GUIDE TO MATERIALS

TOP SEIKO CO., LTD.

Metals with high melting point

Tungsten
(W) Atomic number: 74

Properties

Melting point (°C)	3387	(the highest from all metals)
Thermal conductivity (W/(m・K))	172	
Thermal expansion coefficient ($\times 10^{-6}$)	4.5	(the lowest from all metals)
Specific gravity	19.3	(equal to gold)
Hardness (Hv) (GPa)	4.2	
Young's modulus (GP	345	

◇Heat-resistant, high heat conductivity, high specific gravity

Application
- Filaments for illumination, crucible;
- Vacuum furnace for heaters as well as construction materials;
- All kinds of electrodes for discharge lamps, electrical contacts;
- Heat screen material, TIG welding electrodes;
- Source components for semiconductor ions;
- Sputtering targets;
- Balance weight

Carbide: extremely hard (WC)

Molybdenum
(Mo) Atomic number: 42

Properties

Melting point (°C)	2623
Thermal conductivity (W/(m・K))	142
Thermal expansion coefficient ($\times 10^{-6}$)	5.3
Specific gravity	10.2
Hardness (Hv) (GPa)	2.6
Young's modulus (GP	276

◇Heat-resistant, high heat conductivity

Application
- Illumination parts, light bulb filament support wire;
- Heaters used in hot water kilns as well as shields;
- Crucible, sinter board;
- Parts for power devices;
- Magnetron parts used in microwave ovens;
- Sputtering targets material

Tantalum
(Ta) Atomic number: 73

Properties

Melting point (°C)	2990
Thermal conductivity (W/(m・K))	57.5
Thermal expansion coefficient ($\times 10^{-6}$)	6.3
Specific gravity	16.7
Hardness (Hv) (GPa)	0.7
Young's modulus (GP	185

◇Heat-resistant

Application
- Parts for heat exchanger;
- High temperature reactor components;
- Source components for semiconductor ions

Powder: condenser, target materials;
Oxide: optical lenses' additive;
Carbide: cemented carbide tool

Niobium
(Nb) Atomic number: 41

Properties

Melting point (°C)	2415
Thermal conductivity (W/(m・K))	54
Thermal expansion coefficient ($\times 10^{-6}$)	7.0
Specific gravity	8.6
Hardness (Hv) (GPa)	0.8
Young's modulus (GP	107

◇Heat-resistant

Application
- Iron and steel additive

Carbide: cemented carbide tool;
Intermetallic compound: superconducting magnet;
Compound metal: sputtering target material

Universal metal

Silver
(Ag) Atomic number: 47

Properties

Melting point (°C)	960
Thermal conductivity (W/(m・K))	420
Thermal expansion coefficient ($\times 10^{-6}$)	19.0
Specific gravity	10.5
Hardness (Hv) (GPa)	0.9
Young's modulus (GP	73

◇High heat conductivity, high electric conductivity

Application
- Electric lines (low electric resistance);
- Audio cables;
- Wiring handling high frequency;
- Tableware, jewels, dentist treatment;
- Water purifiers (sterilization);

Can be used as a compound metal

Copper
(Cu) Atomic number: 29

Properties

Melting point (°C)	1084
Thermal conductivity (W/(m・K))	398
Thermal expansion coefficient ($\times 10^{-6}$)	16.6
Specific gravity	8.9
Hardness (Hv) (GPa)	0.8
Young's modulus (GP	130

◇High heat conductivity, high electric conductivity

Application
- Wiring materials for electric appliances;
- Electric lines (electric resistance is low and it is cheaper than silver);
- Coins, building materials;

Can be used as a compound metal brass products etc.

Aluminum
(Al) Atomic number: 13

Properties

Melting point (°C)	660
Thermal conductivity (W/(m・K))	237
Thermal expansion coefficient ($\times 10^{-6}$)	23.2
Specific gravity	2.7
Hardness (Hv) (GPa)	0.5
Young's modulus (GP	71

◇Light weight

Application
- Coins, beverage cans, pots and pans;
- Building materials, car parts;
- Petrol engines;
- Universal machine parts

Can be used as a compound metal duralumin etc.

Stainless steel
(SUS) steel alloy

Properties

Melting point (°C)	1450
Thermal conductivity (W/(m・K))	16.3
Thermal expansion coefficient ($\times 10^{-6}$)	18.0
Specific gravity	7.9
Hardness (Hv) (GPa)	2.0
Young's modulus (GP	200

◇Corrosion-resistant

Application
- *Austenite type:*
  kitchen equipment, tableware, utensils used in chemical medicine, universal machine parts;
- *Martensite type:*
  kitchen knives, high-durability quenching machine parts;
- *Ferrite type:*
  pots using electromagnetic cooker, etc.

