Designation: E2181/E2181M – 19

An American National Standard

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

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 (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 (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 recommendations 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 (MgO) or alumina (Al_2O_3) insulation, and a noble metal alloy or another 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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.6 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

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:*[2]

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/A269M 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-Aluminum Alloys (UNS N06699), Nickel-Chromium-Iron Alloys (UNS N06600, N06601, N06603, N06690, N06693, N06025, N06045, and N06696), Nickel-Chromium-Cobalt-Molybdenum Alloy (UNS N06617), Nickel-Iron-Chromium-Tungsten Alloy (UNS N06674), and

B516 Specification for Welded Nickel-Chromium-Aluminum Alloy (UNS N06699) and Nickel-Chromium-Iron Alloy (UNS N06600, UNS N06601, UNS N06603, UNS N06025, UNS N06045, UNS N06690, and UNS N06693) Tubes

E165/E165M Practice for Liquid Penetrant Testing for General Industry

E220 Test Method for Calibration of Thermocouples By Comparison Techniques

E230/E230M Specification for Temperature-Electromotive Force (emf) Tables for Standardized Thermocouples

E344 Terminology Relating to Thermometry and Hydrometry

[1] This specification is under the jurisdiction of ASTM Committee E20 on Temperature Measurement and is the direct responsibility of Subcommittee E20.12 on Thermocouples - Specifications.

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

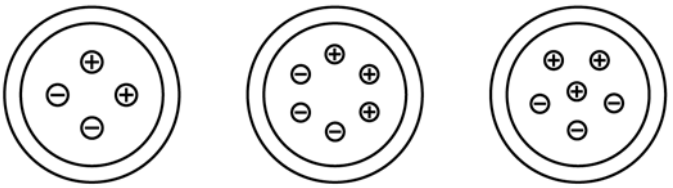

FIG. 1 Examples of Adjacent Configurations

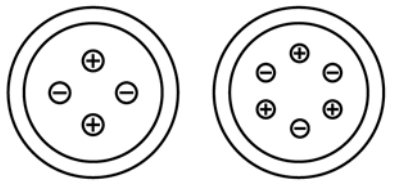

FIG. 2 Examples of Alternating Configurations

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 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:*[3]
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 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. Note that due to noble metal material cost, deviation from the specified minimum thermoelement diameter (Table 3), may be agreed upon by the purchaser and producer with the understanding that reduced diameters may affect long-term performance and stability.

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.

[3] 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

5.1.4 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).

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. Style G is not recommended when the material is supplied with base metal sheaths, such as 300 series stainless steels or other heat-resistant nickel-chrome alloys as they will be more susceptible to drift due to contamination and the development of inhomogeneity. If more than one pair of thermoelements is specified, Style U is further subdivided into Style CU (common ungrounded) and Style IU (isolated ungrounded).[4]

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 the 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 of 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_2O_3) conforming to Specification E1652. Unless otherwise agreed upon between the purchaser and producer, only Type 1P magnesia or Type 1P 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^3 [0.129 $lb/in.^3$] for MgO, and 3970 kg/m^3 [0.144 $lb/in.^3$] for Al_2O_3.[5] 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 Specification B163, B167, or B516; or 310 or 321 stainless steel tubing per Specification A213/A213M, A249/A249M,

[4] 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.

[5] 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]			
			Standard Tolerances		Special Tolerances	
	°C	°F	°C	°F	°C	°F
S, R	0 to 1480	32 to 2700	The greater of ±1.5 °C or ±0.25 %	Note 4	The greater of ±0.6 °C or ±0.1 %	Note 4
B	870 to 1700	1600 to 3100	±0.50 %		±0.25 %	

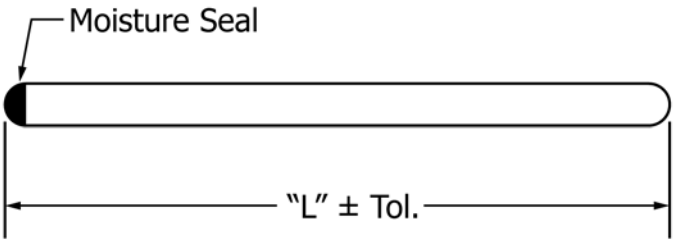

FIG. 3 Sheathed Thermocouple Cable

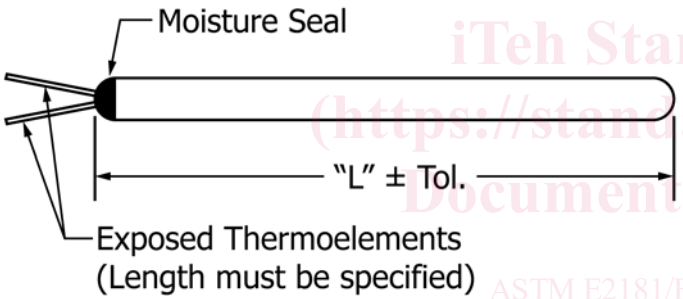

FIG. 4 Sheathed Thermocouple with Exposed Thermoelements

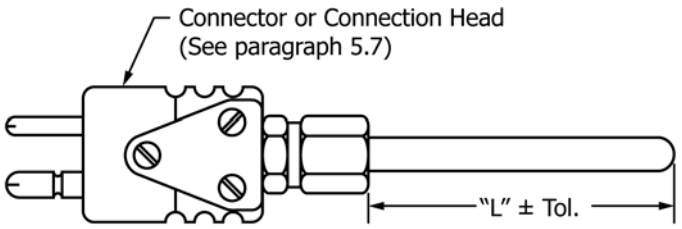

FIG. 5 Sheathed Thermocouple Assembly with Connector or Connection Head (any Type Specified)

