Designation: E1652 – 15

Standard 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[1]

1. Scope

1.1 This specification covers the requirements for magnesium oxide (MgO) and aluminum oxide (Al_2O_3) powders and crushable insulators used to manufacture base metal thermocouples, metal-sheathed platinum resistance thermometers (PRTs), noble metal thermocouples, and their respective cables.

1.2 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

B329 Test Method for Apparent Density of Metal Powders and Compounds Using the Scott Volumeter

C809 Test Methods for Chemical, Mass Spectrometric, and Spectrochemical Analysis of Nuclear-Grade Aluminum Oxide and AluminumOxide-Boron Carbide Composite Pellets

C832 Test Method of Measuring Thermal Expansion and Creep of Refractories Under Load

D2766 Test Method for Specific Heat of Liquids and Solids

E228 Test Method for Linear Thermal Expansion of Solid Materials With a Push-Rod Dilatometer

E235 Specification for Thermocouples, Sheathed, Type K and Type N, for Nuclear or for Other High-Reliability Applications

E344 Terminology Relating to Thermometry and Hydrometry

E585/E585M Specification for Compacted Mineral-Insulated, Metal-Sheathed, Base Metal Thermocouple Cable

E1137/E1137M Specification for Industrial Platinum Resistance Thermometers

E1225 Test Method for Thermal Conductivity of Solids Using the Guarded-Comparative-Longitudinal Heat Flow Technique

E2181/E2181M Specification for Compacted Mineral-Insulated, Metal-Sheathed, Noble Metal Thermocouples and Thermocouple Cable

3. Terminology

3.1 The definitions given in Terminology E344 shall apply to this specification.

4. Significance and Use

4.1 Magnesium oxide and aluminum oxide are used to electrically isolate and mechanically support the thermoelements of a thermocouple (see Specifications E235, E585/E585M, and E2181/E2181M) and the connecting wires of a PRT (see Specification E1137/E1137M) within a metal sheath. The metal sheath is typically reduced in diameter to compact the oxide powder or crushable oxide insulators around the thermoelements or wires.

4.2 In order to be suitable for this purpose, the materials shall meet certain criteria for purity and for mechanical and dimensional characteristics. Material that does not meet the purity criteria may cause premature failure of the sensor.

4.3 Use of this specification for the procurement of powder and crushable insulators will help to ensure that the product obtained is suitable for the intended purpose.

4.4 Useful information about alumina and magnesia is given in the appendixes.

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[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.

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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.

5. Classification

5.1 The purchaser shall specify the appropriate Material and Type from 5.2 through 5.6 below.

5.2 MgO Type 1 in accordance with Table 1.

5.3 Al_2O_3 Type 1 in accordance with Table 1.

5.4 MgO Type 1P in accordance with Table 2.

5.5 Al_2O_3 Type 1P in accordance with Table 2.

5.6 MgO Type 2 in accordance with Table 3.

NOTE 1—There is no corresponding Al_2O_3 Type 2 designation at this time.

5.7 The final product shall be chemically analyzed using appropriate methods listed in 9.1. Major impurities shall not exceed the limits indicated in Table 1 through Table 3 for the appropriate grade. Any detected impurity with a concentration greater than 0.001 % (mass) shall be reported to the purchaser.

6. Ordering Information

6.1 The purchaser shall specify the following when ordering:

6.1.1 *Material and Type in accordance with Section 5.*

6.1.2 *Insulator Outside Diameter.*

6.1.3 *Hole Diameter.*

6.1.4 *Number of Holes.*

6.1.5 *Hole Pattern.*

6.1.6 *Length.*

6.1.7 *Particle Size* (if supplied as powder).

6.2 The purchaser may specify the following additional information when ordering:

6.2.1 *Minimum Inside Diameter (at Maximum Material Condition (MMC)) of the Tubing,* (into which insulators will be inserted, see 8.3).

6.2.2 *Maximum Outside Diameter of Wire which will be inserted into the insulators,* (see 8.3).

6.3 Consult the insulator manufacturer for limitations of relationships between outside diameter, hole diameters, hole patterns, and length.

