



# Standard Specification for Compacted Mineral-Insulated, Metal-Sheathed, Noble Metal Thermocouples and Thermocouple Cable<sup>1</sup>

This standard is issued under the fixed designation E2181/E2181M; 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 ( $\epsilon$ ) 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 (MIMS), 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 MIMS 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 ( $\text{MgO}$ ) or alumina ( $\text{Al}_2\text{O}_3$ ) insulation, and a noble metal alloy or other alternate heat-resistant sheath material. Provisions are also made for selecting a thermocouple measuring junction style 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:<sup>2</sup>

- A213/A213M Specification for Seamless Ferritic and Austenitic Alloy-Steel Boiler, Superheater, and Heat-Exchanger Tubes
- A249/A249M Specification for Welded Austenitic Steel Boiler, Superheater, Heat-Exchanger, and Condenser Tubes
- A269 Specification for Seamless and Welded Austenitic Stainless Steel Tubing for General Service
- A632 Specification for Seamless and Welded Austenitic Stainless Steel Tubing (Small-Diameter) for General Service
- B163 Specification for Seamless Nickel and Nickel Alloy Condenser and Heat-Exchanger Tubes
- B167 Specification for Nickel-Chromium-Iron Alloys (UNS N06600, N06601, N06603, N06690, N06693, N06025, N06045, and N06696), Nickel-Chromium-Cobalt-Molybdenum Alloy (UNS N06617), and Nickel-Iron-Chromium-Tungsten Alloy (UNS N06674) Seamless Pipe and Tube
- B516 Specification for Welded Nickel-Chromium-Iron Alloy (UNS N06600, UNS N06603, UNS N06025, and UNS N06045) Tubes
- E165 Practice for Liquid Penetrant Examination for General Industry
- E220 Test Method for Calibration of Thermocouples By Comparison Techniques
- E230 Specification and Temperature-Electromotive Force (EMF) Tables for Standardized Thermocouples
- E344 Terminology Relating to Thermometry and Hydrometry
- E608/E608M Specification for Mineral-Insulated, Metal-Sheathed Base Metal Thermocouples
- E839 Test Methods for Sheathed Thermocouples and Sheathed Thermocouple Cable
- E1652 Specification for Magnesium Oxide and Aluminum Oxide Powder and Crushable Insulators Used in the

<sup>1</sup> This specification is under the jurisdiction of ASTM Committee E20 on Temperature Measurement and is the direct responsibility of Subcommittee E20.04 on Thermocouples.

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

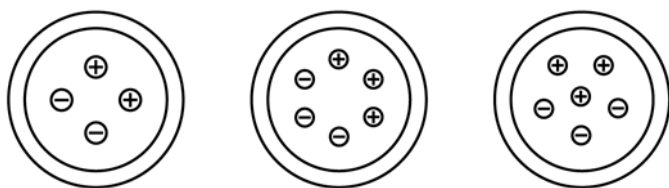


FIG. 1 Examples of Adjacent Configurations

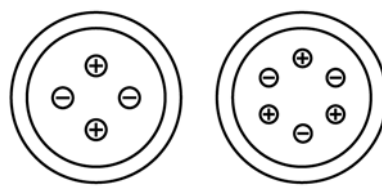


FIG. 2 Examples of Alternating Configurations

Manufacture of Base Metal Thermocouples, Metal-Sheathed Platinum Resistance Thermometers, and Noble Metal Thermocouples

E1751/E1751M Guide for Temperature Electromotive Force (emf) Tables for Non-Letter Designated Thermocouple Combinations

2.3 ANSI Standard:<sup>3</sup>

B46.1 Surface Texture

### 3. Terminology

3.1 *Definitions*—The definitions given in Terminology E344 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 and 3.2.2).

3.2.1.1 *Discussion*—By default, a multi-pair thermocouple or cable with a thermoelement in the center shall 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 and 3.2.1).

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 junction within the same multi-pair thermocouple that is electrically isolated from the sheath but electrically connected to another ungrounded junction.

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

3.2.5 *lot*, *n*—quantity of finished MIMS thermocouples, or length of MIMS thermocouple cable manufactured from tubing or other sheath material from the same heat, wire from the

same spool and heat, and insulation from the same batch, then assembled and processed at the same time under controlled production conditions to the required final configuration.