Ceramics 1

Alumina
(Aluminum oxide) Al_2O_3

Properties

Melting point (°C)	2054
Thermal Shock Resistance (°C)	200
Thermal conductivity (W/(m・K))	30
Thermal expansion coefficient ($\times 10^{-6}$)	5.3
Specific gravity	3.9
Hardness (Hv) (GPa)	18

◇High intensity, abrasion-resistant, heat-resistant, corrosion-resistant

Application
- Insulators, parts insulating electricity;
- Furnace walls, furnace parts, jigs;
- Nozzles, spinning tube;
- Reaction crucible, reaction vessels;
- Semiconductor-related parts;
- Liquid crystal production parts;
- Electron tube parts, pumps, grinding materials

Aluminum nitride
AlN

Properties

Melting point (°C)	2200
Thermal Shock Resistance (°C)	400
Thermal conductivity (W/(m・K))	160
Thermal expansion coefficient ($\times 10^{-6}$)	2.4
Specific gravity	3.3
Hardness (Hv) (GPa)	13

◇High heat conductivity

Application
- Crucible;
- Components for heat sink, heat- resistant sheets;
- Semiconductor devices' parts:
  heaters, ESC,
  dummy wafers,
  susceptor rings,
  shower plates,
  chambers,
  RF-windows

Silicon nitride
Si_3N_4

Properties

Melting point (°C)	1600
Thermal Shock Resistance (°C)	650
Thermal conductivity (W/(m・K))	13
Thermal expansion coefficient ($\times 10^{-6}$)	1.5
Specific gravity	3.2
Hardness (Hv) (GPa)	16

◇High intensity, abrasion resistive, thermal shock-resistant

Application
- Parts for engines;
- Gas turbine parts;
- Bearing, guide rolls;
- Cutting tools, pulverizer parts;
- Gas burner parts;
- Mixing blades

Silicon carbide
SiC

Properties

Melting point (°C)	2730
Thermal Shock Resistance (°C)	450
Thermal conductivity (W/(m・K))	150
Thermal expansion coefficient ($\times 10^{-6}$)	2.9
Specific gravity	3.1
Hardness (Hv) (GPa)	24

◇High solidity, high rigidity, high heat conductivity

Application
- Parts using hot water;
- Slide parts:
  bearing,
  mechanical seals

DPF components (filters collecting dust)

Ceramics 2

Zirconia
(Zirconium dioxide) ZrO_2

Properties

Melting point (°C)	2715
Thermal Shock Resistance (°C)	280
Thermal conductivity (W/(m・K))	3
Thermal expansion coefficient (×10⁻⁶)	7.7
Specific gravity	6.0
Hardness (Hv) (GPa)	13

◇High tenacity, high intensity, abrasion-resistant

Application
- Industrial purposes cutlery;
- Scissors, kitchen knife;
- Gauges:
  pin gauge, block gauge,
  wrecking ball;
- Various wear resistant parts

Boron nitride
BN

Properties

Melting point (°C)	2700
Thermal Shock Resistance (°C)	1500
Thermal conductivity (W/(m・K))	63
Thermal expansion coefficient (×10⁻⁶)	1.4
Specific gravity	1.8
Hardness (Hv) (GPa)	0.8

◇High temperature insulation resistance, thermal shock-resistant

Application
- High temperature atmospheric furnace insulator;
- Various semiconductors;
- Compound semiconductor crucible;
- Electrical part assembly jigs;
- Heat sinks

Powder: high temperature lubrication additive, release agent cosmetic products

Semi-metal

Silicon
(Si) Atomic number : 14

Properties

Melting point (°C)	1400
Thermal Shock Resistance (°C)	-
Thermal conductivity (W/(m・K))	148
Thermal expansion coefficient (×10⁻⁶)	4.2
Specific gravity	2.3
Hardness (Mohs)	6.5

Application
- Semi-conductor parts;
- Semi-conductor manufacturing equipment parts;
- Solar battery

Glass

Quartz glass

Properties

Melting point (°C)	1700
Thermal Shock Resistance (°C)	1000
Thermal conductivity (W/(m・K))	1.4
Thermal expansion coefficient (×10⁻⁶)	0.5
Specific gravity	2.2
Hardness (Hv) (GPa)	9

◇Thermal shock-resistant, low expansion

Application
- Optics:
  optical lens and prisms,
  various lasers lenses;
- Chemistry:
  solvent distilling container,
  chemical experiment equipment;
- Semi conductor industrial uses:
  CVD, all kinds of furnace tube for diffusion purposes,
  photomasks and etc.