TABLE 1 Chemical Requirements for Al_2O_3 Type 1 and MgO Type 1[A, B]

Aluminum Oxide (Al_2O_3)		Magnesium Oxide (MgO)	
Impurity	Concentration, % (mass)	Impurity	Concentration, % (mass)
Al_2O_3	99.65 % min	MgO	99.40 % min
CaO	0.08 max	CaO	0.35 max
SiO_2	0.08 max[B]	SiO_2	0.35 max[B]
MgO	0.08 max	Al_2O_3	0.15 max
Fe_2O_3	0.04 max	Fe_2O_3	0.07 max
ZrO_2	0.08 max		
Na_2O	0.06 max		
C	0.01 max	C	0.02 max
S	0.005 max	S	0.0025 max
B	0.001 max	B	0.0035 max
Cd	0.001 max	Cd	0.001 max
		B+Cd	0.004 max

[A] Platinum thermoelements and Noble Metal thermocouples for use above 650°C shall specify Type 1P composition according to Table 2.

[B] Base metal thermocouples for nuclear environments in accordance with Specification E235 shall specify Type 1P composition according to Table 2.

TABLE 2 Chemical Requirements for Al_2O_3 Type 1P and MgO Type 1P[A]

Aluminum Oxide (Al_2O_3) 99.65 % (mass) min		Magnesium Oxide (MgO) 99.40 % (mass) min	
Impurity	Concentration, % (mass)	Impurity	Concentration, % (mass)
Al_2O_3	99.65 % min	MgO	99.40 % min
CaO	0.08 max	CaO	0.35 max
SiO_2	0.08 max	SiO_2	0.13 max
MgO	0.08 max	Al_2O_3	0.15 max
Fe_2O_3	0.04 max	Fe_2O_3	0.04 max
ZrO_2	0.08 max		
Na_2O	0.06 max		
C	0.01 max	C	0.02 max
S	0.005 max	S	0.0025 max
B	0.08 max	B	0.0035 max
Cd	0.08 max	Cd	0.001 max
		B+Cd	0.004 max

[A] Platinum thermoelements and noble Metal thermocouples for use below 650°C may optionally specify Type 1 composition according to Table 1.

TABLE 3 Chemical Requirements for MgO Type 2

Magnesium Oxide (MgO)	
Impurity	Concentration, % (mass)
MgO	97.00 % min
CaO	1.50 max
Al_2O_3	1.00 max
SiO_2	3.00 max
Fe_2O_3	0.15 max
C	0.02 max
S	0.0025 max
B	0.0050 max
Cd	0.001 max
B + Cd	0.0050 max
MgO + CaO + Al_2O_3 + SiO_2	99.50 min

7. Physical Properties

7.1 *Density*—The density of crushable magnesium oxide and aluminum oxide insulators typically ranges from 2060 kg/m^3 (0.074 $lbm/in.^3$) to 3060 kg/m^3 (0.111 $lbm/in.^3$). Specific density requirements, as well as the test method to be used to determine density, shall be negotiated between the purchaser and manufacturer. See Appendix X3 for suggested test methods.

7.2 *Modulus of Rupture (MOR)*—In the past, a breaking force test that is based on a relative modulus of rupture and is related to crushability has been used. However, with variations in modulus from 21 to 83 MPa (3000 to 12 000 $lb/in.^2$) influenced by insulator configuration, number of holes, and cross-sectional dimensions, specific modulus requirements cannot be listed for each configuration. The modulus of rupture is best used for lot-to-lot comparison of a given insulator size and configuration. See Appendix X4 for a suggested test method and X2.4 for recommended tolerances.

8. Dimensional Requirements

8.1 Outside diameter and hole diameter tolerances for insulators shall be as specified in Table 4 and Table 5, respectively, unless otherwise agreed to between the purchaser and manufacturer.

8.2 The wall and web thicknesses (see Fig. 1) shall be equal within outside the total allowable outside diameter tolerance as

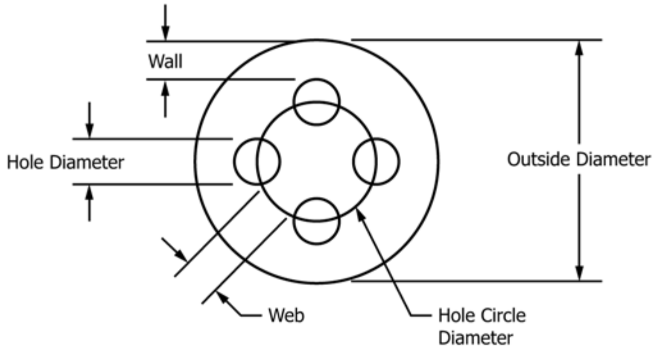
TABLE 4 Outside Diameter (O.D.) Tolerances

