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Standard Specification for Magnesium Oxide and Aluminum Oxide Powder and Crushable Insulators Used in the Manufacture of Metal- Sheathed Platinum Resistance Thermometers, Base Metal Thermocouples, and Noble Metal Thermocouples¹

This standard is issued under the fixed designation E 1652; 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 covers the requirements for magnesium oxide (MgO) and aluminum oxide (Al_2O_3) powders and crushable insulators used to manufacture metal-sheathed platinum resistance thermometers (PRTs), noble metal thermocouples, base 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:

B 329 Test Method for Apparent Density of Metal Powders and Related Compounds Using the Scott Volumeter²

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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C 573 Methods for Chemical Analysis of Fireclay and High-Alumina Refractories³

C 574 Method for Chemical Analysis of Magnesite and Dolomite Refractories⁴

C 809 Test Methods for Chemical, Mass Spectrometric, and Spectrochemical Analysis of Nuclear-Grade Aluminum Oxide and Aluminum Oxide-Boron Carbide Composite Pellets⁵

C 832 Test Method for Measuring the Thermal Expansion and Creep of Refractories Under Load⁶

D 2766 Test Method for Specific Heat of Liquids and Solids⁷

D 2858 Test Method for Thermal Conductivity of Electrical Grade Magnesium Oxide⁸

E 228 Test Method for Linear Thermal Expansion of Solid Materials with a Vitreous Silica Dilatometer⁹

E 235 Specification for Thermocouples, Sheathed, Type K, for Nuclear or for Other High-Reliability Applications¹⁰

E 344 Terminology Relating to Thermometry and Hydrometry¹⁰

E 585/E 585M Specification for Compacted Mineral-Insulated, Metal-Sheathed, Base Metal Thermocouple Cable¹⁰

E 1137 Specification for Industrial Platinum Resistance Thermometers¹⁰

E 1225 Test Method for Thermal Conductivity of Solids by Means of the Guarded-Comparative-Longitudinal Heat Flow Technique⁹

E 2181/E 2181M Specification for Compacted Mineral-Insulated, Metal-Sheathed, Noble Metal Thermocouples and Thermocouple Cable¹⁰

3. Terminology

3.1 The definitions given in Terminology E 344 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 E 235, E 585/E 585M, and ~~E-585~~ E 2181/E 2181M) and the connecting wires of a PRT (see Specification E 1137) 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.

5. Ordering Information

5.1 The purchaser shall specify the following when ordering:

5.1.1 *Material*—from 5.1.1.1 through 5.1.1.5 below:

5.1.1.1 Al₂O₃ Type 1 per Table 1.

5.1.1.2 Al₂O₃ Type 2 per Table 1 and Supplementary Requirement S1.

5.1.1.3 MgO Type 1 per Table 1.

5.1.1.4 MgO Type 2 per Table 1 and Supplementary Requirement S1.

5.1.1.5 MgO Type 3 per Supplementary Requirement S2.

5.1.2 *Insulator Outside Diameter*.

5.1.3 *Hole Diameter*.

5.1.4 *Number of Holes*.

5.1.5 *Hole Pattern*.

5.1.6 *Length*.

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

5.1.8 *Minimum Inside Diameter of Tubing*, into which insulators will be inserted.

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

6. Chemical Requirements

6.1 The final product shall be chemically analyzed using appropriate methods listed in 9.1. Major impurities shall not exceed

² *Annual Book of ASTM Standards*, Vol 02.05.

³ Discontinued. See 1993 *Annual Book of ASTM Standards*, Vol 03.05.

⁴ Discontinued. See 1992 ~~1995~~ *Annual Book of ASTM Standards*, Vol 03.06.

⁵ *Annual Book of ASTM Standards*, Vol 12.01.

⁶ *Annual Book of ASTM Standards*, Vol 15.01.

⁷ *Annual Book of ASTM Standards*, Vol 05.021.

⁸ *Annual Book of ASTM Standards*, Vol 10.042.

⁹ *Annual Book of ASTM Standards*, Vol 14.02.

¹⁰ *Annual Book of ASTM Standards*, Vol 14.03.