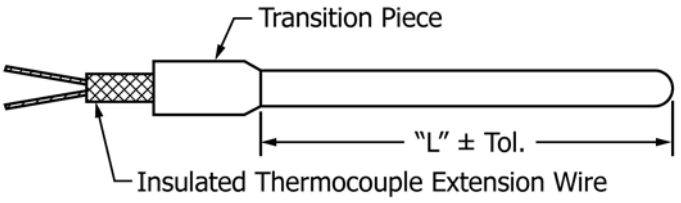

FIG. 6 Sheathed Thermocouple Assembly with Transition Piece

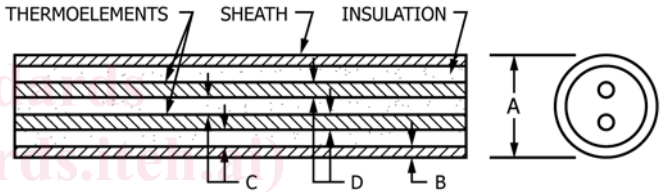

FIG. 7 Sheathed Thermocouple Construction

A269/A269M, 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 or cloth 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 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 and 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 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

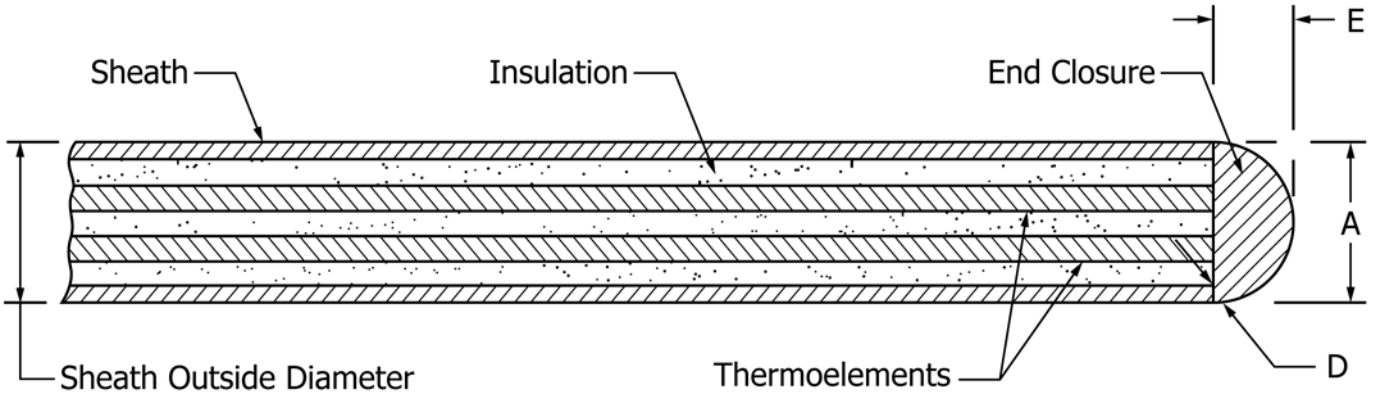

FIG. 8 Grounded Measuring Junction, Style G

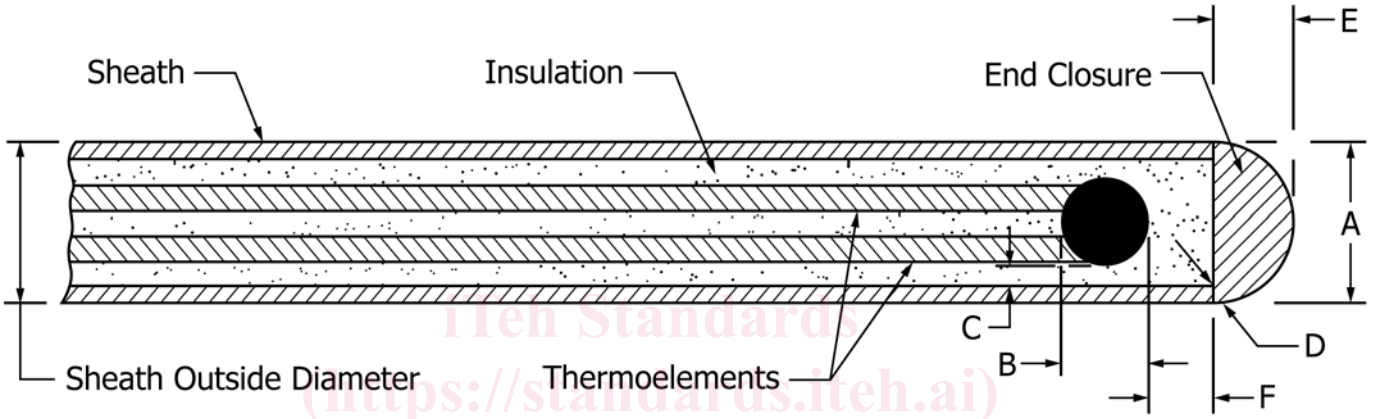

FIG. 9 Ungrounded Measuring Junction, Style U

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_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 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. Thermoelement diameters shall be determined by agreement between the purchaser and producer. 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 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.

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 Insulation Thickness	7 %	5.5 %	4 %

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. Style G is not recommended when the material is supplied with base metal sheaths, such as 300 series stainless steels or other heat-resistant nickel-chrome alloys as they will be more susceptible to drift due to contamination and the development of inhomogeneity.

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 the 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.

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

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) thermocouple 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 the 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 an 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/E230M 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