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

### 4. Significance and Use

4.1 Types 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 E608/E608M).

4.2 To optimize elevated temperature stability, Types S, R, and B thermocouples should be supplied with noble metal sheaths (see 6.3.1). Purchasers and users are cautioned that if Types 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 due to contamination and the development of inhomogeneity. The higher the temperature, the faster the contamination, inhomogeneity, and resultant drift will develop. 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 with purchaser and producer agreement.

5.1.3 The 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 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 (see Table 2), or the emf versus temperature relationship and initial tolerance values if other than Types S, R, or B thermocouples (see 8.1.5 and Guide E1751/E1751M).

<sup>3</sup> Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036.

**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  |

5.1.7 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).

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 when purchasing thermocouples:

5.2.1 The style of measuring junction, Style G (grounded) or Style U (ungrounded). See Figs. 8 and 9. If more than one pair of thermoelements is specified, Style U is further subdivided into Style CU (common ungrounded) and Style IU (isolated ungrounded).<sup>4</sup>

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 temperatures 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 Style U junctions, the minimum acceptable insulation resistance (see 8.1.3.2) shall be stated.

5.3 In addition, the purchasing documents shall specify the following when 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 Type S, R, or B unless otherwise agreed upon between the purchaser and producer.

6.1.2 The thermoelements shall be solid wire, round in cross section. The thermocouple or cable producer shall ensure that all wire used for fabrication shall be free of visible surface oxides, scale, and contaminants, such as drawing compounds, carbon, dirt, and dust. The absence of scale and contaminants can be verified by wiping the wire with a solvent-saturated lint-free cloth. Acetone, isopropyl alcohol, methanol, and ethanol are all acceptable solvents. A light discoloration of the cloth is acceptable unless particles of grit or metal flakes are visually detectable without the use of magnification. If acetone or any other solvent that leaves a harmful residual film upon evaporation is used for initial cleaning, a final cleaning with an acceptable cleaning solvent, such as isopropyl alcohol, methanol, or ethanol is required.

6.1.3 The initial emf versus temperature relationship for Types S, R, and B thermoelements shall satisfy the standard tolerance specified in Table 2 unless otherwise stated in the ordering information.

### 6.2 Insulation:

6.2.1 The insulation shall only be magnesia (MgO) or alumina (Al<sub>2</sub>O<sub>3</sub>) conforming to Specification E1652. Unless otherwise agreed upon between the 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 shall be 70 % of the maximum theoretical density which is 3580 kg/m<sup>3</sup> [0.129 lb/in.<sup>3</sup>] for MgO, and 3970 kg/m<sup>3</sup> [0.144 lb/in.<sup>3</sup>] for Al<sub>2</sub>O<sub>3</sub>.<sup>5</sup> 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-6 % rhodium, platinum-10 % rhodium, platinum-20 % rhodium, or platinum-30 % rhodium. The producer's customary sheath material specification may be used.

6.3.2 Alternately, heat-resistant nickel-chrome alloy tubing per Specifications B163, B167, or B516; or 310 or 321 stainless steel tubing per Specifications A213/A213M, A249/A249M, A269, or A632 may be supplied as sheath materials provided there is an agreement between the purchaser and producer (see 4.2) and the annealing requirements imposed by 6.3.4 are satisfied. The producer's customary sheath material specification may be used.

6.3.3 The thermocouple or cable producer shall ensure that each piece of sheath material shall be free of visible surface oxides, scale, and contaminants, such as drawing compounds, carbon, dirt, and dust. The absence of scale and contaminants can be verified by passing a solvent-saturated swatch of lint-free yarn or cloth against the inner surface of the sheath material. Acetone, isopropyl alcohol, methanol, and ethanol are all acceptable solvents. A light discoloration of the swatch or plug is acceptable unless particles of grit or metal flakes are

<sup>4</sup> Style G, Style U, Style CU and Style IU measuring junctions were previously termed Class 1, Class 2, Class 2A and Class 2B measuring junctions respectively.

<sup>5</sup> Handbook of Chemistry and Physics, Chemical Rubber Publishing Co., No. 76 (1995) edition.

**TABLE 2 Tolerances on Initial Values of EMF versus Temperature for Types S, R, and B MIMS Thermocouples and MIMS Thermocouple Cable**

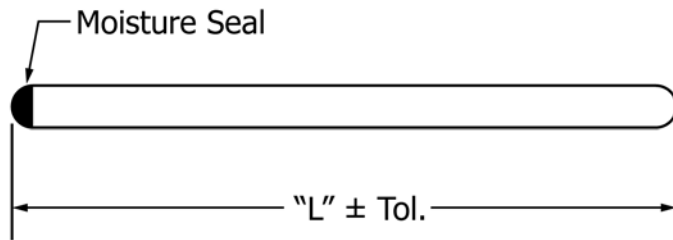
NOTE 1—Tolerances in this table apply to new Platinum sheathed MIMS thermocouples and thermocouple cable.