TABLE 1 Impurity Limits^A

Aluminum Oxide (Al ₂ O ₃) 99.65 % (mass) min		Magnesium Oxide (MgO) 99.40 % (mass) min	
Impurity	Concentration, % (mass)	Impurity	Concentration, % (mass)
Fe ₂ O ₃	0.04 max ^B	CaO	0.35 max ^C
SiO ₂	0.08 max ^D	Al ₂ O ₃	0.15 max ^C
CaO	0.08 max	Fe ₂ O ₃	0.04 max ^{B,C}
MgO	0.08 max	SiO ₂	0.13 max ^{C,D}
ZrO ₂	0.08 max	C	0.02 max
Na ₂ O	0.06 max	S	0.005 max
G	0.04 max	B	0.0025 max
C	<u>0.01 max</u>	B	<u>0.0035 max</u>
S	<u>0.005 max</u>	Cd	<u>0.001 max</u>
Gd	0.001 max	B + Cd	0.003 max
Cd	<u>0.001 max</u>	B + Cd	<u>0.004 max</u>
B	0.001 max		

^A The total compositional analysis should equal 100 %.

^B The presence of Fe₂O₃ can adversely affect the electrical resistivity of these insulators. Moreover, changes in the thermometric properties of platinum and its alloys that are exposed to Fe₂O₃ concentrations above 0.04 % become more pronounced when exposed to the higher service temperatures, for example, above 650 °C (1200 °F), for prolonged periods. However, at lower service temperatures, purchaser may choose to allow Fe₂O₃ concentrations of up to 0.1 % in Al₂O₃ or 0.15 % in MgO. See Supplemental Requirement S1.

^C See Supplemental Requirement S2 for base-metal thermocouple applications.

^D The presence of SiO₂ can, at elevated temperatures, lead to changes in the electrical resistivity, thermoelectric characteristics, and mechanical properties of platinum and its alloys.

the limits indicated in Table 1 unless permitted by supplementary requirements. Any detected impurity with a concentration greater than 0.001 % (mass) shall be reported to the purchaser.

7. Physical Properties

7.1 *Density*—The density of crushable magnesium oxide and aluminum oxide insulators typically ranges from 2060 kg/m³ (0.074 lbf/in.³) to 3060 kg/m³ (0.111 lbf/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*—In the past, a breaking force test has been used that is based on a relative modulus of rupture and is related to crushability. However, with variations in modulus from 21 to 83 MPa (3000 to 12 000 lbf/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.

8. Dimensional Requirements

8.1 Outside diameter and hole diameter tolerances for insulators shall be as specified in Table 2 and Table 3, respectively, unless otherwise agreed to between purchaser and manufacturer.

8.2 Wall and web thicknesses (see Fig. 1) shall be equal within outside diameter tolerance as specified in Table 2 unless otherwise agreed to between purchaser and manufacturer.

8.3 Camber shall not exceed 0.3 % of the length. Insulator shall be capable of passing through a rigid straight tube longer than the insulator and with an inside diameter as specified in 5.1.8.

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

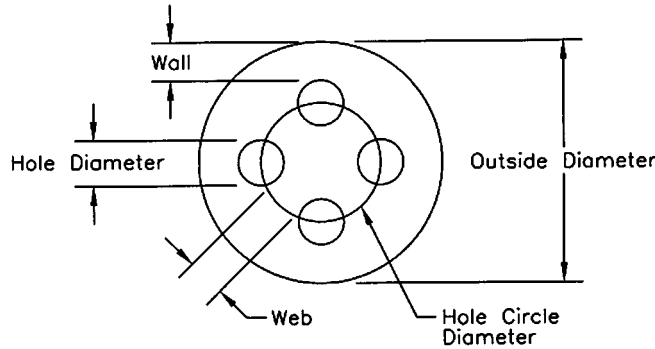
8.5 Length shall be as specified in 5.1.6 with a tolerance of +6/−0.00 mm (+0.25/−0.00 in.).

TABLE 2 Outside Diameter (O.D.) Tolerance

Nominal Insulator O.D.-Range	O.D. Tolerance
0.25 to 1.48 mm (0.010 to 0.058 in.)	±0.051 mm (±0.002 in.)
1.49 to 2.27 mm (0.059 to 0.089 in.)	±0.076 mm (±0.003 in.)
1.49 to 6.33 mm (0.059 to 0.249 in.)	±0.076 mm (±0.003 in.)
2.28 to 3.28 mm (0.090 to 0.129 in.)	±0.076 mm (±0.003 in.)
6.34 to 9.51 mm (0.250 to 0.374 in.)	±0.076 mm (±0.003 in.)
3.29 to 6.33 mm (0.130 to 0.249 in.)	±0.076 mm (±0.003 in.)
9.52 to 12.70 mm (0.375 to 0.500 in.)	±0.076 mm (±0.003 in.)
6.34 to 9.51 mm (0.250 to 0.374 in.)	±0.10 mm (±0.004 in.)
12.71 mm (0.501 in.) and larger	±0.10 mm (±0.004 in.)
9.52 mm (0.375 in.) and larger	±0.15 mm (±0.006 in.)

