Designation: E 2181/E 2181M – 01

Standard Specification for Compacted Mineral-Insulated, Metal-Sheathed, Noble Metal Thermocouples and Thermocouple Cable[1]

This standard is issued under the fixed designation E 2181/E 2181M; 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 specification establishes dimensional and material requirements for compacted, mineral-insulated, metal-sheathed, Type S (platinum-10 % rhodium versus platinum), Type R (platinum-13 % rhodium versus platinum), and Type B (platinum-30 % rhodium versus platinum-6 % rhodium) noble metal thermocouples. This specification also establishes dimensional and material requirements for compacted, mineral-insulated, metal-sheathed cable with at least one noble metal thermoelement pair.

1.2 This specification describes both the required processing and testing requirements and also the optional supplementary testing and quality assurance requirements.

1.3 Provisions are made for selecting the type of noble metal thermocouple or thermoelements, either magnesia (MgO) or alumina (Al_2O_3) insulation, and a noble metal alloy or other alternate heat-resistant sheath material. Provisions are also made for selecting a thermocouple measuring junction configuration and for a transition or termination.

1.4 The values stated in inch-pound units or SI (metric) units may be regarded separately as standard. The values stated in each system are not the exact equivalents, and each system shall be used independently of the other.

1.5 *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 requirements prior to use.*

2. Referenced Documents

2.1 The following documents of the latest issue form a part of this specification to the extent specified herein. In the event of a conflict between this specification and other specifications referenced herein, this specification shall take precedence.

2.2 *ASTM Standards:*

A 213/A 213M Specification for Seamless Ferritic and Austenitic Alloy-Steel Boiler, Superheater, and Heat-Exchanger Tubes[2]

A 249/A 249M Specification for Welded Austenitic Steel Boiler, Superheater, Heat-Exchanger, and Condenser Tubes[2]

A 269 Specification for Seamless and Welded Austenitic Stainless Steel Tubing for General Service[2]

A 632 Specification for Seamless and Welded Austenitic Stainless Steel Tubing (Small-Diameter) for General Service[2]

B 163 Specification for Seamless Nickel and Nickel Alloy Condenser and Heat-Exchanger Tubes[3]

B 167 Specification for Nickel-Chromium-Iron Alloy (UNS N06600, N06601, and N06690) Seamless Pipe and Tube[3]

B 516 Specification for Welded Nickel-Chromium-Iron Alloy (UNS N06600, UNS N06603, UNS N06025, and UNS N06045) Tubes[3]

E 165 Test Method for Liquid Penetrant Examination[4]

E 220 Method for Calibration of Thermocouples by Comparison Techniques[5]

E 230 Specification for Temperature—Electromotive Force (EMF) Tables for Standardized Thermocouples[5]

E 344 Terminology Relating to Thermometry and Hydrometry[5]

E 608/E 608M Specification for Mineral-Insulated, Metal-Sheathed Base Metal Thermocouples[5]

E 839 Test Methods for Sheathed Thermocouples and Sheathed Thermocouple Material[5]

E 1652 Specification for Magnesium Oxide and Aluminum Oxide Powder and Crushable Insulators Used in the Manufacture of Metal-Sheathed Platinum Resistance Thermometers, Base Metal Thermocouples, and Noble Metal Thermocouples[5]

E 1751 Guide for Temperature-Electromotive Force (EMF) Tables for Non-Letter Designated Thermocouple Combinations[5]

2.3 *ANSI Standard:*

[1] This specification is under the jurisdiction of ASTM Committee E20 on Temperature Measurement and is the direct responsibility of Subcommittee E20.04 on Thermocouples.

Current edition approved Dec. 10, 2001. Published February 2002.

[2] *Annual Book of ASTM Standards*, Vol 01.01.

[3] *Annual Book of ASTM Standards*, Vol 02.04.

[4] *Annual Book of ASTM Standards*, Vol 03.03.

[5] *Annual Book of ASTM Standards*, Vol 14.03.

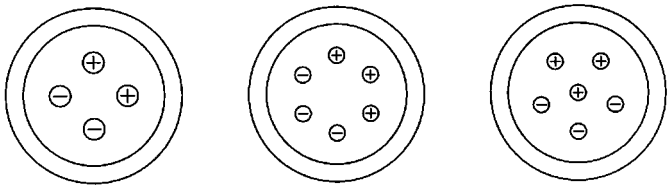

FIG. 1 Examples of Adjacent Configurations

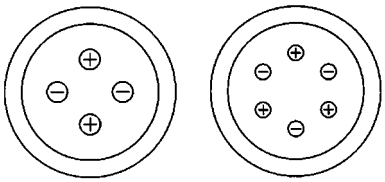

FIG. 2 Examples of Alternating Configurations

B46.1 Surface Texture[6]

2.4 *AWS Standard:*

A5.14 Specification for Nickel and Nickel-Alloy Bare Welding Rods and Electrodes[7]

3. Terminology

3.1 *Definitions*—The definitions given in Terminology E 344 shall apply to this specification.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *adjacent thermoelement configuration, n*—thermoelement configuration within a multi-pair thermocouple or cable where two or more positive thermoelements are immediately adjacent to one another around the circular pattern and two or more negative thermoelements are also immediately adjacent to one another around the circular pattern as shown in Fig. 1 (compare with alternating thermoelement configuration in Fig. 2).

