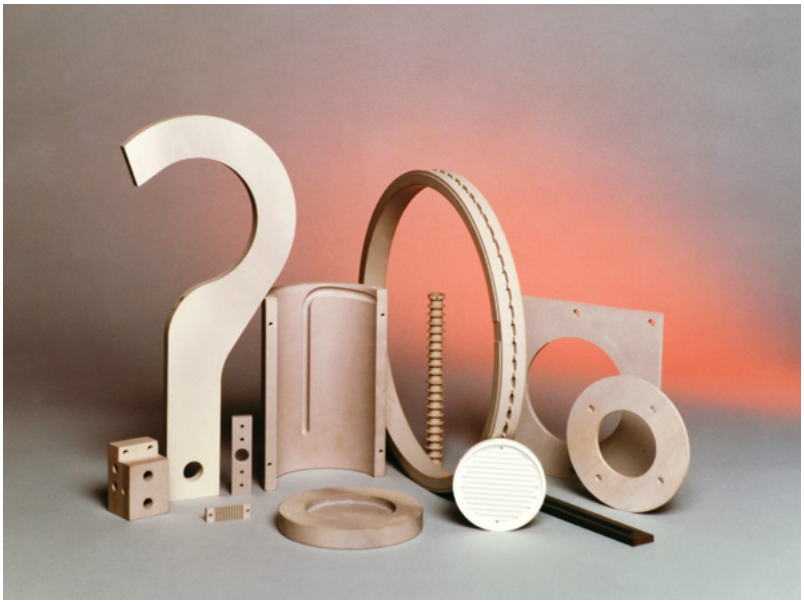
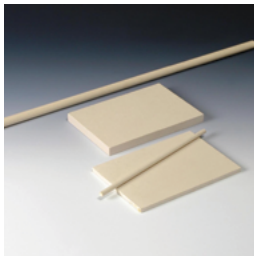
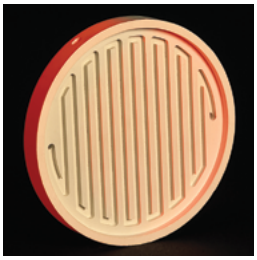
AREMCO

MACHINABLE & DENSE CERAMICS

Technical Bulletin A1







Aremco offers a broad range of machinable and dense ceramics for applications that require high temperature electrical and thermal insulation, and corrosion, impact and wear resistance.

Aremcolox™ and Super-Heat™ ceramics include compositions based on aluminum oxide, alumino-silicate, aluminum nitride, boron nitride, glass-ceramics, magnesium oxide, and zirconium oxide.

Production capabilities include isostatic and dry pressing, low-pressure injection molding, extrusion, slip casting, and CNC machining.

TYPICAL APPLICATIONS

Aerospace
Gas Nozzles, Thermal Insulators, Space Mirrors, and Nose Cones

Automotive
Diesel Port Liners, Manifold Insulation, Catalyst Support Systems, Flow Separator Housings, Regenerator Cores, Turbine Nozzles

Electrical
Connector Housings, Heater And Resistor Supports, Stand-Offs, Instrument and Appliance Insulators, Coil Forms and Bobbins

Electronics
Wafer Chucks, Insulators, Vacuum Tube Structures, Microwave Housings, Arc Barriers, X-Ray Equipment, and PVD Applications

Heat Treating
Brazing/Carburizing Fixtures, Induction Heating Tubes, Furnace and Tooling Insulation, Kiln Furniture, Welding Jigs, Hot Forming Dies

Metallurgical
Molten Metal Crucibles, Nozzles, Troughs, Liners, Transfer Rollers, Structural Parts, Filters, Thermocouple Sheaths, Permanent Molds

Petrochemical
High Temperature Corrosion and Wear-Resistant Components

Plastics
Hot Die Parts for Thermoplastic Forming Equipment

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MACHINABLE GRADES

502-400 Glass-Ceramic
Recommended for high dielectric strength and temperatures to 750 °F (400 °C). Used for high voltage insulators, coil forms, soldering fixtures, and arc barriers. Readily machined and no firing required. Plates are available from ⅛″ to 1″ thick; rods from ¼″ to 1″ diameter.