NOTE 2—Tolerances apply to new material as produced and do not allow for changes in thermoelectric characteristics of the materials during use. The magnitude of such changes depends upon such factors as sheath and thermoelement size, temperature, time of exposure, and environment.

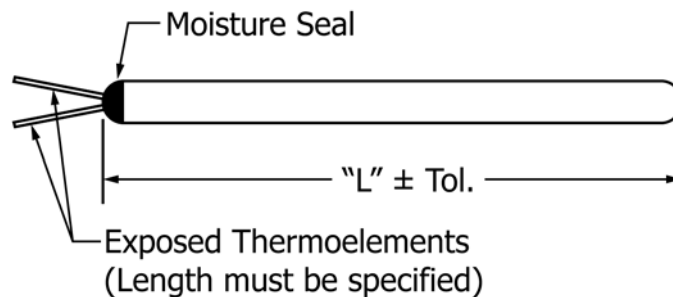
NOTE 3—Where tolerances are given in percent, the percentage applies to the temperature being measured when expressed in degrees Celsius.

NOTE 4—To determine the tolerance in degrees Fahrenheit, multiply the tolerance in degrees Celsius by 9/5.

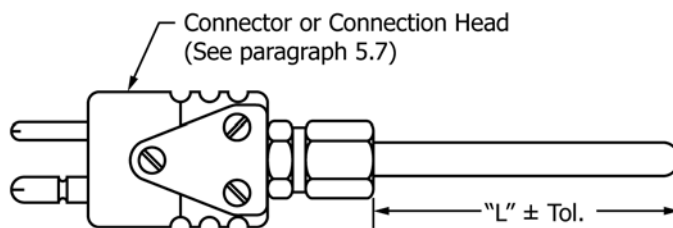
| Thermocouple Type | Temperature Range |              | Tolerances – Reference Junction 0°C [32°F]               |    |                                                         |    |
|-------------------|-------------------|--------------|----------------------------------------------------------|----|---------------------------------------------------------|----|
|                   | °C                | °F           | Standard Tolerances                                      |    | Special Tolerances                                      |    |
|                   |                   |              | °C                                                       | °F | °C                                                      | °F |
| S, R              | 0 to 1480         | 32 to 2700   | The greater of $\pm 1.5^{\circ}\text{C}$ or $\pm 0.25\%$ |    | The greater of $\pm 0.6^{\circ}\text{C}$ or $\pm 0.1\%$ |    |
| B                 | 870 to 1700       | 1600 to 3100 | $\pm 0.50\%$                                             |    | $\pm 0.25\%$                                            |    |



**FIG. 3 Sheathed Thermocouple Cable**



**FIG. 4 Sheathed Thermocouple with Exposed Thermoelements**

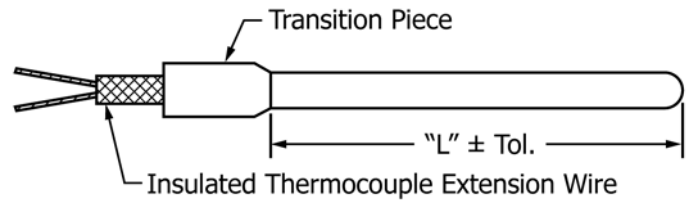


**FIG. 5 Sheathed Thermocouple Assembly with Connector or Connection Head (any Type Specified)**

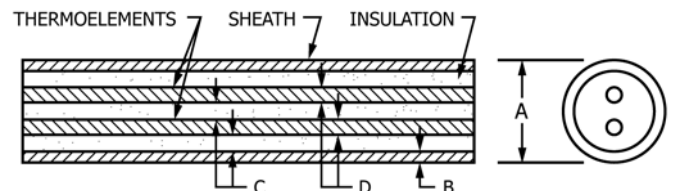
visually detectable without the use of magnification. If acetone or any other solvent that leaves a harmful residual film upon evaporation is used for initial cleaning, a final cleaning with an acceptable cleaning solvent, such as isopropyl alcohol, methanol, or ethanol is required.