3.2.1.1 *Discussion*—By default, a multi-pair thermocouple or cable with a thermoelement in the center must be considered an adjacent configuration.

3.2.2 *alternating thermoelement configuration, n*—thermoelement configuration within a multi-pair thermocouple or cable where positive thermoelements and negative thermoelements alternate around the circular pattern as shown in Fig. 2 (compare with adjacent thermoelement configuration in Fig. 1).

3.2.2.1 *Discussion*—In an alternating thermoelement pattern, there are never two or more positive thermoelements nor two or more negative thermoelements immediately adjacent to one another.

3.2.3 *common ungrounded junction, n*—measuring junctions within the same multi-pair thermocouple that are electrically isolated from the sheath but electrically connected to each other.

3.2.4 *isolated ungrounded junction, n*—measuring junctions within the same multi-pair thermocouple that are electrically isolated from the sheath and electrically isolated from each other.

3.2.5 *lot, n*—quantity of finished mineral-insulated, metal-sheathed thermocouples, or length of thermocouple cable manufactured from tubing from the same heat, wire from the same spool and heat, and insulation from the same batch, then assembled and processed together under controlled production conditions to the required final configuration.

3.2.6 *raw material, n*—tubing, insulation, and wires used in fabrication of the sheathed thermocouples or thermocouple cable.

4. Significance and Use

4.1 Type S, R, and B noble metal thermocouples are generally specified for use when temperatures exceed the upper recommended operating temperatures of base metal thermocouples (see Specification E 608/E 608M).

4.2 To optimize elevated temperature stability, Type S, R, and B thermocouples should be supplied with noble metal sheaths (see 6.3.1). Purchasers and users are cautioned that if Type S, R, and B thermocouples are supplied with base metal sheaths, such as 300 series stainless steels or other heat-resistant nickel-chrome alloys, and are used at temperatures exceeding 600 °C [1100 °F], they will be more susceptible to drift and the development of inhomogeneity. The higher the temperature, the more pronounced the drift and the effects of this inhomogeneity. In some cases, the elevated temperature performance of a noble metal thermocouple with a base metal sheath will be inferior to that of a base metal thermocouple with a base metal sheath.

5. Ordering Information and Basis for Purchase

5.1 The purchasing documents shall specify the following for both thermocouples and cable:

5.1.1 The nominal outside diameter of the sheath (see Table 1).

5.1.2 The type and quantity of noble metal thermoelements (see 6.1). Note that non-letter designated noble metal thermoelements (that is, other than Types S, R, and B) may be used upon purchaser and producer agreement.

5.1.3 The kind of ceramic insulation (see 6.2). Note that other insulation composition and impurity levels may be used with purchaser and producer agreement.

5.1.4 The kind of sheath material (see 6.3), and whether it shall be seamless or welded and drawn. Note that other sheath material may be used with purchaser and producer agreement.

5.1.5 The intended operating temperature range of the thermocouple or cable (see 8.1.5).

5.1.6 The tolerance of initial values of emf versus temperature if other than standard for Types S, R, and B thermocouples, or the emf versus temperature relationship and initial tolerance values if other than Type S, R, or B thermocouples (see 8.1.5 and Guide E 1751).

5.1.7 Optional supplementary testing and test sample rates or optional material requirements (see Supplementary Requirements).

5.1.8 Packaging method and straightness criteria, if required (see 11.3).

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

[7] Available from the American Welding Society (AWS), 2501 North West 7th St., Miami, FL 33125.

TABLE 1 Preferred Outside Diameters, *A*, for Thermocouples and Cable in SI (Metric) and Inch-Pound Units

Diameter	
millimetres	inches
0.50	0.020
. . .	0.032
1.00	0.040
1.50	0.062
2.00	. . .
. . .	0.093
3.00	0.125
4.50	0.188
6.00	0.250
8.00	0.375

5.1.9 The quality assurance and verification program requirements (see Appendix X1).

5.1.10 Any deviations from this specification or its Referenced Documents.

5.2 In addition, the purchasing documents shall specify the following if purchasing thermocouples:

5.2.1 The type of measuring junction, Class 1 (grounded) or Class 2 (ungrounded). See Figs. 8 and 9. If more than one pair of thermoelements is specified, Class 2 is further subdivided into Class 2A (common ungrounded) and Class 2B (isolated ungrounded).

5.2.2 The quantity, sheath length, and sheath length tolerance of each thermocouple. See Figs. 3-6 for examples.

5.2.3 The type and configuration of connection head, connector, transition piece, or termination, and moisture seal required on the end opposite the measuring junction. See Figs. 3-6 for examples. The minimum and maximum intended operating temperature of the connection head, transition, termination, or moisture seal should be specified (see 6.5). For thermocouples with insulated wire attached (see Fig. 6) and Class 2 junctions, state the minimum acceptable insulation resistance (see 8.1.3.2).

5.3 In addition, the purchasing documents shall specify the following if purchasing thermocouple cable:

5.3.1 The thermoelement configuration (see 3.2.1 and 3.2.2). Consult individual manufacturers for the available number of thermoelements within a cable size.

5.3.2 The total length and tolerance of finished thermocouple cable, and the length and length tolerance of each piece of finished thermocouple cable.