Metal Material Properties Table 1

※Published data is for reference only

Data			Unit	Tungsten	Molybdenum	Tantalum	Niobium	Titan	Alloy (W-Cu)	Alloy (Mo-Cu)	Heavy alloy Heavy metal (W-)	Sealing alloy (Kovar)	Sealing alloy (Kovar)
			Material	Metals with high melting point					Alloys				
Material symbol				W	Mo	Ta	Nb	Ti	W-Cu	Mo-Cu	W:90%	FeNiCo (sintered)	FeNiCo (HIP)
Component amount [%]				99.9%～99.99%	99.9%～99.99%	99.9%	99.99%	99.8%～99.98%	W:89% Cu:11%	Mo:65% Cu:35%	W:90%	Ni:29% Co:17% Fe:53.5% Mn:0.3% Si: 0.2%	Ni:29% Co:17% Fe:53.5% Mn:0.3% Si: 0.2%
	Density		[g/cm^3]	19.3	10.2	16.6	8.47	4.54	17.00	9.70	17.0	8.0	8.35
Machining properties	Hardness	Vickers hardness Hv1	[GPa]	4.20	2.60	0.69～1.20	0.50～0.80	1.30(1 type-HB) 1.60(2 type-HB) 2.00(3 type-HB) 2.30(4 type-HB)	3.00	1.70 ※rolled sheet	< 3.20(Hv_{30}) 26(HRC)	1.60	1.50
	Tensile strength	20℃	[MPa]			207	124	270～410(1 type-RT)	> 480	> 280	590	540	540
		600℃	[MPa]			200(100℃)	340～510(2 type-RT)				690 (Compressive		
		800℃	[MPa]			175(200℃)	480～620(3 type-RT)				2.0 impact value		
		1000℃	[MPa]			160(250℃)	550～750(4 type-RT)						
	Yield strength		[MPa]			138	85	>165(1 type-RT) >215(2 type-RT) >345(3 type-RT) >485(4 type-RT)			510	270	270
	Dilation		[%]			20	25	>27(1type-RT) >15(2 type-RT) >18(3 type-RT) >485(4 type-RT)			0.4	35	35
	Flexural rigidity		[GPa]	1900							1.4		
	Young's modulus		[GPa]	403	327	185	103	106	330	220	280	159	159
	Poisson's ratio		-		0.32	0.35	0.38	0.34					
Thermal properties	Max. use temp.	Depending on atmosphere	[℃]	3000	1900	700 and more							
	Recrystallization temperature		[℃]	1150～1350	900～1200	900～1400							
	Melting point		[℃]	3387	2623	3017	2468	1668				1450	1450
	Boiling point		[℃]	5527	4827								
	Linear expansion coefficient	RT	[*10^{-6}/℃]		5.10								
		RT～100℃	[*10^{-6}/℃]	4.5	5.2		7.1	8.4	6.1	8.6	6.0	5.2(200℃) 5.1(300℃)	5.2(200℃) 5.1(300℃)
		RT～500℃	[*10^{-6}/℃]	4.6	5.7	3.6			6.4(300℃)	9.2(300℃)	6.2(300℃)	4.9(400℃) 5.3(450℃)	4.9(400℃) 5.3(450℃)
		RT～1000℃	[*10^{-6}/℃]	4.6	5.75				6.7(450℃)	9.6(450℃)	6.2(450℃)	6.2(500℃)	6.2(500℃)
		RT～1500℃	[*10^{-6}/℃]	5.4(2000℃) 6.6(3000℃)	6.51						6.0		
	Thermal conductivity	20℃	[W/(m・K)]	168	142			17	180	210	90	17	17
		100℃	[W/(m・K)]	159	138	56	52		176	205			
		500℃	[W/(m・K)]	122	122								
		1000℃	[W/(m・K)]	111	105								
		1500℃	[W/(m・K)]	92.98(2000℃)	84								
	Specific heat		[J/(kg・K)]	140(20℃) 140(500℃)	260(20℃) 280(500℃)	78	272	520	160	320		460	460
Electrical characteristics	Electric conductivity		[%I.A.C.S]						> 25	> 47	15		
	Volume resistivity	20℃	[μΩ・cm]	5.5(20℃) 18.0(500℃)	5.7(20℃) 17.6(500℃)	14.7	14.5	47.0	5.3	3.5	12.0	49	49
Magnetic characteristics	Permeability		[Km]								< 1.05		
	Susceptibility		[Xm]								0.00022		
Chemical reactivity	Liquid	hydrochloric acid	Loss	Slightly melts in 100℃ diluted or concentrated hydrochloric acid	Slowly melts in heated diluted hydrochloric acid								
		hydrochloric acid	Loss	no reaction									
		sulfuric acid	Loss	Slightly melts in heated diluted sulfuric acid Melts in concentrated sulfuric acid	Promptly melts in around 200℃concentrated sulfuric acid								
		sulfuric acid	Loss	No reaction in diluted sulfuric acid Melts slightly in concentrated sulfuric acid	Slightly melts in diluted sulfuric acid Slowly melts in 110℃ concentrated sulfuric acid								
		nitric acid	Loss	Slightly melts	Easily melts								
		caustic soda (sodium hydroxide)	Loss		Almost not affected in solution Rapid reaction for molten salt								
		caustic soda (sodium hydroxide)	Loss	Slightly melts in solution Rapid reaction for molten salt	Almost not affected in solution Rapid reaction for molten salt								
	Gas	air or oxygen	Loss	Slightly oxidizes (discoloration) In around 400℃ starts to oxidize	Starts to oxidize in room temperature								
		air or oxygen	Loss	In above 700℃ tungsten trioxide forms and suddenly oxidizes	In above 500℃ molybdenum trioxide forms and suddenly oxidizes								
		vapor	Loss	Promptly oxidizes in red heat state	Starts to oxidize in around 700℃								
		nitrogen	Loss	In about 2300℃ and above forms a nitride	In 600℃ and above embrittles In 1500℃ and above forms a nitride								
		carbon monoxide	Loss	In around 850℃ and above embrittles In about 1000℃ forms a	From about 1000℃ forms a carbide								
		carbon dioxide	Loss	From about 1200℃ forms an oxide	From about 1200℃ forms an oxide								
		hydrogen	Loss	no reaction	no reaction								
		hydrofluoric acid	Loss	Forms a fluoride in room temperature	Slightly melts in room temperature								
		chlorine	Loss	From 250℃ to 300℃ forms a chloride	In 250℃ forms a chloride								
		bromine	Loss	Forms a bromide in red heat state									
		iodine	Loss	Forms an iodide in red heat state	Even in red heat state does not react with iodine								
		ammonia	Loss	Does not react in room temperature	Slightly reacts in room temperature								
		hydrogen sulfide	Loss	Surface reaction occurs while in red heat state	In about 1200℃ forms a sulfide								
	Solid body	sulfur	Loss	Slightly reacts in room temperature	In 600℃ and above forms a sulfide								
		carbon, graphite	Loss	From around 800℃ starts to absorb and embrittles From 1400℃ forms tungsten carbide	In 900℃ starts to embrittle From 1300℃ forms molybdenum trioxide								
Features & applications				High thermal conductivity	High melting point High intensity Electric conductivity Thermal conductivity				Thermal expansion coefficient is variable	Easy to roll or presswork		For sealing hard glass Electronic components	For sealing hard glass Electronic components
Remarks													