Nominal Insulator O.D.	O.D. Tolerance
Over 0.25 to 1.00 mm (0.010 to 0.039 in.), inclusive	±0.05 mm (±0.002 in.)
Over 1.00 to 1.50 mm (0.039 to 0.059 in.), inclusive	±0.08 mm (±0.003 in.)
Over 1.50 to 5.00 mm (0.059 to 0.197 in.), inclusive	±0.10 mm (±0.004 in.)
Over 5.00 to 8.00 mm (0.197 to 0.315 in.), inclusive	±0.13 mm (±0.005 in.)
Over 8.00 to 10.00 mm (0.315 to 0.394 in.), inclusive	±0.15 mm (±0.006 in.)
Over 10.0 mm (0.394 in.)	±1.75%

TABLE 5 Hole Diameter Tolerance[A]

Nominal Insulator Hole Diameter	Hole Diameter Tolerance
Over 0.18 to 1.00 mm (0.007 to 0.039 in.), inclusive	±0.05 mm (±0.002 in.)
Over 1.00 to 2.00 mm (0.040 to 0.079 in.), inclusive	±0.08 mm (±0.003 in.)
Over 2.00 to 2.50 mm (0.079 to 0.098 in.), inclusive	±0.10 mm (±0.004 in.)
Over 2.50 mm (0.098 in.) and larger, inclusive	±05 %

[A] See X2.3 for recommended inspection procedure.



4 hole insulator shown.
Other hole patterns are available – consult manufacturer.

FIG. 1 Wall and Web Thicknesses

specified in Table 5 and the minimum measured web or wall shall be no smaller than 75 % of the maximum measured web or wall, unless otherwise agreed to between the purchaser and manufacturer.

8.3 The camber shall not exceed 0.3 % of the length. The insulator shall be capable of passing through a rigid straight tube longer than the insulator and with an inside diameter as specified in 6.2.1. Local camber defects caused by "knees" or "doglegs" shall not impede the insertion of wire.

8.4 The helical twist of holes shall not exceed 2° per cm (5° per in.) of the length.

8.5 The length shall be as specified in 6.1.6 with a tolerance of +6/−0.00 mm (+0.25/−0.00 in.).

8.6 The ends of each insulator should be cut square and shall be essentially chip-free as agreed upon between the supplier and purchaser.

9. Test Methods

9.1 *Chemical Composition:*

9.1.1 Wet chemical analysis, or fusion calorimetric analysis, or both, can be used for quantitative determination of silicon dioxide (SiO_2), iron oxide (Fe_2O_3), and zirconium oxide (ZrO_2) with gravimetric determination for SiO_2 and Fe_2O_3. The SiO_2 filtrate can be used for further calcium oxide (CaO) determination.

9.1.2 Test Method C809 can be used for quantitative analysis of elemental impurities.

9.1.3 Any method used for quantitative determination should have a detection sensitivity of at least 0.001 % (mass).

9.2 *Density (Powder)*—Test Method B329 can be used for determining the density of Al_2O_3 and MgO powders.

9.3 Appendix X5 lists other optional test methods.

10. Handling and Storage Precautions

10.1 Powders and crushable insulators shall be shipped and stored in containers that prevent contamination and breakage. Powders and crushable insulators should be stored in sealed containers to prevent contamination by moisture absorption. (See Appendix X2.)

11. Keywords

11.1 aluminum oxide; crushable; insulator; magnesium oxide; mineral-insulated, metal-sheathed cable; platinum resistance thermometer; thermocouple, base metal; thermocouple, noble metal

APPENDIXES

(Nonmandatory Information)

X1. MATERIALS AND MANUFACTURE

X1.1 Alumina (Al_2O_3)

X1.1.1 *Sources:*

X1.1.1.1 Bauxite is the principal source of alumina. Gibbsite, $Al(OH)_3$, is the most stable phase. Boehmite, AlO(OH), also occurs in nature. High grade bauxite is low in iron and silica content. The major use of purified alumina is in the production of aluminum metal.