5.3.3 The kind of end seal applied to the open ends, prior to shipment (see 11.1).

6. Material and Manufacturing Requirements

6.1 *Thermoelements*:

6.1.1 The thermoelements shall only be noble metal, and shall be of thermoelectric types S, R, or B unless otherwise agreed upon between purchaser and producer.

6.1.2 The thermoelements shall be solid wire, round in cross section. All wire used for fabrication shall meet the supplemental cleanliness requirements of Specification A 632, except that acetone or any other solvents that might leave a harmful residue shall not be used for final cleaning.

6.1.3 The initial emf versus temperature relationship for Type S, R, and B thermoelements shall satisfy the standard tolerance specified by Specification E 230 unless otherwise stated in the ordering information.

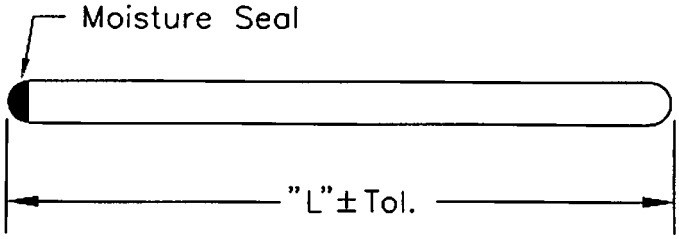

FIG. 3 Sheathed Thermocouple Cable

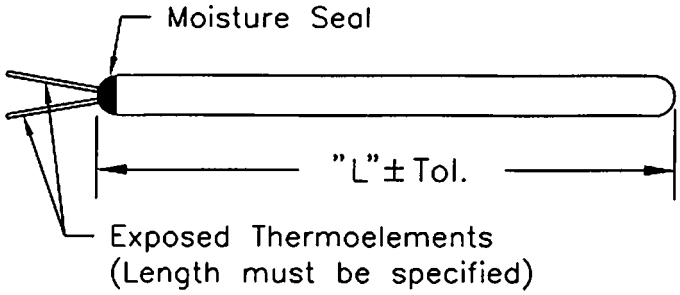

FIG. 4 Sheathed Thermocouple with Exposed Thermoelements

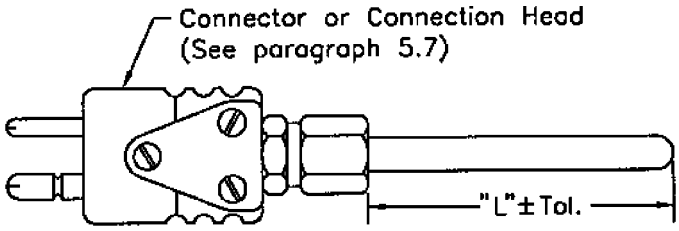

FIG. 5 Sheathed Thermocouple Assembly with Connector or Connection Head (any Type Specified)

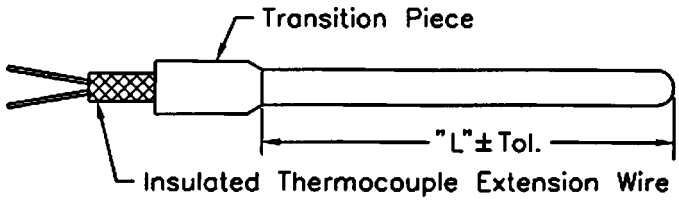

FIG. 6 Sheathed Thermocouple Assembly with Transition Piece

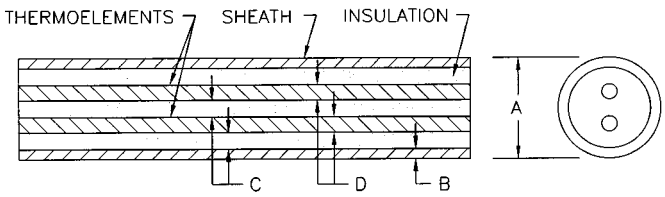

FIG. 7 Sheathed Thermocouple Construction

6.2 *Insulation*:

6.2.1 The insulation shall only be magnesia (MgO) or alumina (Al_2O_3) conforming to Specification E 1652. Unless otherwise agreed upon between purchaser and producer, only Type 1 magnesia or Type 1 alumina shall be used. See 8.2.13 and Supplementary Requirement S11.