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



**FIG. 6 Sheathed Thermocouple Assembly with Transition Piece**



**FIG. 7 Sheathed Thermocouple Construction**

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 E1652. Style U measuring junctions shall be fabricated by welding the thermoelements together without filler metal or flux. The use of plugs or filler metals for the end closure is optional, provided they are of the same nominal chemical composition as the sheath.

6.5 Thermocouples shall be terminated at their reference junction end opposite the measuring junction in a manner specified by the purchaser. All exposed MgO or Al<sub>2</sub>O<sub>3</sub> 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 compatible with their intended installation and operating conditions (see 5.2.3).

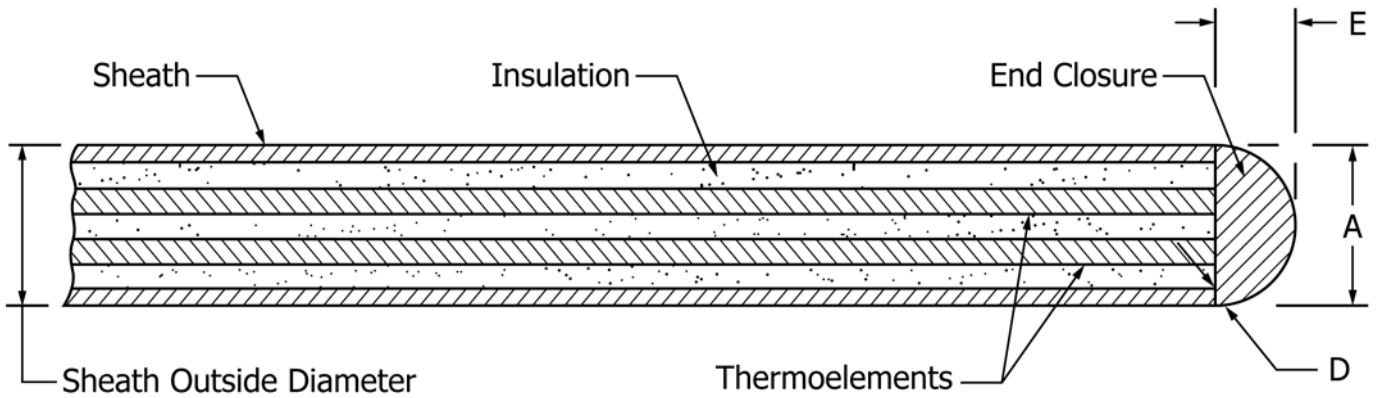


FIG. 8 Grounded Measuring Junction, Style G

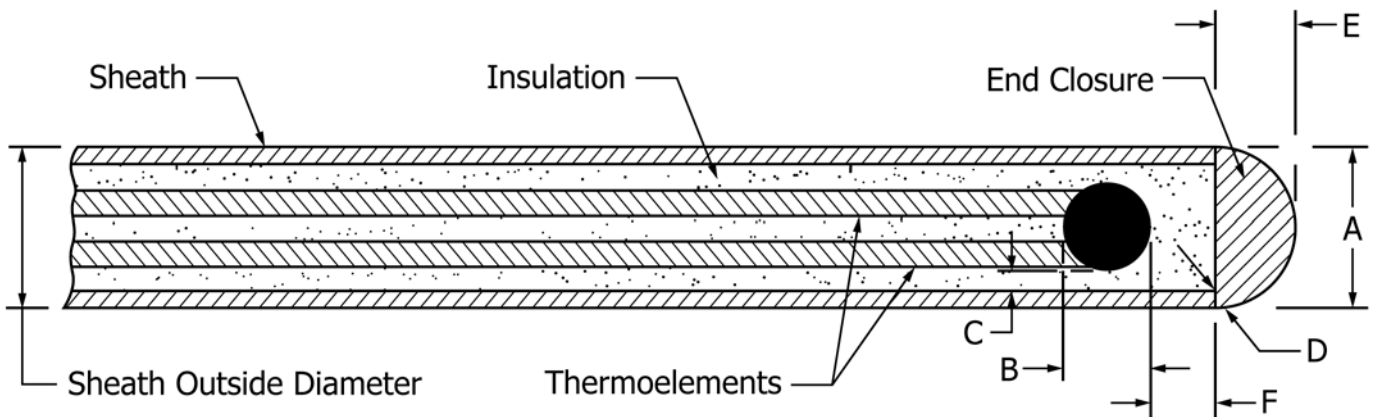


FIG. 9 Ungrounded Measuring Junction, Style U

## 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  $\pm 0.025$  mm [0.001 in.] or  $\pm 1\%$ , 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 E839. The minimum dimensional requirements for sheath wall

thickness, thermoelement diameter, and insulation thickness are summarized in Table 3. 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, Styles G and U**—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 twice the nominal sheath diameter.