X1.1.1.2 Depending upon the application, the economics, and the purity of the bauxite, the purification process could be wet alkaline, wet acid, alkaline furnace, carbothermic furnace, or electrolytic processes.

X1.1.1.3 The wet alkaline processes are the most economical. Gibbsite bauxite is easier to dissolve. It is digested in sodium hydroxide (NaOH) solution at about 150°C (302°F) at 345 kPa (50 lb/in.^{2}). Boehmitic bauxite, AlO(OH), is more difficult to dissolve. It requires a higher concentration of NaOH solution, a pressure of 1930 to 4826 kPa (280 to 700 lb/in.^{2}), and a temperature of about 238°C (545°F).

X1.1.1.4 When digested, the slurry is cooled to about 100°C (212°F) by releasing pressure to atmospheric, and the undissolved "mud" is sedimented or filtered off. When cooled to about 50°C (122°F) and seeded with alumina-trihydrate, precipitation occurs. The precipitated trihydrate is washed and then calcinated. The trihydrate dehydrates slowly. At atmospheric pressures, the dehydration process involves two steps.

X1.1.1.5 The trihydrate dehydrates first to a composition close to boehmite ($Al_2O_3 \cdot H_2O$). Even at 200°C (392°F) the rate of dehydration is very slow. Dehydration is essentially complete at 400°C (752°F) in an oven at below atmospheric pressure or at 500°C (932°F) at atmospheric pressure. In one study, the heating at 538°C (1000°F) for 7 h still resulted in 0.1 moles of H_2O per mole Al_2O_3, that is, about 2 %. Differential thermal analysis (DTA) studies show endothermic effects at 225, 300, and 550°C (437, 572, and 1022°F, respectively). The peak at 550°C (1022°F) represents the dehydration of boehmite.

X1.1.1.6 Activated alumina is a desiccant and is more easily rehydrated when activated in vacuum. Alumina activated in vacuum at 180 to 200°C (356 to 392°F) and then heated in air at about 350 to 450°C (662 to 842°F) does not rehydrate as easily. No rehydration was found with alpha alumina of low surface area. To achieve low surface area the alumina should be heated to at least 1700°C (3092°F). Alumina is sintered at about 1700 to 2000°C (3092 to 3632°F). It melts around 2050°C (3722°F).

X1.1.2 *Typical Crystal Properties :*

X1.1.2.1 *Coefficient of Thermal Expansion*—6 to 9×10^{-6}/K (3.3 to 5×10^{-6}/°F) between 20 and 1000°C (68 and 1832°F).

X1.1.2.2 *Crystal Shape*— Hexagonal.

X1.1.2.3 *Maximum Theoretical Density*—3.98×10^3 kg/m ^{3} (0.144 lbm/in^3).

X1.1.2.4 *Dielectric Strength*—5600 kV/m (142 000 V/in).

X1.1.2.5 *Hardness* (MOHS)—9.

X1.1.2.6 *Softening Temperature*—1750°C (3182°F).

X1.1.2.7 *Melting Temperature*—2050°C (3722°F).

X1.1.2.8 *Molecular Weight*—101.94.

X1.1.2.9 *Typical Electrical Resistivity*—See Table X1.1.

X1.1.2.10 *Specific Heat*— 8.8×10^2 J/kg·K@ 20°C (0.21 Btu/lbm °F @ 68°F). 1.2×10 ^{3} J/kg·K @ 1000°C (0.28 Btu/lbm °F @ 1832°F).

X1.1.2.11 *Typical Thermal Conductivity* —See Table X1.2.

X1.1.2.12 *Macroscopic Thermal Neutron Absorption Cross Section*—1.0 m^{-1} (0.03 in^{-1}).

X1.2 Magnesia (MgO)

X1.2.1 *Sources:*

X1.2.1.1 Magnesia can be made by the oxidation of magnesium metal or by heating easily decomposed oxy-compounds of magnesium, such as the hydroxide, $Mg(OH)_2$, the oxalate, MgC_2O_4, or the naturally occurring carbonate (magnesite), $MgCO_3$. $Mg(OH)_2$ exists as the mineral brucite in small amounts; however the principal commercial source of magnesia is magnesite, which occurs in a relatively pure state in many parts of the world. Another source of magnesia is dolomite (a more abundant substance), a double carbonate of magnesium and calcium. With dolomite, the calcium must be removed.