6.2.2 The minimum density of the compacted insulation

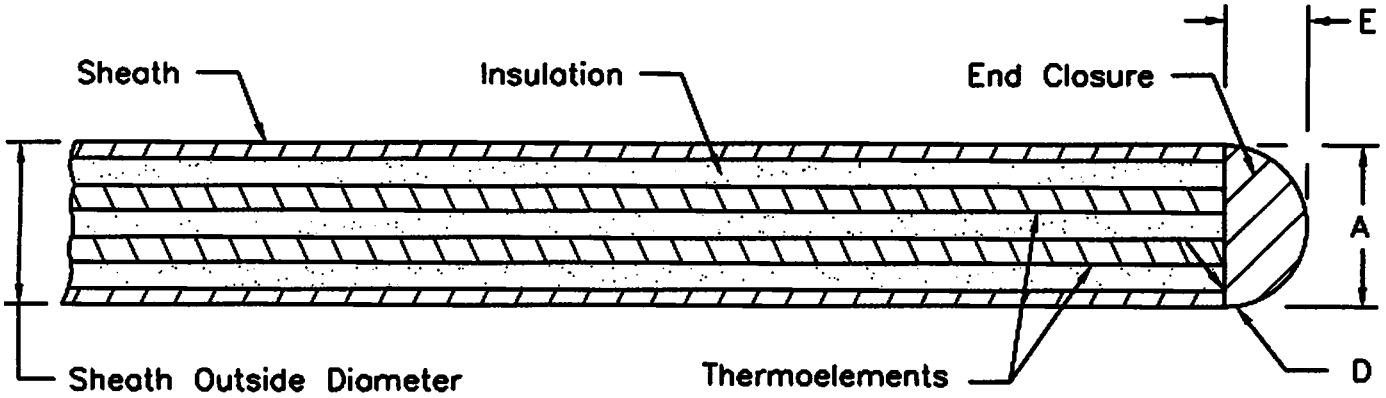

FIG. 8 Grounded Measuring Junction, Class 1

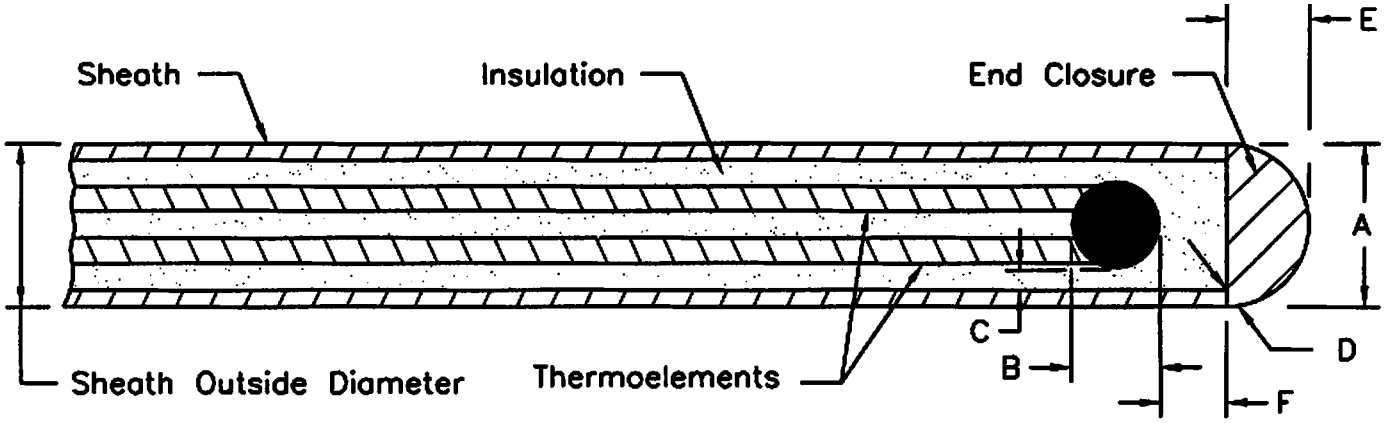

FIG. 9 Ungrounded Measuring Junction, Class 2

shall be 70 % of the maximum theoretical density which is 3580 kg/m^3 [0.129 lb/in.^{3}] for MgO, and 3970 kg/m^3 [0.144 lb/in.^{3}] for Al_2O_3.[8] See 8.2.12 and Supplementary Requirement S10.

6.3 *Sheath*:

6.3.1 The sheath material may be seamless or welded and drawn tubing of platinum, platinum-10 % rhodium, platinum-20 % rhodium, or platinum-30 % rhodium. The producer's customary tubing specification may be used.

6.3.2 Alternately, heat-resistant nickel-chrome alloy tubing per Specifications B 163, B 167, or B 516; or 310 or 321 stainless steel tubing per Specifications A 213/A 213M, A 249/A 249M, A 269, or A 632 may be supplied as sheath materials provided there is an agreement between purchaser and producer (see 4.2) and the annealing requirements imposed by 6.3.4 are satisfied. The producer's customary tubing specification may be used.

6.3.3 Each piece of tubing shall meet the supplemental cleanliness requirements of Specification A 632, except that acetone or any other solvents that might leave a harmful residue may not be used for final cleaning.

6.3.4 The sheath shall be free of visible surface contaminants and oxidation and shall be in the fully annealed state. Tests for proving conformance are in Supplementary Requirement S7 or S12.

6.3.5 The sheath of the finished thermocouple or cable shall exclude gases and liquids. There shall be no holes, cracks, or other void defects that penetrate through the sheath wall. Tests for proving conformance to this requirement are in Supplementary Requirements S2, S3, S4, and S5.

6.4 The end closure of thermocouples shall be seal welded and shall be impervious to gases and liquids. There shall be no cracks, holes, or void defects that penetrate through the metal wall. Any mineral oxide removed during fabrication of the measuring junction shall be replaced with dry oxide of the same type that conforms to the purity requirements of Specification E 1652. Class 2 measuring junctions shall be fabricated by welding the thermoelements together without filler metal or flux. The use of plugs or filler metals is optional, provided they are of the same nominal chemical composition as the sheath.

6.5 Thermocouples shall be terminated at the end opposite the measuring junction in a manner specified by the purchaser. All exposed MgO or Al_2O_3 shall be sealed from moisture to keep the insulation dry. All connectors, connection heads, or transitions shall include a positive method of preventing strain on the thermoelements emerging from the sheathed material. All transitional wire connections shall be brazed or welded. The moisture seal and termination (see Figs. 3-6) shall be

[8] Handbook of Chemistry and Physics, Chemical Rubber Publishing Co., No. 76 (1995) edition.

