

Evaluation Procedure for Electrical Resistance of Electronically-Integrated Textiles

Foreword

At the time this evaluation procedure was developed, electronically-integrated textiles (e-textiles) were still a nascent product category. This evaluation procedure is intended to serve mainly as a tool for iterative design and development purposes. It may be used for resistance measurement of any e-textile material or product. As e-textile technology evolves, more specialized methods, or options within this method, may be developed.

1. Purpose and Scope

1.1 This evaluation procedure determines the electrical resistance of e-textiles above 1 Ω . E-textile fabrics or end products with incorporated conductive paths/traces may be evaluated. This method is not for evaluation of yarns or fibers.

1.2 Electrical resistance may be measured as received, or after treatment such as stretch or laundering, etc. The change in resistance due to treatment may also be calculated.

2. Principle

2.1 Electrical resistance of specimens is measured using a digital multimeter and surface probes. Change in resistance is calculated from measurements before and after treatment, if desired.

3. Referenced Documents

3.1 AATCC TM76, Test Method for Electrical Surface Resistivity of Fabrics (see 15.1).

3.2 ASTM D1776, Standard Practice for Conditioning and Testing Textiles (see 15.2).

4. Terminology

4.1 **electronically-integrated textile (e-textile)**, n.—a fabric or textile product with permanently-integrated electrical circuits or parts of electrical circuits.

4.2 **electrical resistance**, n.—a specific textile's ability to reduce electric current flowing through it at a given voltage. Resistance, R , is expressed in units of ohms (Ω).

5. Safety Precautions

NOTE: These safety precautions are for information purposes only. The pre-

cautions are ancillary to the testing procedures and are not intended to be all inclusive. It is the user's responsibility to use safe and proper techniques in handling materials in this test method. Users MUST consult manufacturers for specific details such as safety data sheets and other recommendations. Consult and follow all applicable OSHA standards and rules.

5.1 Follow good laboratory practices. Wear safety glasses in all laboratory areas.

5.2 Follow manufacturer's safety recommendations when operating laboratory testing equipment.

5.3 Use electrical equipment on a non-conductive or grounded surface (see 7.2).

6. Uses and Limitations

6.1 Each conductive path to be measured must be accessible, at least at the two measurement points. Connectors may be used to provide accessibility. The measured specimen should mimic the intended design of the end product, if known.

6.2 Samples with very low resistance may not be measured accurately by the equipment described in this procedure. Refer to multimeter manufacturer for applicable range. Low-resistance samples may require a more sensitive instrument, or a four-point system to eliminate lead resistance.

6.3 Refer to AATCC TM76 for samples having a resistance higher than $10^5 \Omega$.

7. Apparatus and Materials (see 15.3).

7.1 Conditioning facilities and racks with pull-out, perforated shelves for laying specimens flat (see 15.1).

7.2 Flat workbench with grounded electronic static dissipation (ESD) mat. The surface should be at least as large as the specimen.

7.3 Indelible ink marking pen (see 15.1) or needle and sewing thread, for making benchmarks.

7.4 Digital multimeter, also known as DMM or volt-ohm-meter, VOM. Resolution to 0.1 Ω and 0.9% accuracy. Probes should be appropriate to the test material. Multimeter and probes should be consistent with those used to test other electrical components of the end product.

7.5 Tape or rule marked in millimeters.

8. Test Specimens

8.1 Each conductive path (or section of a path) is considered a specimen and should mimic the intended design of the end product. Measure at least 3 specimens.

8.1.1 Select specimens that can be arranged to lie flat on the measurement surface with no tension and no risk of a short circuit.

8.1.2 For convenience, straight specimens, 150-300 mm in length, are recommended for development testing.

8.1.3 Specimens from end products will depend upon product design. Complete conductive pathway should be tested.

8.2 Select identical specimens from at least 3 swatches or end products.

8.2.1 Size and shape of swatches or end products is not critical to this evaluation procedure.

8.2.2 If measuring resistance after treatment (stretch, laundering, etc.), refer to the appropriate treatment test method or procedure for swatch dimensions.

8.3 Handle specimens with care to avoid contamination, in particular, salts or moisture from human hands, which may affect resistance measurements.

9. Conditioning

9.1 Prior to marking, condition test specimens as directed in ASTM D1776. (Use conditions indicated in Table 1 for Textiles, general. Estimate conditioning time as indicated in Table 2 for the appropriate fiber content.) Lay each swatch or product, separately, on a screen or perforated shelf of a conditioning/drying rack.

9.2 Mark the ends of each specimen. If sewing thread is used, ensure that needle holes do not interrupt the circuit.

9.2.1 If the conductive path to be measured connects to an electronic system, the mark should be made at the point where the path in the textile connects to the electronic system.

9.3 If fraying of swatches is expected in treatment, edges may be pinked or serged.

10. Procedure

10.1 Arrange the first specimen on flat, non-conductive surface for measurements.

10.2 Set multimeter to resistance measurement mode, in units of ohms.

10.3 Place the positive and negative

probes of the meter at the marked points.

10.3.1 Pressure and contact area between probes and specimen during resistance measurement may greatly affect readings. Maintain consistent force to ensure repeatable results. Limiting measurements to a single operator, while not required, may also improve reliability and consistency of the measurements collected.

10.3.2 The multimeter may be connected to the specimen using any suitable probes or connections system. Note the probes or connection system in the report. Do not compare measurements taken using different probes or connection systems.