Metal Material Properties Table 2

※Published data is for reference only

Data			Unit	Niobium	Copper	Aluminum	Iron	Stainless steel	Gold
			Material	Universal metals					
Material symbol				Ni	Cu	Al	S45C	SUS304	Ag
Component amount [%]				99.0%～99.95%	99.9%～99.99%	99.0%～99.999%			99.99%～99.999%
	Density		[g/cm^3]	8.90	8.90	2.70	7.83	7.90	10.50
Machining properties	Hardness	Vickers hardness Hv1	[GPa]	0.90	0.80	0.50	2.45	2.00	0.88
	Tensile strength	20℃	[MPa]	335	195	55	828	520	
		600℃	[MPa]						
		800℃	[MPa]						
		1000℃	[MPa]						
	Yield strength		[MPa]						
	Dilation		[%]						
	Flexural rigidity		[GPa]						
	Young's modulus		[GPa]	209	130	71	210	200	73
	Poisson's ratio		-						
Thermal properties	Max. use temp.	Depending on atmosphere	[℃]		400	400	550	700	
	Recrystallization temperature		[℃]						
	Melting point		[℃]	1455	1084	660	1535	1450	960
	Boiling point		[℃]						
	Linear expansion coefficient	RT	[*10^{-6}/℃]						
		RT～100℃	[*10^{-6}/℃]	13.7	16.6	23.2	11.9	18.0	19.0
		RT～500℃	[*10^{-6}/℃]						
		RT～1000℃	[*10^{-6}/℃]						
		RT～1500℃	[*10^{-6}/℃]						
	Thermal conductivity	20℃	[W/(m･K)]	91	398	237	41	16	420
		100℃	[W/(m･K)]						
		500℃	[W/(m･K)]						
		1000℃	[W/(m･K)]						
		1500℃	[W/(m･K)]						
	Specific heat		[J/(kg･K)]	440	380	900	440	502	233
Electrical characteristics	Electric conductivity		[%I.A.C.S]						
	Volume resistivity	20℃	[μΩ･cm]	7.0	1.7	2.7	10.0	72.0	1.6
Magnetic characteristics	Permeability		[Km]						
	Susceptibility		[Xm]						
Chemical reactivity	Liquid	hydrochloric acid	Loss						
		hydrochloric acid	Loss						
		sulfuric acid	Loss						
		sulfuric acid	Loss						
		nitric acid	Loss						
		caustic soda (sodium hydroxide)	Loss						
		caustic soda (sodium hydroxide)	Loss						
	Gas	air or oxygen	Loss						
		air or oxygen	Loss						
		vapor	Loss						
		nitrogen	Loss						
		carbon monoxide	Loss						
		carbon dioxide	Loss						
		hydrogen	Loss						
		hydrofluoric acid	Loss						
		chlorine	Loss						
		bromine	Loss						
		iodine	Loss						
		ammonia	Loss						
		hydrogen sulfide	Loss						
	Solid body	sulfur	Loss						
		carbon, graphite	Loss						
Features & applications									
Remarks									