TABLE 2 Summary of Thermocouple and Cable Dimensional Requirements (Percent of Nominal Outside Diameter)

Number of Thermoelements	2	4	6
Minimum Sheath Thickness	10 %	10 %	10 %
Minimum Thermoelement Diameter	15 %	12 %	9 %
Minimum Insulation Thickness	7 %	5.5 %	4 %

TABLE 3 Room-Temperature Insulation Resistance Requirements for Thermocouple Cable in SI (Metric) and Inch-Pound Units

Nominal Sheath Outside Diameter	Applied Voltage, min, V, dc	Insulation Resistance, min, MΩ
Less than 0.80 mm [0.030 in.]	50	1000
0.80 to 1.45 mm [0.030 to 0.057 in.]	50	5000
Larger than 1.45 mm [0.057 in.]	500	10 000

compatible with their intended installation and operating conditions (see 5.2.3).

7. Dimensional Requirements

7.1 *Dimensions*—The dimensional and tolerance requirements for sheath diameter and wall thickness, thermoelement diameter, and insulation thickness depicted in Fig. 3 shall be based on nominal sheath outside diameters. The preferred cable sizes are listed in Table 1. For any nominal sheath size, the outside diameter tolerance, *A*, shall be ±0.025 mm [0.001 in.] or ±1 %, whichever is greater. The wall thickness, *B*, shall be at least 10 % of the nominal sheath outside diameter and shall be uniform within 20 % of the minimum required wall thickness. The thermoelement diameters, *D*, shall be at least 15 % of the nominal sheath outside diameter if 2 thermoelements are included, at least 12 % of the nominal sheath outside diameter if 4 thermoelements are included, or at least 9 % of the nominal sheath outside diameter if 6 thermoelements are included. All thermoelement diameters shall be uniform within 20 % of their minimum required diameters. The insulation thickness, *C*, either thermoelement to thermoelement or thermoelement to inside surface of the sheath, shall be at least 7 % of the nominal sheath outside diameter if 2 thermoelements are included, at least 5.5 % of the nominal sheath outside diameter if 4 thermoelements are included, or at least 4 % of the nominal sheath outside diameter if 6 thermoelements are included. The inside sheath diameter is equal to Diameter *A* minus 2 times Dimension *B*. Dimensions shall be measured per Test Methods E 839. The minimum dimensional requirements for sheath wall thickness, thermoelement diameter, and insulation thickness are summarized in Table 2. The purchaser need specify only the outside diameter and number of thermoelements in the ordering documents.

7.2 In addition, the required measuring junction configurations for thermocouples are shown in cross section in Figs. 8 and 9. The tip shape is optional as long as the dimensional requirements are maintained. The measuring junction dimensional requirements are as follows:

7.2.1 *Dimension A, End Closure Diameter, Classes 1 and 2*—The end closure maximum diameter shall be no larger than the nominal sheath diameter plus a weld allowance of 0.05 mm [0.002 in.] or 2 % of the nominal sheath diameter, whichever is larger. Localized reduction of the end closure diameter caused by weld shrinkage shall not exceed 0.05 mm [0.002 in.] or 2 % of the nominal sheath diameter, whichever is larger. This expanded end closure diametrical tolerance shall apply from the tip of the end closure over a length not exceeding 2× the nominal sheath diameter.

7.2.2 *Dimension D, Minimum Material Thickness, Class 1 and Class 2 Junctions*—The thickness at any point of the end closure weld interface shall not be less than 10 % of the nominal sheath diameter. Wall thinning caused by welding shall be limited to the minimum material sheath wall thickness requirement of 10 % of the nominal diameter.

7.2.3 *Dimension E, End Closure Thickness*—The end closure thickness on both Class 1 and Class 2 junctions shall be a minimum of 10 % and a maximum of 80 % of the nominal sheath diameter.

7.2.4 *Dimension F, Measuring Junction Location*—The measuring junction or junctions of Class 2A and 2B thermocouples respectively shall be located a minimum of 10 % of the nominal sheath diameter and a maximum of either 0.75 mm [0.030 in.] or 50 % of the nominal sheath diameter, whichever is greater, from the inside surface of the end closure. Dimension *F* is defined as the shortest axial distance between end closure and measuring junction.

8. Inspection and Testing Requirements

8.1 The following are minimum testing and inspection requirements for each thermocouple or lot of thermocouple cable fabricated to this specification. The producer shall perform these inspections and tests using methods delineated in Test Methods E 839.

8.1.1 *Visual and Dimensional Inspection*:

8.1.1.1 Measure each thermocouple, or length of cable, to verify that the outside diameter conforms to 7.1 and that the length conforms to 5.2.2 or 5.3.2.

8.1.1.2 Visually inspect surface finish, straightness, and cleanliness of the sheath to ensure acceptability.

8.1.1.3 Measure the end closure of each thermocouple to ensure it is within the diametrical limits specified in 7.2.1. Visually examine each thermocouple to ensure that the connector or termination is the correct type, size, and configuration, and that a moisture seal is present.

8.1.1.4 Measure a sample of thermocouple cable to verify conformance of the thermoelement diameter, sheath wall thickness, and insulation thickness to 7.1.

