data is recorded.

12.1.3.1 From the temperature rise data for the two sensors on each panel, create an average temperature rise curve (ρT_{avg}). Compare this curve, ρT_{avg} for each panel with the Stoll Curve.

12.1.3.2 For the ρT_{avg} curves which are above the Stoll

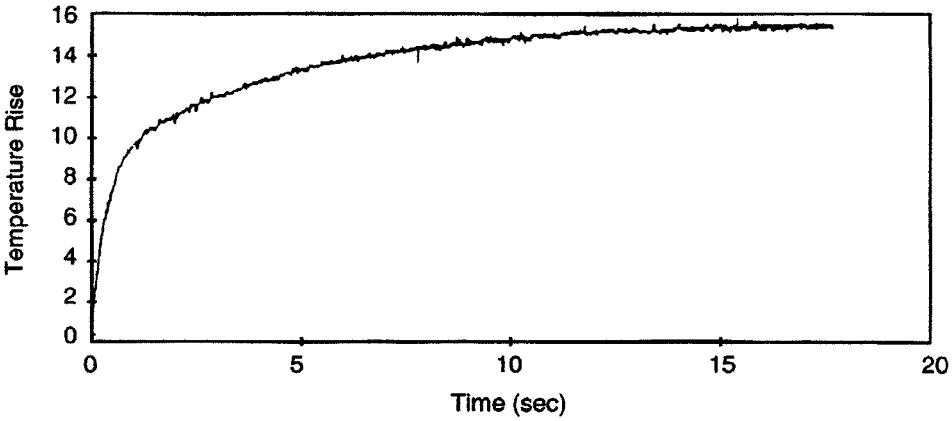


FIG. 9 Typical Sensor Temperature Rise Curve with Time Scale and Baseline Correction

Curve, record the maximum difference in C degrees between the ρT_{avg} curve and the Stoll Curve. These values will be positive in sign or zero indicating the ρT_{avg} curves are at or above the Stoll Curve. Label this positive value "ρStoll/avg" for the maximum difference between the Stoll Curve and the ρT_{avg} curve.

12.1.3.3 For the ρT_{avg} curves which are below the Stoll Curve, record the minimum difference in C degrees between the ρT_{avg} curve and the Stoll Curve. These values will be negative in sign indicating the ρT_{avg} curves are below the Stoll Curve. Label this negative value "ρStoll/avg" for the minimum difference between the Stoll Curve and the ρT_{avg} curve.

12.1.4 *Incident Energy (E_i) Monitor Sensor Responses*—For each panel in an arc exposure, calculate the average of the maximum rise, ρ$T\ C_{\text{avg/max}}$, for the two adjacent monitor sensors. Convert this ρ$T\ C_{\text{avg/max}}$ into cal/cm^2 by multiplying by the copper calorimeter conversion constant of 0.135 cal/cm^2 C to determine the incident exposure energy, E_i, for each panel in an arc exposure.

12.1.5 *Determining Arc Thermal Performance Values*—For each panel, plot the positive value or the negative value of ρStoll/avg as the horizontal axis and E_i as the vertical axis. For each arc exposure, the three panels will create three data points of ρStoll/avg versus E_i. In order to have sufficient data for analysis, at least 20 data points, representing 20 panels, shall be obtained with no less than 20 % of the data being positive and no less than 20 % of the data being negative values. Not more than 10 percent of the data points shall be greater than 5°C above or below the Stoll curve. All data points meeting these criteria shall be used in the calculation of ATPV and HAF. If ATPV cannot be calculated due to breakopen, use the method of data analysis in 12.2.

12.1.6 Create the best fit straight line for the ρStoll/avg data points and determine the 95 % confidence intervals for average and for point values. To calculate the confidence intervals estimate the variance (sigma squared) by

$$S^2 = \frac{S_R}{n-2} \tag{1}$$

where:

$$S_R = \Sigma(y-\bar{y})^2 - b^2\Sigma(x-\bar{x})^2 = \Sigma(y-\bar{y})^2 - b\Sigma(x-\bar{x})(y-\bar{y})$$