Ceramic Material Properties Table 1

Data \ Material			Unit	Fine ceramics									
				Alumina	Alumina	Alumina	Alumina	Zirconia	Silicon nitride	Aluminum nitride	Boron nitride	Silicon carbide	Boron carbide
Main component amount [%] Other component or binder				Al_2O_3 : 99.5%	Al_2O_3 : 99.7%	Al_2O_3 : 99.8%	Al_2O_3 : 99.99%	ZrO_2:	Si_3N_4:	AlN:99.0% and above	BN:99.5% and above binderless	SiC:	B_4C: 98.5%
General properties	Color		-	White	Beige	Light yellow	White	Milky white	Dark grey	Grey beige	White	Black	
General properties	Density		[g/cm^3]	3.9	3.9	3.9 and above	3.9	6.0	3.2	3.3	1.8	3.1	2.5
General properties	Water absorption		[%]	0	0	0	0	0	0	0	0.04	0	
Machining properties	Hardness (HV)		[GPa]	18	15	16	18	13	16	13	0.8 12 (HS)	24	34
Machining properties	Flexural rigidity	20℃	[MPa]	450 (impact bending 0.5～0.7)	340	400	480 (impact bending 0.5～0.7)	1000	750	350	30	500	550
Machining properties	Flexural rigidity	1000℃	[MPa]							330			
Machining properties	Flexural rigidity	1200℃	[MPa]	300			300	350	550	250		600	
Machining properties	Compressive strength		[MPa]	2350	2900		2450						2000
Machining properties	Fracture toughness		[MPam$^{1/2}$]	4		4	4	6	6	3		3	
Machining properties	Young's modulus		[GPa]	390	350	390	400	200	300	320	10	410	450
Machining properties	Poisson's ratio		-	0.24	0.23		0.24	0.32	0.28	0.29		0.16	
Thermal properties	Max. use temp	Oxidizing atmosphere	[℃]	1300	1500		1500				950		2450 (melting point)
Thermal properties	Max. use temp	Non-oxidizing atmosphere	[℃]								2200(inactive) 2000(in vacuo)		
Thermal properties	Thermal expansion coefficient	RT～200℃	[$*10^{-6}$/℃]	5.4	6.5	5.7	5.3	7.7	1.5	2.4		2.9	
Thermal properties	Thermal expansion coefficient	RT～400℃	[$*10^{-6}$/℃]		7.0					3.9(300℃)	-1.8		
Thermal properties	Thermal expansion coefficient	RT～600℃	[$*10^{-6}$/℃]	7.3(500℃)	7.5		7.5(500℃)	10.0(500℃)	3.1(500℃)	4.0(500℃)	-1.5	4.6(500℃)	
Thermal properties	Thermal expansion coefficient	RT～800℃	[$*10^{-6}$/℃]	8.5(1000℃)	7.9		8.6(1000℃)	11.0(1000℃)	3.7(1000℃)	5.2(1000℃)	-1.4(1000℃)	5.0(1000℃)	4.5
Thermal properties	Thermal conductivity	20℃	[W/(m·K)]	30		28	33	3	13	160	63	150	20
Thermal properties	Thermal conductivity	400℃	[W/(m·K)]								45		
Thermal properties	Thermal conductivity	800℃	[W/(m·K)]								30		
Thermal properties	Specific heat	RT	[J/(kg·K)]	800		920	800	470	680	740	800	660	960
Thermal properties	Specific heat	400℃	[J/(kg·K)]								1500		
Thermal properties	Specific heat	800℃	[J/(kg·K)]										
Thermal properties	Impact resistance (ΔT)		[℃]	200		200	200	280	650	400	1500	450	
Electrical characteristics	Dielectric strength		[kV/mm]	＞30	＞10	12	＞30	＞10	＞30	＞30	25		
Electrical characteristics	Volume resistivity	20℃	[Ω·cm]	＞10^{14}	$1*10^{15}$	＞10^{14}	＞10^{14}	＞10^{12}	＞10^{14}	＞10^{14}	$10*10^{15}$	＞10^{6}	0.3～0.8
Electrical characteristics	Volume resistivity	500℃	[Ω·cm]		$60*10^{9}$						10^{6} (1200℃)		
Electrical characteristics	Dielectric constant	1MHz	-	10	10.0	10.2	10	35	8	9	4.5		
Electrical characteristics	Dielectric constant	3GHz	-	10			10	40	8	8			
Electrical characteristics	Dielectric loss	1MHz	[$*10^{-4}$]	30	4	82	7	20	30	10	9		
Electrical characteristics	Dielectric loss	3GHz	[$*10^{-4}$]	4				10	30	130			
Anti-corrosion properties	Chemical resistance	hydrochloric acid	WT Loss [mg/cm^2/day]	-0.3μm (20%-72hr)			-0.3μm (20%-72hr)	0.0μm (20%-72hr)	-2.8μm (20%-72hr)	erosion μm (20%-72hr)		0.0μm (20%-72hr)	
Anti-corrosion properties	Chemical resistance	hydrochloric acid	WT Loss [mg/cm^2/day]	0.0μm (20%-24hr)			0.0μm (20%-24hr)	0.0μm (20%-24hr)	0.0μm (20%-24hr)	-0.6μm (20%-24hr)		0.0μm (20%-24hr)	
Anti-corrosion properties	Chemical resistance	sulfuric acid	WT Loss [mg/cm^2/day]	-0.3μm (20%-72hr)			-0.3μm (20%-72hr)	0.0μm (20%-72hr)	-5.3μm (20%-72hr)	erosion μm (20%-72hr)		0.0μm (20%-72hr)	
Anti-corrosion properties	Chemical resistance	sulfuric acid	WT Loss [mg/cm^2/day]	0.0μm (20%-24hr)			0.0μm (20%-24hr)	0.0μm (20%-24hr)	-0.3μm (20%-24hr)	-0.9μm (20%-24hr)		0.0μm (20%-24hr)	
Anti-corrosion properties	Chemical resistance	nitric acid	WT Loss [mg/cm^2/day]	0.0μm (61%-72hr)			0.0μm (61%-72hr)	0.0μm (61%-72hr)	-1.9μm (61%-72hr)	erosionμm (61%-72hr)		0.0μm (61%-72hr)	
Anti-corrosion properties	Chemical resistance	nitric acid	WT Loss [mg/cm^2/day]	0.0μm (61%-24hr)			0.0μm (61%-24hr)	0.0μm (61%-24hr)	0.0μm (61%-24hr)	-0.6μm (61%-24hr)		0.0μm (61%-24hr)	
Anti-corrosion properties	Chemical resistance	phosphoric acid	WT Loss [mg/cm^2/day]	erosionμm (85%-72hr)			-0.3μm (85%-72hr)	-3.2μm (85%-72hr)	-1.3μm (85%-72hr)	erosionμm (85%-72hr)		0.0μm (85%-72hr)	
Anti-corrosion properties	Chemical resistance	phosphoric acid	WT Loss [mg/cm^2/day]	0.0μm (85%-24hr)			0.0μm (85%-24hr)	0.0μm (85%-24hr)	0.0μm (85%-24hr)	-1.8μm (85%-24hr)		0.0μm (85%-24hr)	
Anti-corrosion properties	Chemical resistance	caustic soda (sodium hydroxide)	WT Loss [mg/cm^2/day]	0.0μm (20%-72hr)			0.0μm (20%-72hr)	0.0μm (20%-72hr)	-0.3μm (20%-72hr)	erosion μm (20%-72hr)		0.0μm (20%-72hr)	
Anti-corrosion properties	Chemical resistance	caustic soda (sodium hydroxide)	WT Loss [mg/cm^2/day]	0.0μm (20%-24hr)			0.0μm (20%-24hr)	0.0μm (20%-24hr)	0.0μm (20%-24hr)	-1.5μm (20%-24hr)		0.0μm (20%-24hr)	
Anti-corrosion properties	Chemical resistance	hydrogen fluoride	WT Loss [mg/cm^2/day]	erosion μm (47%-72hr)			-0.5μm (47%-72hr)	erosionμm (47%-72hr)	-0.9μm (47%-72hr)	-3.6μm (47%-72hr)		0.0μm (47%-72hr)	
	Abrasiveness	Blast abrasion amount	[μm]	2.1			1.0	0.5	0.6			1.6	
Features & applications				High intensity Wear resistance Thermal resistance Large shape possible Relatively low price			High intensity Wear resistance Thermal resistance Large shape possible Relatively low price	High tenacity High intensity Wear resistance	High intensity Wear resistance Thermal shock resistance	High thermal conductivity	High temperature insulator Setter for firing ceramics Jig for semi-conductor manufacturing equipment Jig for glass casts Crucible for melting Heat-resistive	High hardness High stiffness High thermal conductivity	Wear resistance Light weight
Remarks					CIP	mold							