10.4 Record the resistance as soon as the reading stabilizes for a period of 3 s. Take 1 resistance measurement per specimen.

10.5 Measure and record distance between marked points, to the nearest mm.

10.6 Repeat resistance and distance measurements for the remaining specimens.

10.6.1 If only a single specimen is available, measure the resistance of the specimen 3 times. Note this modification in the test report.

11. Evaluation after Treatment (optional)

11.1 Subject specimens to treatment as directed in an applicable test method or laboratory procedure. Record treatment details as directed.

11.2 Recondition specimens (Section 9.1) before final measurement.

11.3 Measure and record electrical resistances after treatment. Use the same marked points and connection system as for the initial resistance measurement.

11.4 Measure and record distance between marked points to the nearest mm.

12. Calculation

12.1 Calculate the mean resistance for all measured specimens. This is R .

12.1.1 If testing was performed before treatment, calculate the mean of initial resistance measurements for all specimens. This is R_i .

12.1.2 If testing was performed after treatment, calculate the mean of final resistance measurements for all specimens. This is R_f .

12.1.3 If only a single specimen was used, calculate the mean of 3 resistance measurements for the specimen.

12.2 Calculate the mean distance between marked points for all specimens, to the nearest mm. This is d .

12.2.1 If testing was performed before treatment, calculate the mean initial distance for all specimens. This is d_i .

12.2.2 If testing was performed after treatment, calculate the mean final distance for all specimens. This is d_f .

12.3 If applicable, calculate % resistance change after treatment using Equation 1.

$$RC = (R_f - R_i)/R_i \times 100\% \quad (\text{Eq. 1})$$

Where:

RC = % resistance change after treatment,

R_f = Mean final resistance, after treatment (Ω),

R_i = Mean initial resistance (Ω).

13. Report

13.1 A description or identification of the tested sample.

13.2 Evaluation was performed using AATCC EP13-2018.

13.3 Number of specimens tested.

13.4 Description of specimen (conductive path length, width, shape, material, etc.)

13.4 Multimeter resolution and accuracy.

13.5 Probe type and connection system.

13.6 Distance between marked points for individual specimens.

13.7 Mean distance, d , between marked points, to the nearest mm. (Initial distance, d_i , and final distance, d_f , if applicable.)

13.8 Resistance between marked points for individual specimens.

13.9 Mean resistance, R , between marked points. (Initial resistance, R_i , and final resistance, R_f , if applicable.)

13.10 Treatment description and number of cycles, if applicable.

13.11 Resistance change after treatment, if applicable.

13.12 Any modification(s) of the procedure.

14. Precision and Bias

14.1 *Precision*. Five different laboratories participated in an interlaboratory study to measure resistance of e-textiles according to this method. The experiment was replicated on a second day by each of the participating labs.

14.1.1 Samples were a stainless steel conductive thread embroidered on a woven base fabric and silver-based conductive ink printed on thermoplastic polyurethane (TPU) film and applied to a knitted fabric. Printed lines of 0.5-mm width and 1.0-mm width were evaluated separately. All specimens were 100 cm in length.

14.1.2 ANOVA test indicated that there is no significant difference between the results of day 1 and day 2. Among the 5 different labs, the mean values of 3 labs

Table I—Within-Laboratory and Between-Laboratory Precision Values

n	Within-Laboratory	Between-Laboratory
1	0.5278	1.2253
2	0.3738	0.8678
3	0.3047	0.7074
4	0.2639	0.6127
5	0.2360	0.5480
6	0.2155	0.5002

Note: Grand mean of resistance for all interlab measurements was 5.3 Ω . Mean resistance for conductive thread specimens was 5.9 Ω . Mean resistance for 0.5-mm printed specimens was 6.7 Ω . Mean resistance for 1.0-mm printed specimens was 3.5 Ω .

clustered around a measured average resistance of 5.5 Ω and the mean values of the 2 other labs clustered around a measured average resistance of 4.6 Ω . While the standard deviations of the 5 labs were somewhat similar, they were all high, thus implying that there is an inherently high variation in the measurement and that at least 3 replicate specimens are needed for this test. Table I lists *within-laboratory* and *between-laboratory* precision values for different sample sizes.

14.1.3 Refer to Section 10.3.1 to ensure consistent resistance measurements across multiple samples.

14.2 *Bias*. Electrical resistance of e-textiles can be defined only in terms of a test method. There is no independent method for determining the true value. As a means of estimating this property, the method has no known bias.

15. Notes

15.1 Available from AATCC, PO Box 12215, Research Triangle Park NC 27709, USA; +1. 919.549.8141; ordering@aatcc.org; www.aatcc.org.

15.2 Available from ASTM International, 100 Barr Harbor Dr., W. Conshohocken PA 19428, USA; +1.610.832.9500; www.astm.org.

15.3 For potential equipment information pertaining to this test method, please visit the online *AATCC Buyer's Guide* at www.aatcc.org/bg. AATCC provides the possibility of listing equipment and materials sold by its Corporate members, but AATCC does not qualify, or in any way approve, endorse or certify that any of the listed equipment or materials meets the requirements in its test methods.

16. History

16.1 Reaffirmed 2020

16.2 Editorially revised 2019 to correct materials sources.

16.3 Developed in 2018 by AATCC Committee RA111.