X1.2.1.2 When magnesite is heated, the change to MgO is completed at about 620°C (1148°F). The MgO remains as submicroscopic crystals up to about 1000°C (1832°F). At 1200°C (2192°F) the crystals grow to about 1 µm (39.37 µin.). With additives, such as sodium chloride, the crystals could be 3 to 4 µm (120 to 160 µin.) in size at 1200°C (2192°F). The crystal size increases with increases in the temperature of sintering. The calcination and sintering of magnesite is carried out in rotating kilns at 1600 to 1700°C (2912 to 3092°F). For requirements of purest quality, the MgO is fused in an electric furnace where many of the impurities are removed by volatilization. The fused MgO is crushed to the required size.

X1.2.1.3 Magnesia prepared by heating magnesite can vary widely in purity and in the composition of the impurities, depending upon the source of the magnesite. The impurities are principally oxides of calcium, silicon, aluminum, iron, and boron. The size of the magnesia crystals depends upon the

TABLE X1.1 Typical Electrical Resistivity of Alumina (Theoretical, 100 % Density)

Temperature		Typical Resistivity	
°C	°F	ohm-cm	ohm-in.
20	68	>1 × 10^{14}	>4 × 10^{13}
400	752	1 × 10^{11}	4 × 10^{10}
800	1472	1 × 10^{9}	4 × 10^{8}
1300	2372	1 × 10^{6}	4 × 10^{5}

TABLE X1.2 Typical Thermal Conductivity of Alumina

Temperature		Typical Thermal Conductivity	
°C	°F	W/(m·K)	Btu·in./(h·ft^2·°F)
20	68	33	227
500	932	11.4	41
1200	2192	6.7	28

TABLE X1.3 Typical Electrical Resistivity of Magnesia (Theoretical, 100 % Density)

Temperature		Typical Electrical Resistivity	
°C	°F	ohm-cm	ohm-in.
0	32	$>1 \times 10^{16}$	$>4 \times 10^{15}$
400	752	1×10^{13}	4×10^{12}
800	1472	1×10^{9}	4×10^{8}
1200	2192	1×10^{5}	4×10^{4}

TABLE X1.4 Typical Thermal Conductivity of Magnesia

Temperature		Typical Thermal Conductivity	
°C	°F	W/(m·K)	Btu·in./(h·ft^2·°F)
100	212	29.4	202
600	1112	12.3	67
1000	1832	8.1	36

temperature of sintering and upon the impurities (mineralizers) that are present. The magnesia content can be less than 90 % to as high as 99 %.

X1.2.1.4 Large amounts of magnesia of high purity are extracted from the magnesium salts in seawater. The magnesium concentration in seawater is about 0.13 %. Limestone or dolomite is calcined to lime and slaked into a fine powder in hydrators. The hydrated powder is made into a slurry and then mixed with seawater. Magnesium hydroxide is precipitated as a fine suspension that is allowed to settle in large tanks. After washing and filtering, the "cake," about 50 to 70 % solid, is calcined at 900°C (1652°F) to form the reactive magnesia. The latter material is often pressed into pellets and heated to a dense refractory product. Without special purification, commercial seawater magnesia powder is typically 96 to 98 % pure. When MgO is in the active finely divided powder state (when heated to only about 800 to 900°C (1472 to 1652°F) in the preparation process), magnesia readily absorbs moisture and carbon dioxide. The hydration process is complete in about three days. The reactivity with water begins to decrease when magnesia is heated, starting at about 1000 to 1100°C (1832 to 2012°F). When heated to 1450°C (2642°F), the hydration process becomes asymptotic to around 61.4 % of complete hydration. When heated to above 1700°C (3092°F) (dead burned magnesia), the fine crystals grow, and the material becomes more resistant to hydration.

X1.2.1.5 Magnesia is electrically fused to purify and to prepare large crystals. The crystals are more resistant to hydration than the fine powder of the porous magnesia crystals.

X1.2.1.6 Magnesia of 99.98 % purity can be obtained by electric fusion. It contains as impurities Ca, Si, Fe, Na, and K in amounts of 60, 40, 20, 30, and 40 ppm, respectively.