Ceramic Material Properties Table 2

※Published data is for reference only

Data			Unit	Macerite	Macerite S	Photoveel	Photoveel Ⅱ	Macor	Glass (fused quartz)	Glass (Tempax)	Glass (Neoceram)	Sapphire	Electrically Conductive (Corseed)
Material				Machinable ceramics					Other materials				
Main component amount [%]				Fluorine phlogopite:		Fluorine phlogopite:			SiO2:99.99%				:99.9%
Other component or binder						ZrO_2:							
General properties	Color		-	White	White	White	Grey	White	Transparent		Transparent	Transparent	Dark grey
General properties	Density		[g/cm^3]	3.1	2.6	2.6	2.6	2.5	2.2	2.2	2.5	4.0	4.2
General properties	Water absorption		[%]	0	0	0	0	0	0			0	
Machining properties	Hardness (HV)		[GPa]	1.2	2.2	2.2	2.3	25(HS)	9	5	7	23	10
Machining properties	Flexural rigidity	20℃	[MPa]	300	120	147	440	130	94		170	700	310
Machining properties	Flexural rigidity	1000℃	[MPa]					100(600℃)					
Machining properties	Flexural rigidity	1200℃	[MPa]					50(800℃)					
Machining properties	Compressive strength		[MPa]	500	440				1130				
Machining properties	Fracture toughness		[MPam$^{1/2}$]										3.0
Machining properties	Young's modulus		[GPa]	110	86	66	157	67	74	64	94	470	288
Machining properties	Poisson's ratio		-	0.11	0.25			0.29	0.17	0.22			0.27
Thermal properties	Max. use temp	Oxidizing atmosphere	[℃]	800	1200 and more	1000		1000	1070(strain point) 1180(annealing point)	522(strain point) 562(transition point) 568(annealing point)			
Thermal properties	Max. use temp	Non-oxidizing atmosphere	[℃]				1000		1720(softening point)	652(yield point) 815(softening point)			
Thermal properties	Thermal expansion coefficient	RT～200℃	[$*10^{-6}$/℃]	4.5	10.6						-0.6(-50℃)	7.2(//C axis)	
Thermal properties	Thermal expansion coefficient	RT～400℃	[$*10^{-6}$/℃]	5.0	10.5	8.5	1.4	9.3(300℃)	0.64(500℃)		-0.4(50℃)		
Thermal properties	Thermal expansion coefficient	RT～600℃	[$*10^{-6}$/℃]		10.1	9.0		11.4		3.2	-0.1(380℃)		
Thermal properties	Thermal expansion coefficient	RT～800℃	[$*10^{-6}$/℃]		10.3			12.6	0.6		0.1(750℃)		8.8
Thermal properties	Thermal conductivity	20℃	[W/(m·K)]	20	1.6	1.7	50	1.7	1		2	42	6
Thermal properties	Thermal conductivity	400℃	[W/(m·K)]	12	1.9								
Thermal properties	Thermal conductivity	800℃	[W/(m·K)]		2.4								
Thermal properties	Specific heat	RT	[J/(kg·K)]	680	800			790	749		800		670
Thermal properties	Specific heat	400℃	[J/(kg·K)]		1000								
Thermal properties	Specific heat	800℃	[J/(kg·K)]		1200								
Thermal properties	Impact resistance (ΔT)		[℃]	650	150	150	600	150			800		
Electrical characteristics	Dielectric strength		[kV/mm]	21	> 10	18	35	40				> 10	
Electrical characteristics	Volume resistivity	20℃	[Ω·cm]	$9.3*10^{14}$	$1*10^{15}$	$1.8*10^{15}$	$2.2*10^{15}$	10^{16}	$5*10^{16}$		13	> 10^{14}	1
Electrical characteristics	Volume resistivity	500℃	[Ω·cm]	$8.8*10^{7}$	$6*10^{5}$						7(250℃) 5(350℃)		
Electrical characteristics	Dielectric constant	1MHz	-	9.0	6	6		6	3.9(500MHz)	4.7	8.0	11.5(//C axis)	
Electrical characteristics	Dielectric constant	3GHz	-				5.5(1GHz)						
Electrical characteristics	Dielectric loss	1MHz	[$*10^{-4}$]	150	70	50	10	50	< 1(500MHz)	55	190		
Electrical characteristics	Dielectric loss	3GHz	[$*10^{-4}$]										
Anti-corrosion properties	Chemical resistance	hydrochloric acid	WT Loss [mg/cm^2/day]					100 (5%-95℃-24hr)					
Anti-corrosion properties	Chemical resistance	hydrochloric acid	WT Loss [mg/cm^2/day]										
Anti-corrosion properties	Chemical resistance	sulfuric acid	WT Loss [mg/cm^2/day]										
Anti-corrosion properties	Chemical resistance	sulfuric acid	WT Loss [mg/cm^2/day]										
Anti-corrosion properties	Chemical resistance	nitric acid	WT Loss [mg/cm^2/day]					0.6 (0.002N-95℃-24hr)					
Anti-corrosion properties	Chemical resistance	nitric acid	WT Loss [mg/cm^2/day]										
Anti-corrosion properties	Chemical resistance	phosphoric acid	WT Loss [mg/cm^2/day]										
Anti-corrosion properties	Chemical resistance	phosphoric acid	WT Loss [mg/cm^2/day]										
Anti-corrosion properties	Chemical resistance	caustic soda (sodium hydroxide)	WT Loss [mg/cm^2/day]					10 (5%-95℃-6hr)					
Anti-corrosion properties	Chemical resistance	caustic soda (sodium hydroxide)	WT Loss [mg/cm^2/day]										
Anti-corrosion properties	Chemical resistance	hydrogen fluoride	WT Loss [mg/cm^2/day]										
	Abrasiveness	Blast abrasion amount	[μm]										
Features & applications						Precision machinability Electric insulation Adiabaticity Short delivery time	High intensity Low thermal expansibility Precision machinability	Free-cutting Insulation Adiabaticity Vacuum properties	High purity Heat-resistive Chemical resistance				Electric conductivity More accurate than normal alumina Use in reducing atmosphere with high temperature
Remarks													