8.1.2 *Electrical Continuity*—Verify the continuity of each thermoelement within a thermocouple cable, or each thermoelement pair within a thermocouple with an ohmmeter. Also verify the continuity of Class 1 (grounded) junctions to the sheath. No quantitative measurements are required. The continuity test is not a substitute for the polarity test.

8.1.3 *Room Temperature Insulation Resistance*:

8.1.3.1 Measure the insulation resistance between each thermoelement of every thermocouple cable length and every other thermoelement within that cable and the respective sheath for conformance with Table 3 with the applied voltage specified (both direct and reversed polarity).

8.1.3.2 Measure the insulation resistance of each Class 2 (ungrounded) thermocouple between all thermoelement pairs

TABLE 4 Room-Temperature Insulation Resistance Requirements for Thermocouples in SI (Metric) and Inch-Pound Units

Nominal Sheath Outside Diameter	Applied Voltage, min, V, dc	Insulation Resistance, min, MΩ
Less than 0.80 mm [0.030 in.]	50	100
0.80 to 1.45 mm [0.030 to 0.057 in.]	50	500
Larger than 1.45 mm [0.057 in.]	500	1000

TABLE 5 Calibration Temperatures

Thermocouple Type	Nominal Calibration Temperature	
	°C	°F
S, R	300	600
	700	1300
	1100	2000
B	900	1650
	1100	2000
	1300	2400

and sheath for conformance with Table 4 with the applied voltage specified (both direct and reversed polarity). In addition, measure the insulation resistance of each Class 2B (isolated ungrounded) thermocouple between thermoelement pairs for conformance with Table 4 with the applied voltage specified (both direct and reversed polarity). Document measured values. Measure Class 2 thermocouples with thermocouple extension wire attached (see Fig. 6) before and after attachment. Use the values measured prior to termination to judge conformance. The values measured after termination must exceed the values agreed upon between the purchaser and the producer. This test can also apply to Class 1 (grounded junction) thermocouples if both producer and purchaser agree that the purchaser can select a sample thermocouple from the lot, remove the junction, exercising caution to prevent moisture pickup, and measure insulation resistance. In the event that this sample thermocouple has insulation resistance less than that specified in Table 4 or, in the case of thermocouples with extension wire attached, less than that agreed upon between the purchaser and the producer, the entire lot shall be deemed to be not in conformance with this specification.

8.1.4 *Thermocouple Polarity Test*—Verify that each thermocouple assembly that has a connection head, connector, transition piece, or termination device of any kind has the proper polarity by heating the measuring junction and noting the polarity of the electromotive force at the termination.

8.1.5 *Calibration*—Calibrate a sample from each lot of finished thermocouple cable to demonstrate that the values of emf versus temperature are initially within the required tolerances as defined in Specification E 230. Unless otherwise specified in the ordering information, standard tolerances shall be assumed to apply. The cable samples shall be fabricated into thermocouples and calibrated with the general procedures outlined in Method E 220. The calibration shall be performed in order of increasing temperature at temperatures that represent the minimum, intermediate, and maximum intended operating conditions of the finished cable. If the purchaser does not furnish this information, calibration shall be performed at the temperatures specified in Table 5. The actual temperature of the heat source used for calibration may deviate up to 25 °C [45 °F] from the calibration temperature specified. The purchaser may specify other calibration temperatures (see Supplementary Requirement S9).

8.2 In addition, the purchaser may specify any of the optional tests and inspections listed below in whole or part in the ordering information. The purchaser shall also specify the sample rate. Perform these optional tests in accordance with the Supplementary Requirements:

8.2.1 Radiographic Inspection of the Measuring Junction, End Closure and Sheath per Supplementary Requirement S1.

8.2.2 End Closure Weld and Sheath Integrity Test Using the Dye Penetrant Method per Supplementary Requirement S2.

8.2.3 End Closure Weld and Sheath Integrity Test Using the Helium Mass Spectrometer Method per Supplementary Requirement S3.

8.2.4 End Closure Weld and Sheath Integrity Test Using the Fast Water Test Method per Supplementary Requirement S4 (thermocouples with Class 2 measuring junctions and cable only).

8.2.5 End Closure Weld and Sheath Integrity Test Using the Basic Water Test Method per Supplementary Requirement S5 (thermocouples with Class 2 measuring junctions and cable only).

8.2.6 Optional Elevated Temperature Insulation Resistance per Supplementary Requirement S6 (thermocouples with Class 2 measuring junctions and cable only).

8.2.7 Calibration of thermocouples per 8.1.5.

8.2.8 Calibration at other temperatures per Supplementary Requirement S9 (thermocouples and cable).

8.2.9 Sheath condition and flexibility per Supplementary Requirement S7 (thermocouples with Class 2 measuring junctions and cable only).

8.2.10 Metallurgical Structure of the Sheath per Supplementary Requirement S12.

8.2.11 Surface Finish of the Sheath per Supplementary Requirement S8.

8.2.12 Compaction Density Measurement per Supplementary Requirement S10.

8.2.13 Insulation Material Analysis per Supplementary Requirement S11.

8.3 *Documentation*—When requested in the ordering information, copies of the documented test results shall be supplied to the purchaser, along with a certification of conformance in accordance with Section 10.

9. Processing Requirements

9.1 The producer is responsible for all processing of all component materials to ensure that the overall requirements of this specification are met. The producer is also responsible for the quality of the finished product.