502-600 Glass-Ceramic
Recommended for high dielectric and mechanical strength requirements and temperatures to 1100 °F (593 °C). Used for high voltage insulators, lamp housings, thermal switches, and radiation parts. Readily machined and no firing required. Plates are available from ⅛″ to 1″ thick; rods from ¼″ to 1″ diameter.

502-800 Macor Glass-Ceramic
Recommended for temperatures to 1472 °F (800 °C) and peaks up to 1832 °F (1000 °C). Demonstrates low thermal conductivity, high strength, high electrical insulation, zero porosity, non-wetting, and coefficient of thermal expansion similar to most metals and sealing glasses. Machines to tight tolerances up to 0.0005″, surface finish of less than 20µin, and polishes to a smoothness of 0.5µin. Used for ultra high vacuum, aerospace, nuclear, welding, fixturing, and medical applications. Readily machined and no firing required. Bars, disks, rods and plates are available from 1⁄16″ thick up to 12″ diameter.

502-1100-UF Alumino-Silicate (Unfired)
Machined easily to close tolerances and can be used as-is or fired to increase temperature resistance and improve mechanical strength. Used for prototyping and small production runs of electrical and thermal insulators and brazing and heat-treating fixtures. Standard plates from ¼″ to 1″ thick × 12″ × 12″; rods from ¼″ to 4″ diameter × 12″; bars from 1″ × 1″ to 4″ × 4″ × 12″.

502-1400-BF Aluminum Oxide (Bisque-Fired)
Bisque-Fired ceramic is machined easily to close tolerances and can be used as-is or fired to increase mechanical and thermal properties. Plates are available from ¼″ to ¾″ thick × 6″ × 6″; rods from ¼″ to 3″ diameter × 12″ long. This ceramic offers excellent corrosion, abrasion, and electrical and thermal shock resistance. Used for producing guides, fixtures, nozzles, pump liners, shafts, valve seats, and more.

502-1600-94 & 502-1600-99 Boron Nitride
Hot-pressed 94% and 99% boron nitride provides high thermal conductivity, electrical insulation, and low coefficient of thermal expansion. Grades are non-reactive with molten salts, aluminum and other metals. Easily machined and available in plates from ¼″ to 1″ thick by 5″ × 5″, rods from ¼″ to 3″ diameter by 12″ long, and bars from ¼″ × ¼″ to 2″ × 2″ by 12″ long.

502-1800 Boron Nitride Aluminum Nitride
Hot-pressed boron nitride – aluminum nitride composite that demonstrates high thermal conductivity, dielectric strength, and abrasion resistance. Readily machined and available in rods from ¼″ to 1″ diameter × 12″ long and plates from ¼″ to 1″ thick by 5″ × 5″.

FULL-FIRED DENSE GRADES

502-676 Magnesium Oxide
This is a high density, fine grain, high purity (99.38%) magnesium oxide fabricated into thin-walled crucibles from 1″ to 6″ diameter and 1″ to 10″ high for applications to 4000 °F (2200 °C). Used for processing beta-alumina, metal alloys, piezoelectrics, and superconductors.

502-1100-FF Alumino-Silicate (Full-Fired)
Offers higher temperature resistance and improved mechanical strength over 502-1100-UF. Used for prototyping and small production runs of electrical and thermal insulators and brazing and heat-treating fixtures. Recommended for producing insulators, standoffs, feed-thrus, furnace carriers, and brazing fixtures.

502-1400-FF Aluminum Oxide (Full-Fired)
Full-fired, dense aluminum oxide offers excellent corrosion, abrasion, and electrical and thermal shock resistance. Used for producing guides, fixtures, nozzles, pump liners, shafts, valve seats, and more.