Ceramic Material Properties Table 3

※Published data is for reference only

Data / Material			Unit	Ceramic compound material（MMC）									
				Silicon carbide based	Silicon carbide based	Silicon carbide based	Silicon carbide based	Silicon carbide based	Silicon carbide based	Silicon carbide based	Silicon carbide based	Silicon carbide based	Silicon carbide based
Main component amount [%]				SiC:50%	SiC:65%	SiC:70%	SiC:80%	α-SiC:82%	SiC:85%	SiC:25%	SiC:30%	SiC:40%	SiC:70%
Other component or binder				Si:50%	Si:35%	Si:30%	Si:20%	Si:18%	Si:15%	Al:75%	Al:70%	Al:60%	Al:30%
General properties	Color		-										
	Density		[g/cm^3]	2.8	3.0	3.0	3.0	3.0	3.1	2.8	2.8	2.9	3.0
	Water absorption		[%]										
Machining properties	Hardness (HV)		[GPa]				20				90(HRB)	93(HRB)	110(HRB) 35(HRC)
	Flexural rigidity	20℃	[MPa]	300	300	300	250	250	300				380
		1000℃	[MPa]					220(800℃)					
		1200℃	[MPa]				250(1300℃)	220(1200℃)					
	Compressive strength		[MPa]										
	Fracture toughness		[MPam$^{1/2}$]	3	3	3			3		15	14	10
	Young's modulus		[GPa]	280	310	330	350	370 (360:800℃ , 340:1200℃)	380	115	125	150	260
	Poisson's ratio		-	0.20	0.20	0.20		0.18	0.20	0.29	0.29	0.29	0.10
Thermal properties	Max. use temp	Oxidizing atmosphere	[℃]				1350	1350					
		Non-oxidizing atmosphere	[℃]										
	Thermal expansion coefficient	RT～200℃	[*10^{-6}/℃]	2.8	4.7	3.0			3.0	15.0	14.0	13.0	6.0
		RT～400℃	[*10^{-6}/℃]										
		RT～600℃	[*10^{-6}/℃]					3.4(700℃)					
		RT～800℃	[*10^{-6}/℃]				4.5	4.3(1200℃)					
	Thermal conductivity	20℃	[W/(m·K)]	175	210	190		220	210	145	150	155	170
		400℃	[W/(m·K)]				100(350℃)						
		800℃	[W/(m·K)]					60(700℃)					
	Specific heat	RT	[J/(kg·K)]	790	700	700	700	700	700		800	900	1000
		400℃	[J/(kg·K)]										
		800℃	[J/(kg·K)]				1000(1000℃)	1230(700℃)					
	Impact resistance (ΔT)		[℃]										
Electrical characteristics	Dielectric strength		[kV/mm]										
	Volume resistivity	20℃	[Ω·cm]	2*10^{-2}	2*10^{-1}	2*10^{-2}	10^{-3}		5*10^{-2}				1*10^{-5}
		500℃	[Ω·cm]										
	Dielectric constant	1MHz	-										
		3GHz	-										
	Dielectric loss	1MHz	[*10^{-4}]										
		3GHz	[*10^{-4}]										
Anti-corrosion properties	Chemical resistance	hydrochloric acid	WT Loss [mg/cm^2/day]										
		hydrochloric acid	WT Loss [mg/cm^2/day]										
		sulfuric acid	WT Loss [mg/cm^2/day]										
		sulfuric acid	WT Loss [mg/cm^2/day]										
		nitric acid	WT Loss [mg/cm^2/day]										
		nitric acid	WT Loss [mg/cm^2/day]										
		phosphoric acid	WT Loss [mg/cm^2/day]										
		phosphoric acid	WT Loss [mg/cm^2/day]										
		caustic soda (sodium hydroxide)	WT Loss [mg/cm^2/day]										
		caustic soda (sodium hydroxide)	WT Loss [mg/cm^2/day]										
		hydrogen fluoride	WT Loss [mg/cm^2/day]										
	Abrasiveness	Blast abrasion amount	[μm]										
Features & applications				Light weight High stiffness Low thermal expansion Vacuum support Pore-free Mirror finish	Light weight High stiffness Low thermal expansion Vacuum support Pore-free Mirror finish				High stiffness Low thermal expansion Vacuum support Pore-free Mirror finish				
Remarks				Pressureless Infiltration Technique	Pressureless Infiltration Technique	Pressureless Infiltration Technique			Pressureless Infiltration Technique	Casting process	Casting process	Casting process	Pressureless Infiltration Technique