X1.2.1.7 Magnesia is thermally very stable; it melts at 2800°C (5072°F). The vapor pressure at 2700°C (4892°F) is calculated to be about 30.5 kPa, (9.05 in. Hg). Hence, the upper temperature limit of use of magnesia bricks is around 2200°C (3992°F); 1700°C (3092°F) in reducing environment. In a reducing atmosphere, the fine smoke that is produced is thought to be MgO that is formed by the recombination of Mg metal vapor with oxygen. Magnesium is an alkaline substance. It will react with acidic substances (like silica) to form magnesium silicates; or with amphoteric substances (like alumina) to form magnesium aluminates. On the other hand, magnesia is highly resistant to other alkaline substances, for example, lead oxides. Magnesia is not reducible by most other metals at their melting points. Iron, zinc, lead, tin, copper, nickel, and the like can be melted in sintered magnesia crucibles.

X1.2.1.8 When purest magnesia is sintered in an oven below atmospheric pressure at 1950°C (3542°F), the electrical resistivity can be $>1 \times 10^{14}$ ohm-cm ($>4 \times 10^{13}$ ohm-in.) at room temperature and 5×10^{7} ohm-cm (2×10^{7} ohm-in.) at 1000°C (1832°F).

X1.2.2 *Typical Crystal Properties :*

X1.2.2.1 *Coefficient of Thermal Expansion* 1.6×10^{-5}/K (9×10^{-6}/°F) between 0 and 815°C (32 and 1500°F).

X1.2.2.2 *Crystal Shape*—Cubic (Periclase).

X1.2.2.3 *Maximum Theoretical Density*—3.58×10^{3} kg/m^{3} (0.13 lbm/in.^{3}).

X1.2.2.4 *Dielectric Strength*—5000 kV/m (127 000 V/in.).

X1.2.2.5 *Hardness (MOHS)*—5 to 6.

X1.2.2.6 *Softening Temperature*—1250 ± 50°C (2282 ± 90°F).

X1.2.2.7 *Melting Temperature*—2800°C (5072°F).

X1.2.2.8 *Molecular Weight*—40.32.

X1.2.2.9 *Typical Electrical Resistivity*—Theoretical, 100 % density. See Table X1.3.

X1.2.2.10 *Specific Heat*—1×10^{3} J/(kg·K) (0.24 Btu/lbm°F) @ 0 % Porosity.

X1.2.2.11 *Typical Thermal Conductivity* —See Table X1.4.

X1.2.2.12 *Macroscopic Thermal Neutron Absorption Cross Section*—(3.2 m^{-1} (0.08 in.$^{-1}$)).

X2. RECOMMENDED PRACTICES

X2.1 Crushable insulators and insulating materials should be handled only with clean gloves to prevent contamination. Film type gloves such as plastic, rubber, or other synthetic materials are recommended. If fibrous gloves are used, then the fibers shall not be loose, because they will get caught and be left on the surface of the insulators.

X2.2 Insulators and insulation materials should be fired prior to use to remove moisture and organic contaminants. They should be placed in suitable hard-fired ceramic containers and fired in an oxidizing atmosphere electric oven or furnace at a temperature between 950 and 1000°C (1700 and 1800°F) for at least 1 h.

X2.3 The hole diameter as specified in 8.1 and Table 5 should be evaluated using pin or plug gauges in minimum incremental diameters of 0.025 mm (0.001 in.). The hole diameter is determined as the largest pin gauge that can be freely inserted into each hole of the insulator a minimum depth of ten times the outside diameter of the gauge pin. The measured hole diameter should be within the tolerances listed in Table 5 for the hole diameter specified in 6.1.3 unless otherwise agreed to between the purchaser and manufacturer.

X2.4 Modulus of Rupture specifications should be composed on the basis of process experience on a part by part basis. As discussed in 7.2, it is not feasible to construct a universal table of acceptable Modulus of Rupture (MOR) ranges as a function of diameter or intended use. The MOR property has a diameter bias whereby smaller diameter parts analyzed by this procedure demonstrate higher values than larger diameter parts of the same intrinsic mechanical integrity. Nonetheless, it often remains useful to specify desired MOR values that are based on historical performance for a given insulator for use in a given process.