Then the variance of the estimate of y at some particular x_0 can be calculated from the expressions:

$$\hat{V}(\hat{y})_{avg} = \left[\frac{1}{n} + \frac{(xo-\bar{x})}{\Sigma(x-\bar{x})^2}\right]s^2 \tag{2}$$

$$\hat{V}(\hat{y}o)_{pnt} = \left[1 + \frac{1}{n} + \frac{(xo-\bar{x})}{\Sigma(x-\bar{x})^2}\right]s^2 \tag{3}$$

A 1-α confidence interval for the estimate of y at some particular x_0 is then given by

$$\hat{y}o \neq t_{a}/_{2}\sqrt{\hat{V}(\hat{y}0)_{avg}} \tag{4}$$

$$\hat{y}o \neq t_{a}/_{2}\sqrt{\hat{V}(\hat{y}0)_{pnt}} \tag{5}$$

where t has n-2 degrees of freedom. Software packages may be used to determine the 95 % confidence interval band for the best fit line from 12.1.6. An example of regression line fit can be seen in Fig. 10 and Table 2 and Table 3.

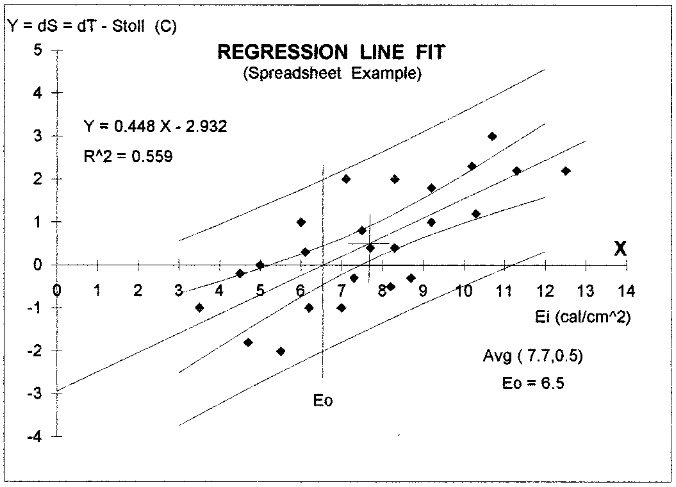


FIG. 10 Example of Regression Line Fit

12.1.7 *Determination of the Arc Thermal Performance Value (ATPV)*—ATPV is the E_i value where ρStoll/avg equals zero, based on the best fit line from 12.1.6. The ATPV 95 % confidence interval is the E_i interval formed by the 95 % confidence band at ρStoll/avg equals zero.