10. Certification

10.1 A certificate of conformance covering the completed mineral-insulated, metal-sheathed thermocouples or cable and the data taken during the testing by the producer shall be provided to the purchaser when requested in the ordering information. The certificate shall state that the product has been manufactured from materials specified in the purchase order, that the material was tested in accordance with this specification, that the results are in accordance with this specification,

and that the test data and certifications are on file at the producer's facility. It is suggested that these records be retained for a minimum of 3 years.

11. Packaging, Marking, and Shipping

11.1 *Sealing*—All open ends of mineral-insulated, metal-sheathed thermocouple cable shall be sealed when processing allows and especially before shipment, in order to prevent entry of moisture inside the cable. Seal welding and epoxy seals are examples of techniques used for sealing.

11.2 *Cleaning Prior to Packaging*—The outer sheath shall be cleaned free of grease, oil, dirt, and other foreign substances.

11.3 The method of packaging thermocouples and cable shall be per producer's usual practice, unless otherwise requested by the purchaser.

11.4 Each thermocouple and individual length of cable shall be marked with the producer's name, unique lot identification number, sheath diameter, type of thermocouple or thermoelements, calibration results, kind of sheath material, quantity of thermocouples or thermoelements, kind of insulation material, and the purchaser's order number.

11.5 Each shipping container shall be legibly marked with at least the following information:

11.5.1 Producer's name and address,

11.5.2 Purchaser's order number,

11.5.3 Quantity of thermocouples or lengths of cable,

11.5.4 The lengths of the thermocouple sheaths or cable pieces,

11.5.5 Nominal sheath diameter,

11.5.6 Sheath material,

11.5.7 Insulation material, and

11.5.8 Quantity and thermometric type of the thermoelement pairs.

12. Keywords

12.1 junction; metal-sheathed; moisture seal; sheathed thermocouple material; sheathed thermocouples; termination; thermocouple; thermoelement

SUPPLEMENTARY REQUIREMENTS

The following supplementary requirements shall apply only when specified by the purchaser in the inquiry, contract, or order.

S1. Radiographic Inspection

S1.1 **WARNING**—The requirements of this section necessitate the use of techniques more sophisticated than normally used in radiography.

S1.2 If this optional requirement is specified, a length of the fabricated thermocouple extending a minimum of 75 mm [3 in.] from the measuring junction and including the end closure shall be examined by radiography to verify that the dimensions are in conformance with 7.2, and that the defects do not exceed the following limits:

S1.2.1 Cracks, voids, or inclusions in the end closure weld larger than 2.5 % of the nominal sheath outside diameter, or 0.05 mm [0.002 in.], whichever is greater, or which reduce the closure thickness to less than the required minimum 10 % of the nominal outside sheath diameter.

S1.2.2 Cracks, voids, or inclusions in the sheath wall, or thinning of the sheath wall which reduce the sheath wall to less than the required minimum 10 % of the nominal outside sheath diameter.

S1.2.3 Cracks, voids, inclusions, or local reduction of the thermoelements in or near the measuring junction greater than 25 % of the thermoelement diameter or 0.05 mm [0.002 in.], whichever is greater.

S1.2.4 Voids or inclusions in the insulation greater than 50 % of the thermoelement-to-sheath or thermoelement-to-thermoelement separation.

S1.3 *Radiographic Method:*

S1.3.1 Perform Radiographic Inspection in accordance with Test Methods E 839.

S1.3.2 Use single-coated, ultra-fine grain film.

S1.3.3 The radiograph shall have appropriate means to identify the image with the thermocouple.

S1.3.4 Supply the radiograph to the purchaser upon request with appropriate means to identify the thermocouple with its radiograph.

S2. End Closure Weld Integrity Test Using the Dye Penetrant Method

S2.1 If this optional requirement is specified, the integrity of the thermocouple's end closure weld and a minimum of 25 mm [1 in.] of sheath length shall be examined using dye penetrant in accordance with Procedure A-2 of Test Method E 165 to verify there are no cracks, seams, holes, or other surface defects.

S3. End Closure Weld and Sheath Integrity Test Using the Helium Mass Spectrometer Method

S3.1 If this optional requirement is specified, the integrity of a thermocouple's end closure and sheath or the integrity of cable sheath shall be verified by testing in accordance with the section titled "Sheath Integrity-Mass Spectrometer Method" in Test Methods E 839. The purchaser shall specify the length of sheath to be included in the test.

S4. End Closure Weld and Sheath Integrity Test Using Water and the Fast Test Method

S4.1 If this optional requirement is specified, the integrity of the end closure and sheath of a thermocouple with Class 2, ungrounded measuring junction or the integrity of cable sheath shall be verified by testing in accordance with the section titled "Fast Sheath Integrity Test Using Water" in Test Methods E 839.

TABLE S1 Minimum Insulation Resistance at 1000 °C [1832 °F]

NOTE 1—Apply the dc voltage using both direct and reversed polarity, and average the two readings.

NOTE 2—At elevated temperatures, such as 1000 °C, insulation resistance is inversely proportional to the length in the elevated temperature.