X2.4.1 Modulus of rupture tolerances should include an interval of at least ±33 % from the requested nominal value and should apply only to the average of all test results. Even with the best known test platforms and procedures, standard deviations of 5-10 % are typical with skilled measurements and ideal parts. If expressed in range format, the value of the upper limit should be at least double the value of the lower limit.

Example: A specification of 20.7 ± 6.9 MPa (3000 ± 1000 lb/in^2) is an acceptable range to specify for the finished product. In alternate format, this may be expressed as 13.8-26.8 MPa (2000-4000 lb/in^2). The average of the test results from X4.4 should be used to determine compliance regardless of the individual readings.

X3. DENSITY MEASUREMENT

X3.1 A minimum of 0.25 % of a lot but no fewer than 3 pieces shall be tested.

X3.2 Test specimens shall be dry initially and tested in a location where the moisture content of the ambient atmosphere does not exceed the equivalent of 50 % relative humidity at 22°C (72°F).

X3.3 *Displacement Method:*

X3.3.1 Weigh each specimen in air to determine its dry mass in kilograms (pounds mass).

X3.3.2 Attach a suspension wire to each specimen.

X3.3.3 Immerse the specimens in a beaker of water and boil for 2 h, or until bubbles cease emerging from the specimen. Ensure that the specimens remain entirely covered while boiling.

X3.3.4 Allow each beaker with its specimen to cool to room temperature. This may be accelerated by the addition of cold water to the beaker.

X3.3.5 Weigh each of the specimens suspended in its beaker to determine its apparent mass in water in kg (lbm).

X3.3.6 Remove each specimen from its beaker and shake once or twice to remove water trapped within the insulators. Blot the outside surface of each insulator with a damp cloth to remove water adhering to the outside surface. Avoid excessive blotting, which may introduce errors.

X3.3.7 Weigh each of the specimens in air to determine its wet mass in kilograms (pounds mass).

X3.3.8 Calculate the density of each specimen as follows:

$$O = \frac{mO_w}{(A + B - C)} \qquad \text{(X3.1)}$$

where:

O = density, kg/m^3 (lbm/in.^{3}),
m = dry mass of specimen, kg (lbm),
O_w = density of water, 997.5 kg/m^3 (0.036 lbm/in.^{3}),
A = wet mass of specimen, kg (lbm),
B = mass of suspension wire, kg (lbm), and
C = apparent mass of specimen, in water, kg (lbm).

X3.4 *Dry Method:*

X3.4.1 Weigh each specimen to determine its dry mass in kilograms (pounds mass).

X3.4.2 Measure the outside diameter of each specimen in metres (inches) at various points around the diameter and along the length, and average the measurements.

X3.4.3 Measure the length of each specimen in metres (inches).

X3.4.4 Measure the inside diameter of the holes of each specimen in metres (inches) using gauge pins, and average the measurements. The hole diameter shall be considered to be the diameter of the largest pin that can fit inside the hole to a depth of 6.3 mm (0.25 in.).

X3.4.5 Calculate the density of each specimen as follows:

$$O = \frac{4m}{\pi L\left(D^2 - NB^2\right)} \tag{X3.2}$$

where:

O = density, kg/m^3 (lbm/in.^{3}),
m = dry mass of specimen, kg (lbm),
π = 3.1416,
L = length of specimen, m (in.),
D = average outside diameter of specimen, m (in.),
N = number of holes in the specimen, and
B = average inside diameter of the holes of the specimen, m (in.).

X3.5 Record results for each specimen tested.

X4. MODULUS OF RUPTURE TEST

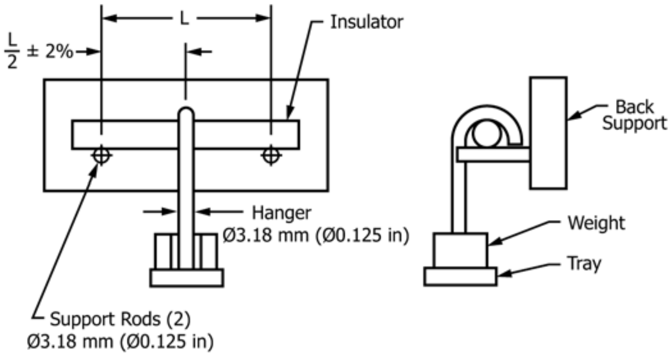
X4.1 *Scope*: This procedure is most suitable for round insulator configurations from 1.5 mm to 15 mm (0.059 in to 0.590 in) diameter. Sizes outside this range may require alternate interpretations of data, such as reportage of the maximum value tested instead of the average value.