TABLE 3 Hole Diameter Tolerance

Nominal Insulator Hole Diameter-Range	Hole Diameter Tolerance
0.05 to 0.26 mm (0.002 to 0.010 in.)	±0.038 mm (±0.0015 in.)
0.18 to 0.26 mm (0.007 to 0.010 in.)	±0.038 mm (±0.0015 in.)
0.27 to 1.51 mm (0.011 to 0.059 in.)	±0.051 mm (±0.002 in.)
1.52 to 2.52 mm (0.060 to 0.099 in.)	±0.076 mm (±0.003 in.)
2.53 to 3.79 mm (0.100 to 0.149 in.)	±04 %
3.80 mm (0.150 in.) and larger	±05 %



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

FIG. 1 Wall and Web Thicknesses

8.6 The ends of each insulator should be cut square and not be chipped.

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 (SiO₂), iron oxide (Fe₂O₃), and zirconium oxide (ZrO₂) with gravimetric determination for SiO₂ and Fe₂O₃. The SiO₂ filtrate can be used for further calcium oxide (CaO) determination.

9.1.2 Test Method C 809 can be used for quantitative analysis of elemental impurities.

9.1.3 Methods C 573 can be used for quantitative analysis of Fe₂O₃, SiO₂, CaO, MgO, and sodium monoxide (Na₂O) in Al₂O₃.

9.1.4 Method C 574 can be used for quantitative analysis of CaO, Al₂O₃, Fe₂O₃, and SiO₂ in MgO.

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

9.2 *Density (Powder)*—Test Method B 329 can be used for determining the density of Al₂O₃ 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 a sealed container to prevent contamination by moisture absorption. (See Appendix X2.)

11. Keywords

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

SUPPLEMENTARY REQUIREMENTS

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

S1. Iron Oxide (Fe₂O₃) Concentration

S1.1 Insulators used in service at temperatures 650 °C (1200 °F) and below shall conform to the chemical requirements of 6.1 except that the impurity Fe₂O₃ may have a maximum concentration of 0.10 % for Al₂O₃ or 0.15 % for MgO. These oxide compositions shall be designated Al₂O₃ Type 2 and MgO Type 2, respectively.

S2. Insulators for Base Metal Thermocouples

S2.1 Calcium oxide, aluminum oxide, and silicon oxide are no more likely than is magnesium oxide to react deleteriously with the thermoelement alloys of base metal thermocouples at temperatures that are recommended for the operation of those thermoelement alloys. Therefore, optionally, for base metal thermocouples only, MgO insulators shall conform to the chemical requirements of 6.1 and Table S2.1 instead of Table 1. This oxide composition shall be designated MgO Type 3.

APPENDIXES
(Nonmandatory Information)
X1. MATERIALS AND MANUFACTURE
X1.1 Alumina (Al₂O₃)
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 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 (Al₂O₃·H₂O). Even at 200 °C (392 °F) the rate of dehydration is very slow. Dehydration is found to be essentially complete at 400 °C (752 °F) in an oven at below atmospheric pressure or at 500 °C (932 °F) at atmospheric pressure. In a study, the heating at 538 °C (1000 °F) for 7 h still showed 0.1 moles of H₂O per mole Al₂O₃, 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, when activated in vacuum, is more easily rehydrated. Alumina activated in

TABLE S2.1 Impurity Limits^A

Magnesium Oxide (MgO) 97.00 % (mass) min	
Impurity	Concentration, % (mass)
CaO	0.80 max
Al ₂ O ₃	1.00 max
Fe ₂ O ₃	0.08 max
SiO ₂	1.20 max
Fe	0.02 max
C	0.02 max
S	0.005 max
B	0.0025 max
Cd	0.001 max
B + Cd	0.003 max
MgO + CaO + Al ₂ O ₃ + SiO ₂	99.50 min

^A The total compositional analysis should equal 100 %.

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 $9 \times 10^{-6}/K$ (3.3 to $5 \times 10^{-6}/^{\circ}F$) 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/m³ (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, MgC₂O₄, or the naturally occurring carbonate (magnesite), MgCO₃. Mg(OH)₂ exists as the mineral brucite in small amounts; however the principal commercial source of magnesia is magnesite, which occurs in 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 increase 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 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. 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. (Carbon dioxide is acidic.) The hydration process is completed 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.

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

Temperature		Typical Resistivity	
°C	°F	ohm-cm	ohm-in.
20	68	$>1 \times 10^{14}$	$>4 \times 10^{13}$
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)
100	212	2.9	20
600	1112	0.9	6
1200	2192	0.5	4

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; 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*

$1.6 \times 10^{-5}/K$ ($9 \times 10^{-6}/^{\circ}F$) 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/m³ (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)).