502-1900-ZTA Zirconia Toughened Alumina
This grade is made up of > 80% alumina and the balance yttria stabilized zirconia (Y-TZP). Provides some of the advantages of pure Y-TZP at a reduced price. The addition of zirconia increases greatly the fracture toughness, mechanical strength and impact resistance of the alumina. Used for pump components, bushings, bearings, and cutting tool inserts.

502-1900-MTTZ Magnesia Partially Stabilized Zirconia
This grade offers the highest level of fracture toughness of all the zirconia materials. Features include excellent fracture, corrosion, thermal shock, and wear resistance. Used for pump parts, valve components, bearings, and wear linings.

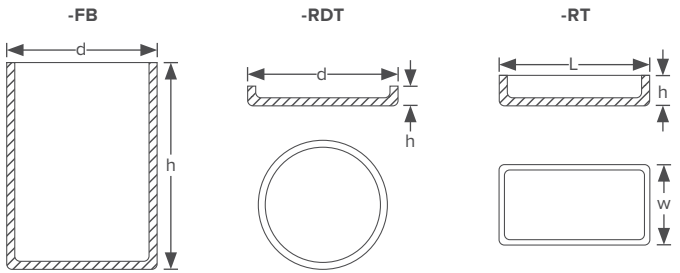
502-1900-YTZP Yttria Stabilized Zirconia
This grade offers the highest flexural strength of all the zirconia materials. The fine grain size lends itself to be used in cutting tools where a very sharp edge can be achieved and maintained due to its high wear resistance. Also provides excellent mechanical strength, corrosion and thermal shock resistance, impact toughness, and very low thermal conductivity. Used for structural components, wear parts, fiber optic ferrules and sleeves, oxygen sensors, and solid oxide fuel cells.

AREMCOLOX™ 502 SERIES CERAMICS—PRODUCT SPECIFICATIONS

Product Number	502-400	502-600	502-800	502-676	502-1100 Unfired (UF)	502-1100 Full-Fired (FF)	502-1400 Bisque-Fired (BF)	502-1400 Full-Fired (FF)	502-1600[1] 94%	502-1600[1] 99%	502-1800	502-1900-ZTA	502-1900-MTTZ	502-1900-YTZP
Composition	Glass Ceramic		Macor Glass Ceramic	Magnesium Oxide[1]	Alumino-Silicate		Aluminum Oxide[1,2]		Boron Nitride[3]		ALN-BN Composite	Zirconia-Toughened Al_2O_3 (Y-TZP)	MgO Partially Stabilized (3.5%) Zirconia	Yttria Stabilized (12%) Zirconia
Max Operating Temperature, °F (°C)	750 (400)	1100 (593)	1472 (800)	3270 (1800)	1000 (537)	2100 (1150)	2600 (1427)	3000 (1649)	2100 (1150)	5430 (3000)	2200 (1200) Vac 1200 (700) Air	2190 (1200)	2190 (1200)	3270 (1800)
Density, g/cc	3.0	2.8	2.52	3.45	2.4	2.3	3.0	3.9	1.9	1.7	2.43	4.3	5.85	5.85
Porosity, %	0	0	0	4.5	2.6	2.3	25	0	11	22	9	0	0	0
Thermal Conductivity, BTU-in/hr-ft^2-°F (W/m-K)	6 (.9)	9.1 (1.3)	10.16 (1.46)	15 (2.2)	11 (1.6)	9 (1.3)	30 (4.3)	220 (31.7)	382 (55)	153 (22)	278 (40)	186 (27)	15 (2.2)	15 (2.2)
Thermal Expansion, in/in/°F x 10^{-6} (°C)	6.0 (10.8)	5.8 (10.5)	7.0 (12.6)	7.7 (13.9)	2.5 (4.5)	2.9 (5.2)	3.5 (6.3)	3.5 (6.3)	2.2 (4.0)	0.2 (0.3)	3.1 (5.6)	4.6 (8.3)	5.6 (10.1)	5.8 (10.5)
Compressive Strength, psi	45,000	32,000	50,000	120,000	12,000	25,000	9,000	340,000	10,000	4,800	—	421,000	254,000	363,000
Flexural Strength, psi	13,000	11,000	13,600	35,000	4,500	10,000	4,000	46,000	7,500	2,800	18,200	65,000	60,000	30,000
Hardness, Moh's Scale	5.5	5	—	5.5	1–2	6	1–2	9	—	—	—	10	8	8
Dielectric Strength, volts/mil (AC)	730	420	785	150	80	100	80	225	1,340	865	1,090	228	240	228
Dielectric Loss at 1 MHz	0.009	0.012	~0.005	—	0.06	0.053	0.003	0.0018	< 0.0002	< 0.0002	—	0.0005	0.001	0.001
Dielectric Constant at 1 MHz	6.7	6.8	~6.0	9.6	5.8	5.3	5.5	9.3	4.1	3.8	6.4	10.6	28	29