Nominal Sheath Outside Diameter	Applied Voltage min, V, dc	Insulation Resistance, min Ω per 300 mm [1 ft] at 1000 °C
0.5 mm [0.020 in.] to 1.45 mm [0.057 in.]	50	5000
Larger than 1.45 mm [0.057 in.]	100	100 000

S5. End Closure Weld and Sheath Integrity Test Using Water and the Basic Test Method

S5.1 If this optional requirement is specified, the integrity of the end closure and sheath of a thermocouple with Class 2, ungrounded measuring junction or the integrity of cable sheath shall be verified by testing in accordance with the section titled "Basic Sheath Integrity Test Using Water" in Test Methods E 839.

S6. Optional Elevated-Temperature Insulation Resistance

S6.1 If this optional requirement is specified, the insulation resistance of cable or thermocouples with Class 2 ungrounded junction shall be measured at 1000 °C [1832 °F] to indicate if insulation contamination, which cannot be detected at room temperature, is present. Perform this high temperature insulation resistance test in accordance with section 8.5.2 of Test Methods E 839. The insulation resistance requirements are shown in Table S1.

S6.2 The purchaser and the producer shall agree upon the sample plan.

S7. Sheath Condition and Flexibility

S7.1 If this optional requirement is specified, the annealed sheath condition shall be demonstrated on one sample selected from each lot of thermocouples with Class 2 ungrounded junction or from each lot of cable.

S7.1.1 Close wind the selected section of the sheath three full turns on a mandrel twice the sheath diameter. Check the continuity of each thermoelement and insulation resistance between each thermoelement and the sheath and between thermoelements before and after winding. The following is cause for rejection of the lot of material: a reduction in the insulation resistance by a factor of 10 or more, an open thermoelement, a short between thermoelements, or a short between any thermoelement and the sheath.

S7.1.2 Cut the center turn from the section and examine under 30× magnification. Any visual evidence of sheath cracking shall be cause for rejection of the lot.

S8. Surface Finish

S8.1 If this optional requirement is specified, the outside surface of all finished thermocouples and cable shall have a bright appearance with a finish no rougher than 0.81 µm [32 µin.] rms. A visual comparison made with roughness standards in accordance with ANSI B46.1 shall be acceptable.

S9. Calibration at Other Temperatures

S9.1 The purchaser may specify calibration at other temperatures in addition to, or instead of, the temperatures specified in Table 5. The upper-use temperature of both the sheath and the thermoelements should be taken into consideration. For more information, see ASTM MNL 12.[9]

S10. Requirements for Measuring Insulation Compaction Density

S10.1 *Compaction Density Measurement*—If this optional requirement is specified, the test method for determining compaction density shall be agreed upon between the purchaser and the producer.

S11. Analysis of the Insulating Material

S11.1 If this optional requirement is specified, a certified analysis of the composition of the insulating material as supplied to the thermocouple or cable producer shall be furnished to the purchaser. The thermocouple or cable producer shall be responsible for maintaining the purity within the specified limits in the finished product.

S12. Metallurgical Structure of the Sheath

S12.1 If this optional requirement is specified, a section from the sheath of the sample thermocouple or cable shall be examined for grain size and for cracks or localized wall thinning.

S12.2 The test methods and the acceptance levels shall be agreed upon between the purchaser and the producer.

[9] Manual on the Use of Thermocouples in Temperature Measurement, MNL-12, Fourth Edition, ASTM, April 1993. (Revision of STP 470B.)

APPENDIX

(Nonmandatory Information)

X1. IDENTIFICATION AND DOCUMENTATION OF QUALITY ASSURANCE AND QUALITY VERIFICATION

X1.1 Scope

X1.1.1 This appendix shall apply only when specified by the purchaser in the inquiry, contract, or ordering information. This appendix has been prepared as a guide for the purchaser to determine what specific requirements should be covered by the purchaser's quality assurance documents.

X1.1.2 If specified, the producer shall be responsible for observing the requirements of the purchaser's quality assurance and verification program specifications during the manufacturing and testing of the sheathed thermocouple material. This may also include the verification of all raw materials used in their manufacture.

X1.2 Identification and Documentation

X1.2.1 Identification and documentation shall make it possible to trace any finished thermocouple material length back through production and testing to the raw materials used in that length. The producer shall identify all raw materials and thermocouple material through all phases of production, storage, and shipment. For this, the producer shall use the identification methods submitted to the purchaser for approval (and approved by the purchaser), for positive identification by labeling, tagging, and coding.

X1.3 Test Procedures

X1.3.1 All tests shall be performed in accordance with written test procedures prepared in accordance with the purchaser's quality assurance and verification program specification.

X1.3.1.1 The purchaser shall state in the ordering documents whether he will accept the producer's standard test procedures, or whether specific test procedures for the purchase order shall be prepared and submitted to the purchaser for approval.

X1.3.1.2 If the test procedures shall be submitted to the purchaser for approval, the producer shall itemize and specify the test procedure required, referencing the appropriate sections of this specification and the supplementary requirements of this specification.

X1.3.1.3 If the procedures shall include raw material procurement, then the purchaser shall so state in the ordering documents.

X1.4 Documentation

X1.4.1 All documentation shall be submitted in accordance with purchaser's quality assurance and verification program specification. It is suggested that the documentation include the following:

X1.4.1.1 The certifications covering all raw materials,

X1.4.1.2 The in-process certifications and results, and

X1.4.1.3 Certifications and test results for all tests stated in this specification.

X1.5 In-Process Surveillance

X1.5.1 Any in-process surveillance by the purchaser shall be determined by agreement between the purchaser and the producer and shall be covered by the purchase documents.