Certain configurations may be untestable, or require additional procedures. For example, a thin wall single hole tube may fail due to wall breakage instead of bending failure. In this situation, a value for MOR can not be determined by this method.

X4.2 *Test Fixture*: A test stand or equivalent equipment may be used for application of load. See X4.1 for a schematic representation of a simple gravimetric test stand. Mechanically driven testers should not exceed a strain rate of 5 mm/min (0.2 in/min) during the force loading phase of the test.

X4.3 *Test Procedure*:

X4.3.1 Apply the load midway between the support rods as shown in Fig. X4.1. The orientation of the holes to the direction of force is not important. The insulator does not have to be longitudinally centered on the support rods, which permits the opportunity for multiple results on one insulator. However, at least one diameter length should overhang each end. The support rod spacing shall be as specified in Fig. X4.1.



NOTE 1—L dimension is based on insulator outside diameter.

Nominal Insulator Outside Diameter	L
3.75 mm (0.148 in.) and smaller	19 mm (0.75 in.)
3.75 to 5.30 mm (0.148 to 0.209 in.)	25 mm (1.00 in.)
5.30 to 7.40 mm (0.209 to 0.291 in.)	38 mm (1.50 in.)
7.40 to 10.55 mm (0.291 to 0.415 in.)	50 mm (2.00 in.)
10.55 to 14.80 mm (0.415 to 0.583 in.)	75 mm (3.00 in.)
14.80 to 19.00 mm (0.583 to 0.750 in.)	100 mm (4.00 in.)
19.00 to 23.25 mm (0.750 to 0.915 in.)	125 mm (5.00 in.)
23.25 mm (.915 in.) and larger	150 mm (6.00 in.)

FIG. X4.1 Test Fixture

X4.3.2 Obtain a minimum of 8 measurements from each lot. These results shall come from 3 insulators or 0.25 % of a lot, whichever is greater. If necessary, increase the number of measurements in order to test at least 0.25 % of the lot. It is acceptable to obtain multiple measurements from a single piece if the part is of sufficient length to allow multiple breaks.

X4.3.3 3 For gravimetric test stands, apply an increasing load by adding weights to the tray at a uniform rate until the specimen breaks. Record the mass of the total load that caused the break in kilograms (pounds mass), including the mass of the weights and the tare mass of the hanger and tray. If the last weight increment exceeds 5 % of the total load, then deduct half of the increment from the result. If the last increment exceeds 20 % of the total load, the result should be discarded and the test repeated with smaller weight increments.

If using alternative test equipment such as mechanically driven testers, operate the equipment appropriately and make the necessary data conversions to calculate the modulus of rupture according to the principles of X4.1, as suggested by X4.2.

X4.3.4 Measure the diameter at four points approximately 45° apart near the point of breakage, and calculate the average in millimetres (inches).

X4.3.5 Calculate the modulus of rupture of each specimen as follows:

$$M = \frac{8\,Pg_cL}{\pi D^3} \tag{X4.1}$$

$$M = \frac{8\,FL}{\pi D^3} \tag{X4.2}$$

where:

M = modulus of rupture, MPa (psi),
P = mass of load at rupture, kg (lbm),
g_c = 9.8 N/kg (32.2 lbf/lbm),
F = force at rupture N (lbf)
L = distance between supports, mm (in.),
π = 3.1416, and
D = average outside diameter of specimen, mm (in.).

X4.3.6 The calculated modulus of rupture is considered to be an indirect measure of crushability for that lot of insulators.

X4.4 *Data Evaluation*: Record results for each specimen tested. Compute the average result.

X4.5 Test Report:

X4.5.1 Report the following information:

X4.5.1.1 Identification of the material tested.

X4.5.1.2 The average of the computed modulus of rupture values.

X5. OTHER TESTS FOR MAGNESIUM OXIDE AND ALUMINUM OXIDE

X5.1 *Specific Heat*—Test Method D2766.

X5.2 *Thermal Conductivity*—Test Method E1225.

X5.3 *Thermal Expansion*—Test Method C832 and Test Method E228.

ADDITIONAL MATERIAL

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