Reference Notes

[1] Super-Heat™ 502-676 and Aremcolox™ 502-1400-FF slip cast crucibles are available in stock shapes up to 6″ diameter and 10″ high. Wall thickness is 0.2″ maximum, typically 0.09″ to 0.15″. Tolerances on outside dimensions are ± 0.125″ or ± 5%, whichever is less.



FLAT BOTTOM | **CRUCIBLE COVER (OR ROUND TRAY)** | **RECTANGULAR TRAY**

Flanged lids are available for all stock shapes.
Super-Heat™ crucibles are not resistant to thermal shock. Creep occurs above 2200 °F (1200 °C), so crucibles should be supported using MgO sand to prevent sagging. The maximum recommended ramp rate is 200 °C per hour.

[2] 502-1400-FF Alumina Fasteners

Size	Destructive Torque (in-lbs)	Tensile Strength (psi)
4–40	2.4	4,400
6–32	3.3	5,000
8–32	7.4	7,000
10–32	11.7	8,000
¼–20	14.6	Not Available

The destructive torque is the force at which the bolt head shears off upon tightening.

[3] Boron Nitride operates to a maximum of 850 °C in an oxidizing atmosphere and as high as 3000 °C in a reducing atmosphere. BN 94% contains a calcium borate binder which has a melting point near 1150 °C, the maximum use temperature in a vacuum/inert atmosphere. BN 99% binderless diffusion-bonded product is stable to 1600 °C in a 10^{-3} vacuum. BN 99% may be stable up to 3000 °C as long as it is in the presence of an inert gas whose vapor pressure exceeds the vapor pressure of BN at that temperature. BN 99% is stable in dry hydrogen only.

Boron Nitride Vapor Pressure

Temp. (°C)	Vacuum (Torr)
200	3.1×10^{-25}
500	3.1×10^{-17}
800	6.8×10^{-12}
1200	9.9×10^{-7}
1600	8.1×10^{-3}
2000	11.5

Send engineering drawings to Aremco for quotation on fabricated parts.

MACHINING GUIDELINES FOR MACHINABLE CERAMICS

Fixturing
Hold parts carefully to prevent chipping or cracking. Place soft paper sheet in between ceramic and gripping jaws as needed. Support plates for drilling or milling operations using a soft backup block and mounting adhesive such as Aremco's Crystalbond 509™ or 590 (refer to Technical Bulletin A9). Support cylinders using an internal metal sleeve. Do not use pointed screws to hold parts.

Lubricant
Dry machining is recommended for 502-1100, 502-1400, 502-1600 and 502-1800 because these ceramics have high open porosity and absorb water readily. A low concentrate water-soluble lubricant is recommended for 502-400, 502-600 and 502-800.

Cleaning
When coolant is used, bake out parts at 200–250 °F for 1–2 hours to remove residual moisture. Remove any discoloration caused by the lubricant by clean firing up to 1000 °F.