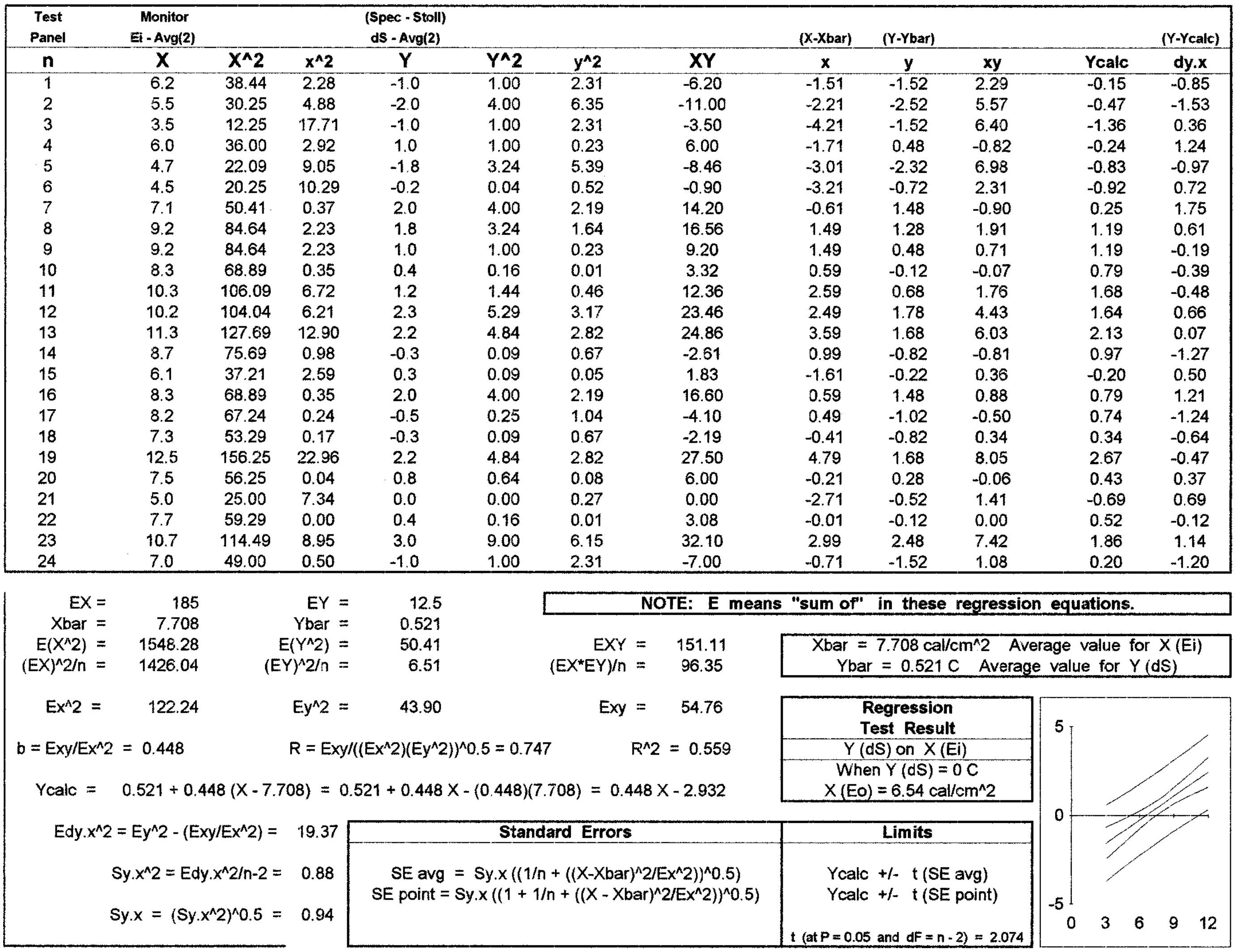
12.1.8 *Graphic Depiction of ATPV*—The readily available statistical analysis programs for determining the ATPV 95 % confidence interval require that E_i be plotted on the vertical axis and ρStoll/avg on the horizontal axis. However, this plotting arrangement tends to be counter-intuitive. Consequently, once the 95 % confidence interval is determined per 12.1.7, the plot of ρStoll/avg on E_i shall be reconstructed with ρStoll/avg plotted on the vertical axis and E_i plotted on the horizontal axis.

12.1.9 *Determination of Heat Attenuation Factor (HAF)*—Determine the maximum ρ$T\ C_{\text{max}}$ for the two sensors on each panel. Calculate the average of the ρ$T\ C_{\text{max}}$ for the two sensors of each panel and label this as ρ$T\ C_{\text{avg/max}}$. For each panel of each exposure divide ρ$T\ C_{\text{avg/max}}$ by the ρ$T\ C_{\text{max/mon}}$ for the two monitor sensors (from 12.1.4) adjacent to the panel and identify this value as E_t (fraction of the incident energy which is transmitted through the specimen). A HAF data point (haf) for each panel is calculated according to the formula: $haf = 100(1–E_t)$. The HAF value is then determined by calculating the average of all the haf values. At least 20 data points representing 20 panels shall be used. Also calculate the standard deviation (sd) of the points, and the standard error (SE) of the average given by the ratio of the standard deviation to the square root of the number of points, n. The 95 % confidence intervals of the HAF average value and points value are obtained by multiplying the standard deviation by the t-value for n-1 degrees of freedom, similar to the expressions in 12.1.6.

12.2 *Determination of Breakopen Threshold Energy*—If the required 20 % of the data over the Stoll curve cannot be generated without breakopen, an arc thermal protective value cannot be generated. Use the five or more highest E_i values below the Stoll curve for which the specimens do not exhibit breakopen. The average is E_{BT}, for example,