**7.2.2 Dimension D, Minimum Material Thickness, Styles G and U Junctions**—The thickness at any point of the end closure weld interface shall be not 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.

**TABLE 3 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 4 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                         |

**TABLE 5 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                           |

**7.2.3 Dimension E, End Closure Thickness**—The end closure thickness on both Style G and Style U 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 Styles U, CU, and IU 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 the end closure and the 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 E839.

### 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 that 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 thermocouple circuit within a thermocouple with an ohmmeter. Also verify the continuity of Style G (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 its respective sheath for conformance with Table 4 with the specified voltage applied in both direct and reversed polarity.

8.1.3.2 Measure the insulation resistance of each Style U (ungrounded) thermocouple between all thermocouple circuits and the sheath for conformance with Table 5 with the specified voltage applied in both direct and reversed polarity and record those measured values. In addition, measure the insulation resistance of each Style IU (isolated ungrounded) thermo-

couple between thermocouple circuits for conformance with Table 5 with the specified voltage applied in both direct and reversed polarity and record those measured values. Measure Style U 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 shall exceed the values agreed upon between the purchaser and the producer. This test can also be applied to Style G (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 5 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 when compared to the emf versus temperature relationship defined in Specification E230 for the same thermocouple type, the temperature differences are initially within the required tolerances defined in Table 2. 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 Test Method E220. The calibration may be performed in order of increasing or decreasing 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 6. The actual temperature of the heat source used for calibration may deviate up to 25°C [45°F]

**TABLE 6 Calibration Temperatures**

| Thermocouple Type | Nominal Calibration Temperature <sup>A</sup> |      |
|-------------------|----------------------------------------------|------|
|                   | °C                                           | °F   |
| S, R              | 300                                          | 600  |
|                   | 700                                          | 1300 |
|                   | 1100                                         | 2000 |
| B                 | 900                                          | 1650 |
|                   | 1100                                         | 2000 |
|                   | 1300                                         | 2400 |

<sup>A</sup> These nominal calibration temperatures are applicable to MIMS cable and thermocouples manufactured with platinum alloy sheaths as specified in 6.3.1. They may not be appropriate for the alternate sheath materials specified in 6.3.2.

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 in 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 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 Water and the Fast Test Method per Supplementary Requirement S4 (thermocouples with Style U measuring junctions and cable only).

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

8.2.6 Optional Elevated Temperature Insulation Resistance per Supplementary Requirement S6 (thermocouples with Style U 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 Style U 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 shall be responsible for all processing of all component materials to ensure that the overall requirements of this specification are met. The producer shall also be responsible for the quality of the finished product.

## 10. Certification

10.1 A certificate of conformance covering the completed MIMS thermocouples or cable and the data produced 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 three years.

## 11. Packaging, Marking, and Shipping

11.1 *Sealing*—All open ends of MIMS 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 the 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, sheath material, quantity of thermocouples or thermoelements, 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; noble metal thermocouple; platinum thermocouple; sheathed thermocouple material; sheathed thermocouples; termination; thermocouple; thermoelement; Type B; Type R; Type S



## 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 radiographically 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 the Radiographic Inspection in accordance with Test Methods E839.

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 E165 to verify that 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 E839. The purchaser shall specify the length of sheath to be included in the test.

**TABLE S1.1 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 $\Omega$ 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                                                         |

### 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 Style U, 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 E839.

### 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 Style U, 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 E839.

### S6. Optional Elevated-Temperature Insulation Resistance

S6.1 If this optional requirement is specified, the insulation resistance of cable or thermocouples with Style U 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 E839. The insulation resistance requirements are shown in Table S1.1.

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 Style U 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 2**. The upper-use temperature of both the sheath and the thermoelements should be taken into consideration. For more information, see ASTM MNL 12.<sup>6</sup>

<sup>6</sup> Manual on the Use of Thermocouples in Temperature Measurement, MNL-12, Fourth Edition, ASTM, April 1993. (Revision of STP 470B.)

## **S10. Insulation Compaction Density Measurement**

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 insulation purity in the finished product within the specified limits.

## **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.

# **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 will 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 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 the 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.

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