Cutting
Use sharp cutting tools only as ceramics are abrasive by nature. Dull cutters may cause localized heating and lead to chipping. Carbide tools (Titanium coated or Tungsten) and/or bonded diamond wheels are preferred but high-speed tools can be used for short runs. Cut down into the work, never up from the bottom. Keep speed from 2000–2500 rpm and advance the cut by feel. The wheel should cut steadily without dragging.

Drilling
Solid carbide drills, preferably with micro-grain carbide, will give best results. Do not drill thru in order to avoid chipping. For best results, work from one side, then rotate piece and work from the other side. Otherwise, allow for 1⁄16″ of extra material on drill break-thru side to allow for grinding cleanup. For large quantities, accurate two-sided hardened bushed drill jigs will provide accurate results. The drill should be advanced slowly by 1⁄4″ per turn.

Drill Size	Spindle Speed*	Feed Rate
1⁄4″	300–2000 rpm	.003–.005
1⁄2″	250–1200 rpm	.004–.007
3⁄4″	200–700 rpm	.005–.010
1″	100–300 rpm	.006–.012

*The higher end of the speed range is recommended for most products except 502-800 Macor.

Grinding
Use silicon carbide resin-bonded wheels for surface grinding at speeds recommended by the equipment manufacturer. Use a soft, coarse-grained wheel for heavy grinding. Use 1% soluble oil solution to extend life of grinding wheels. Use a 35-grit Blanchard-Besley type grinder for rough heavy grind; use a 60–80-grit wheel for surface grinders.

Milling
Micro-grain Carbide end mills are recommended.

Drill Size	Spindle Speed
1⁄4″	< 1000 rpm
1⁄2″	< 800 rpm
3⁄4″	< 600 rpm
1″	< 400 rpm

Depth of Cut .050–.070″ per cut
Feed Rate 3″ per minute

Slotting
Slotting may be accomplished using a metal-bonded diamond or silicon carbide wheel on a surface grinder for slots up to 0.050″. Alternatively, a carbide end-mill can be used making small cuts up to 0.025″ with plenty of lubricant.

Tapping
Use tungsten carbide tool bits and keep tools sharp. For internal threads, make clearance holes slightly larger than standard tap drill recommendations. Chamfer both sides of hole prior to threading to minimize chipping. Run the tap in one direction only as turning the tap back and forth can cause chipping. Continuously flush with water or coolant to clear chips and dust from the tap.

502-1100-UF Unfired—Machining & Firing Notes
Typical tolerances after firing are ± 1% or ± 0.005″ whichever is greater. Tighter tolerances can be achieved by wet grinding after firing. Machine all dimensions 1–2% undersize to allow for expansion during firing. All dimensions including centered and off-centered internal holes will increase by this percentage after firing. Maximum recommended cross-sectional thickness is 3⁄8″. Hollow cut or drill holes thru the unfired ceramic to maintain a 3⁄8″ maximum cross-section. When it is necessary to exceed 3⁄8″, do not exceed 5⁄8″ and the rate of firing should be slowed.

Bake at 200 °F for two hours to remove moisture and increase temperature at a rate of 200 °F per hour maximum (slower for thicker sections) to 1100 °F. Soak at 1100 °F for six hours. Increase temperature at a rate of 200 °F per hour to 2050 °F and soak for 30 minutes for each 1⁄4″ of cross-section (eg. soak a 1⁄2″ thick part for one hour). Turn off furnace and allow cooling to below 150 °F before removing parts.

502-1400-BF Bisque-Fired—Firing Notes
This product has been bisque-fired to 2475 °F, but additional firing to 3075–3125 °F can be performed to achieve high density, hardness and mechanical strength. Allow for 15–18% shrinkage using the following firing schedule. Raise temperature 500 °F per hour to 2000 °F and 200 °F per hour to 3125 °F. Soak for 12 hours then cool in furnace to room temperature before removing.