$$E_{BT} = (E_{i1} + E_{i2} + E_{i3} \ldots + E_{\text{in}})/\text{n} \tag{6}$$

12.3 *Electrical Data*—Consistency in maintaining the arc



Test Panel n	Monitor Ei - Avg(2) X	X^2	x^2	(Spec - Stoll) dS - Avg(2) Y	Y^2	y^2	XY	(X-Xbar) x	(Y-Ybar) y	xy	Ycalc	(Y-Ycalc) dy.x
1	6.2	38.44	2.28	-1.0	1.00	2.31	-6.20	-1.51	-1.52	2.29	-0.15	-0.85
2	5.5	30.25	4.88	-2.0	4.00	6.35	-11.00	-2.21	-2.52	5.57	-0.47	-1.53
3	3.5	12.25	17.71	-1.0	1.00	2.31	-3.50	-4.21	-1.52	6.40	-1.36	0.36
4	6.0	36.00	2.92	1.0	1.00	0.23	6.00	-1.71	0.48	-0.82	-0.24	1.24
5	4.7	22.09	9.05	-1.8	3.24	5.39	-8.46	-3.01	-2.32	6.98	-0.83	-0.97
6	4.5	20.25	10.29	-0.2	0.04	0.52	-0.90	-3.21	-0.72	2.31	-0.92	0.72
7	7.1	50.41	0.37	2.0	4.00	2.19	14.20	-0.61	1.48	-0.90	0.25	1.75
8	9.2	84.64	2.23	1.8	3.24	1.64	16.56	1.49	1.28	1.91	1.19	0.61
9	9.2	84.64	2.23	1.0	1.00	0.23	9.20	1.49	0.48	0.71	1.19	-0.19
10	8.3	68.89	0.35	0.4	0.16	0.01	3.32	0.59	-0.12	-0.07	0.79	-0.39
11	10.3	106.09	6.72	1.2	1.44	0.46	12.36	2.59	0.68	1.76	1.68	-0.48
12	10.2	104.04	6.21	2.3	5.29	3.17	23.46	2.49	1.78	4.43	1.64	0.66
13	11.3	127.69	12.90	2.2	4.84	2.82	24.86	3.59	1.68	6.03	2.13	0.07
14	8.7	75.69	0.98	-0.3	0.09	0.67	-2.61	0.99	-0.82	-0.81	0.97	-1.27
15	6.1	37.21	2.59	0.3	0.09	0.05	1.83	-1.61	-0.22	0.36	-0.20	0.50
16	8.3	68.89	0.35	2.0	4.00	2.19	16.60	0.59	1.48	0.88	0.79	1.21
17	8.2	67.24	0.24	-0.5	0.25	1.04	-4.10	0.49	-1.02	-0.50	0.74	-1.24
18	7.3	53.29	0.17	-0.3	0.09	0.67	-2.19	-0.41	-0.82	0.34	0.34	-0.64
19	12.5	156.25	22.96	2.2	4.84	2.82	27.50	4.79	1.68	8.05	2.67	-0.47
20	7.5	56.25	0.04	0.8	0.64	0.08	6.00	-0.21	0.28	-0.06	0.43	0.37
21	5.0	25.00	7.34	0.0	0.00	0.27	0.00	-2.71	-0.52	1.41	-0.69	0.69
22	7.7	59.29	0.00	0.4	0.16	0.01	3.08	-0.01	-0.12	0.00	0.52	-0.12
23	10.7	114.49	8.95	3.0	9.00	6.15	32.10	2.99	2.48	7.42	1.86	1.14
24	7.0	49.00	0.50	-1.0	1.00	2.31	-7.00	-0.71	-1.52	1.08	0.20	-1.20

EX = 185 EY = 12.5

Xbar = 7.708 Ybar = 0.521

E(X^2) = 1548.28 E(Y^2) = 50.41 EXY = 151.11

(EX)^2/n = 1426.04 (EY)^2/n = 6.51 (EX*EY)/n = 96.35

Ex^2 = 122.24 Ey^2 = 43.90 Exy = 54.76

b = Exy/Ex^2 = 0.448 R = Exy/((Ex^2)(Ey^2))^0.5 = 0.747 R^2 = 0.559

Ycalc = 0.521 + 0.448 (X - 7.708) = 0.521 + 0.448 X - (0.448)(7.708) = 0.448 X - 2.932

Edy.x^2 = Ey^2 - (Exy/Ex^2) = 19.37

Sy.x^2 = Edy.x^2/n-2 = 0.88

Sy.x = (Sy.x^2)^0.5 = 0.94

NOTE: E means "sum of" in these regression equations.