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	3.4	24
600	1112	1.1	7.6
1200	2192	0.6	4.1

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 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 1 h minimum.

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:

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

where:

O = density, kg/m³ (lbm/in.³),

m = dry mass of specimen, kg (lbm),

O_w = density of water, 997.5 kg/m³(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 gage 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:

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

where:

- O = density, kg/m³ (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 *Test Fixture*—A test stand or equivalent equipment may be used for application of load.

X4.2 *Test Procedure:*

X4.2.1 Apply the load midway between the support rods as shown in Fig. X4.1. Note position of the holes for insulators with more than one hole as shown in Fig. X4.2.

X4.2.2 Test a minimum of 0.25 % of a lot but no fewer than 3 pieces.

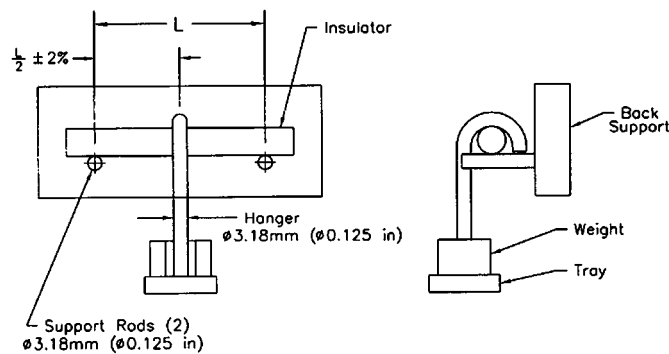
X4.2.3 Test the insulators dry in a location where the moisture content of the ambient atmosphere does not exceed the equivalent of 50 % relative humidity at 22 °C (72 °F).

X4.2.4 Apply an increasing load by adding weights to the tray at a uniform rate until the specimen breaks. Record the mass of the load that caused the break in kilograms (pounds mass). Include the mass of the weights and the tare mass of the hanger and tray.

X4.2.5 Measure the diameter at four points approximately 45° apart near the point of breakage, and calculate the average in millimetres (inches).

X4.2.6 Calculate the modulus of rupture of each specimen as follows:

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



NOTE— L dimension is based on insulator outside diameter.

Nominal Insulator Outside Diameter	L
5.0 mm (0.200 in.) and smaller	49 mm (0.75 in.)
3.69 mm (0.145 in.) and smaller	19 mm (0.75 in.)
5.1 mm (0.201 in.) to 12.5 mm (0.499 in.)	25 mm (1.0 in.)
3.70 to 5.31 mm (0.146 to 0.209 in.)	25 mm (1.0 in.)
5.32 to 7.40 mm (0.210 to 0.291 in.)	38 mm (1.50 in.)
12.6 mm (0.500 in.) and larger	51 mm (2.0 in.)
7.41 to 10.55 mm (0.292 to 0.415 in.)	51 mm (2.0 in.)
10.564 mm (2-)	76 mm (3.0 in.)
10.56 to 14.79 mm (0.416 to 0.582 in.)	76 mm (3.0 in.)
14.80 to 19.06 mm (0.583 to 0.750 in.)	102 mm (4.0 in.)
19.07 to 23.25 mm (0.751 to 0.915 in.)	127 mm (5.0 in.)
23.26 mm (0.916 in.) and larger	152 mm (6.0 in.)

FIG. X4.1 Test Fixture

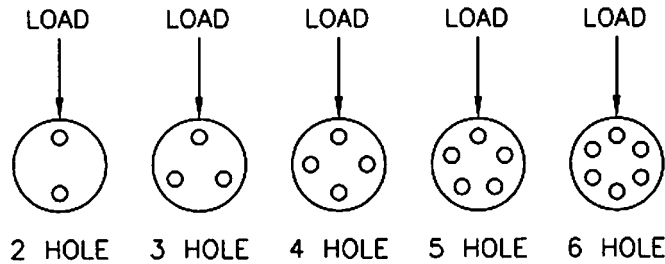


FIG. X4.2 Load Orientation

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),

L = distance between supports, mm (in.),

π = 3.1416, and

D = average outside diameter of specimen, mm (in.).

X4.2.7 The calculated modulus of rupture is considered to be an indirect measure of crushability for that lot of insulators.

X4.3 Record results for each specimen tested.

X5. OTHER TESTS FOR MAGNESIUM OXIDE AND ALUMINUM OXIDE

X5.1 *Specific Heat*—Test Method D 2766.

X5.2 *Thermal Conductivity*—Test Methods D 2858 and E 1225.

X5.3 *Thermal Expansion*—Test Method C 832, and Test Method E 228.

ADDITIONAL MATERIAL

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