Xbar = 7.708 cal/cm^2 Average value for X (Ei)
Ybar = 0.521 C Average value for Y (dS)

Regression Test Result
Y (dS) on X (Ei)
When Y (dS) = 0 C
X (Eo) = 6.54 cal/cm^2

Standard Errors	Limits
SE avg = Sy.x ((1/n + ((X-Xbar)^2/Ex^2))^0.5) SE point = Sy.x ((1 + 1/n + ((X - Xbar)^2/Ex^2))^0.5)	Ycalc +/- t (SE avg) Ycalc +/- t (SE point) t (at P = 0.05 and dF = n - 2) = 2.074

TABLE 2 Regression Calculation Example from Spreadsheet

TABLE 3 Limit Values for Regression

X	Y_{calc}	Average		Point	
		UL	LL	UL	LL
3	–1.59	–0.67	–2.51	0.32	–3.50
4	–1.14	–0.38	–1.90	0.77	–3.05
5	–0.69	–0.07	–1.31	1.23	–2.61
6	–0.24	0.25	–0.74	1.68	–2.17
7	0.20	0.62	–0.21	2.13	–1.72
8	0.65	1.05	0.25	2.58	–1.28
9	1.10	1.56	0.64	3.03	–0.83
10	1.55	2.11	0.98	3.48	–0.39
11	2.00	2.70	1.29	3.93	0.06
12	2.44	3.30	1.59	4.39	0.50

voltage, arc current, arc duration and closing may vary from test lab to test lab. Section 6.6 requires no more than 2 % variation from test to test, given identical test parameters. Tests that exceed this 2 % variation should be investigated.

12.4 *Subjective Data*—Observe the effect of the exposure on the fabric specimens and, after the exposed specimens have cooled, carefully remove the fabric and other layers from the panel 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*) *charring*, (*5*) *embrittlement*, (*6*) *shrinkage*, and (*7*) *ignition*.

13. Report

13.1 State that the test has been performed as directed in this test method, F 1959 and report the following information:

13.1.1 Specimen data as indicated in 10.4.

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, and (*7*) plot of arc current.

13.1.3 Test data including; (*1*) test number, (*2*) specimen(s), (*3*) order of layers, (*4*) distance from the arc center line to the panel surface, (*5*) subjective evaluation as outline in 12.4, (*6*) plot of the response of the two monitor sensors and the two panel sensors for each panel test, (*7*) plot of the average response from the two panel sensors and from the two monitor sensors for each panel test, (*8*) arc thermal performance value

(ATPV) and ATPV 95 % confidence intervals, (*9*) plot of“ρ Stoll/avg” on E_i, (*10*) heat attentuation factor (HAF) and HAF 95 % confidence intervals, (*11*) plot of HAF on E_i, and (*12*) plot of the incident energy distribution E_i (bare) from the bare shot analysis and (*13*) weight of each of the layer(s) tested.

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

13.3 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 the test number, date, etc.

14. Precision and Bias

14.1 *Single User Determination*—In February 1998, at the only available testing facility for the three panel arc test method, a client user tested a series of fabrics in one layer and two layer configurations. These test results were offered and used as the basis of a temporary precision statement, in which only within-laboratory precision is addressed.

14.1.1 Eight fabrics were tested as single layers, using a current of 8 kA, with stainless steel electrodes, an electrode gap of 12 in., and a distance from the electrodes of 12 in. Similarly, seven fabric combinations were tested as two layer systems, using a current of either 8 kA, or 12 kA. Each of these fifteen test sets required seven test shots, in which cycles were varied to produce different exposure energy levels, so that data points were appropriately spaced above and below the Stoll criteria, as directed by the test method. The data set for ATPV was analyzed by regression. The data set for HAF was analysed as scatter around the average value.

14.2 *Precision*:

14.2.1 Precision parameters for ATPV and HAF, based on a single laboratory (user) determination, are given in Table 4.

14.2.2 The results from each of the fifteen test sets (21 data points in each) are given separately.

14.2.3 Components of variance are shown as standard deviations, either for variates, or for averages.

14.2.4 Precision, stated as a confidence interval, is given for each test set for ATPV and HAF, both for variates and for averages.

14.2.5 Precision, stated as a critical difference, is given for each test set for ATPV and HAF, both for variates and for averages.

14.3 *Interpretation*:

14.3.1 *Confidence Interval*—ATPV and HAF values derived within a laboratory from use of this test method may be expected to lie within the stated interval in 95 of 100 similar tests of the same material. In the course of running an individual test set, a test result that lies outside the estimated confidence interval indicates a causative factor other than chance, on a certainty of 95 %.

14.3.2 *Critical Difference*—Within a laboratory, differences between test results of the same material in similar tests should not exceed the critical difference in 95 of 100 comparisons. In the course of running individual test sets of the same material, a difference between two such test results that exceeds the estimated critical difference indicates a causitive factor other than chance, on a certainty of 95 %.

14.3.3 This is an estimate of within-laboratory precision obtained by one test method user in one testing facility. It is included as guidance. Users of the test method are urged to exercise appropriate statistical caution in comparisons of test results derived from its application. A more comprehensive precision determination must be completed within five years, including an estimate of between-laboratory precision.

14.4 *Bias*:

14.4.1 Values of ATPV and HAF can be defined only in terms of a test method. There is no independent test method, nor any established standard reference material, by which any bias in the test method may be determined. The test method has no known bias.

TABLE 4 Three Panel Arc Test – Within-laboratory Precision Parameters– 95 % Confidence Level

	Fabric Specimen	ATPV (cal/cm^2)	(Ei on Diff) Regression Calculation[A]						HAF (%)	Scatter on Average Values			HAF Calculation[B] Point Values		
			Average Values			Point Values									
			SE	±CI	CD	sd	±CI	CD		SE	±CI	CD	sd	±CI	CD
One Layer															
	1	8.7	0.27	0.6	0.8	1.24	2.6	3.5	76.3	0.61	1.3	1.7	2.81	5.9	7.9
	2	8.5	0.17	0.4	0.5	0.79	1.7	2.2	76.4	0.47	1.0	1.3	2.16	4.5	6.0
	3	9.4	0.25	0.5	0.7	1.16	2.4	3.3	77.1	0.5	1.0	1.4	2.28	4.8	6.4
	4	10.1	0.31	0.7	0.9	1.36	2.8	3.8	78.1	0.56	1.2	1.6	2.56	5.3	7.2
	5	13.0	0.53	1.1	1.5	2.47	5.2	6.9	81.2	0.74	1.5	2.1	3.39	7.1	9.5
	6	15.6	0.36	0.7	1.0	1.50	3.1	4.2	82.0	0.69	1.4	1.9	3.16	6.6	8.8
	7	18.5	0.91	1.9	2.5	3.79	7.9	10.6	84.3	1.03	2.1	2.9	4.70	9.8	13.2
Coated	8	6.9	0.36	0.8	1.0	1.60	3.3	4.5	68.6	1.19	2.5	3.3	5.43	11.3	15.2
Two Layer															
	9	22.6	1.10	2.3	3.1	4.66	9.7	13.0	87.4	0.80	1.7	2.2	3.67	7.7	10.3
	10	22.5	0.68	1.4	1.9	3.06	6.4	8.6	90.3	0.41	0.9	1.2	1.88	3.9	5.3
	11	29.4	0.67	1.4	1.9	3.14	6.6	8.8	92.5	0.43	0.9	1.2	1.95	4.1	5.5
	12	34.6	1.33	2.8	3.7	6.16	12.9	17.3	93.2	0.46	1.0	1.4	2.22	4.6	6.2
	13	30.8	0.56	1.2	1.6	2.57	5.4	7.2	93.5	0.37	0.8	1.0	1.72	3.6	4.8
	14	36.1	0.67	1.4	1.9	2.89	6.0	8.1	94.3	0.30	0.6	0.6	1.37	2.9	3.8
	15	40.1	1.11	2.3	3.1	4.72	9.9	13.2	94.1	0.21	0.4	0.6	0.98	2.1	2.8

[A] Regression confidence interval calculated on 21 data points, and $t = 2.093$ at 19 degrees of freedom. Critical difference calculated conventionally as 2.8 SE, or 2.8 sd.

[B] Scatter confidence interval calculated on 21 data points, and $t = 2.086$ at 20 degrees of freedom. Critical difference calculated conventionally as 2.8 SE, or 2.8 sd. Statistics headings: sd = standard deviation for variates; SE = Standard Error (standard deviation for average of 21 data points); CI = confidence interval; CD = critical difference. Testing was conducted at the lone practicing laboratory, for a test method user client.

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