Ceramic Material Properties Table 4

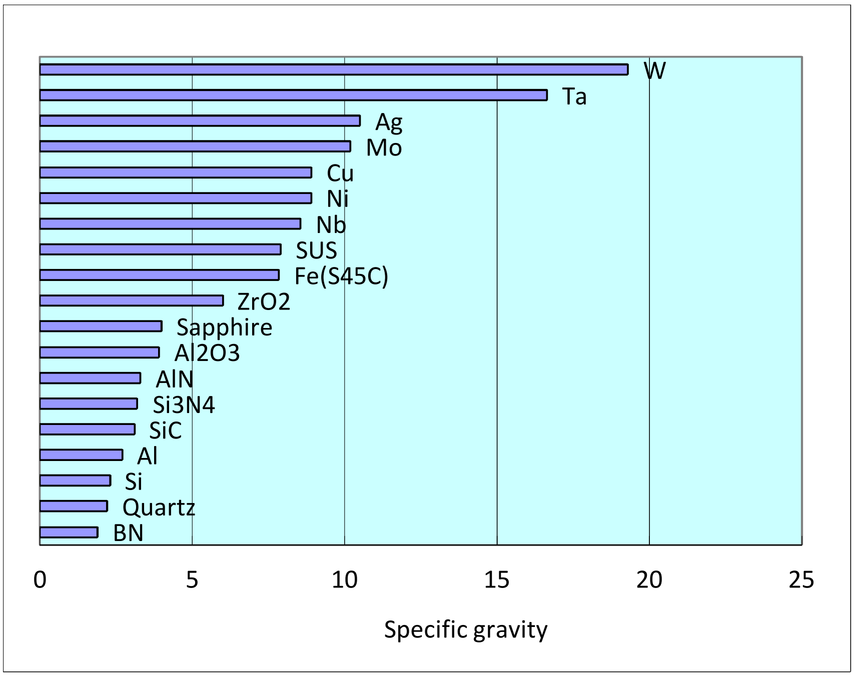
※Published data is for reference only

			Material / Data / Unit	Ceramic compound material（MMC）									
				Boron nitride based	Boron nitride based	Boron nitride based	Boron nitride based	Boron nitride based	Boron nitride based	Boron nitride based	Boron nitride based	Boron nitride based	Boron nitride based
Main component amount [%]				BN:97%	BN:99.5% and more	BN:99.5% and more	BN:40%	BN:35%	BN:30%	BN:20%	BN:30%	BN:50%	BN:70%
Other component or binder				$CaO \cdot B_2O_3$	binderless	binderless	$Al_2O_3 \cdot SiO_2$	$TiB_2 \cdot AlN$	AlN:70%	AlN:80%	Si_3N_4:70%	Si_3N_4:50%	Si_3N_4:30%
General properties	Color		-	White	White		White					Light grey	
General properties	Density		[g/cm^3]	2.0	1.8	1.6	2.2	3.1	2.8	2.6	2.7	2.5	2.2
General properties	Water absorption		[%]	0.4	0.04								
Machining properties	Hardness (HV)		[GPa]	1.3 20(HS)	0.8 12(HS)	11(HS)	45(HS)	60(HS)	76(HS)	40(HS)	75(HS)	5.5 69(HS)	48(HS)
Machining properties	Flexural rigidity	20℃	[MPa]	35	30	28	140	160	280	120	300	270	140
Machining properties	Flexural rigidity	1000℃	[MPa]										
Machining properties	Flexural rigidity	1200℃	[MPa]										
Machining properties	Compressive strength		[MPa]										
Machining properties	Fracture toughness		[MPam$^{1/2}$]										
Machining properties	Young's modulus		[GPa]	20	10							80	
Machining properties	Poisson's ratio		-										
Thermal properties	Max. use temp	Oxidizing atmosphere	[℃]	950	950	950	1100	950	950	950	950	950	950
Thermal properties	Max. use temp	Non-oxidizing atmosphere	[℃]	1800(inactive) 1600(in vacuo)	2200(inactive) 2000(in vacuo)	2200(inactive) 2000(in vacuo)	1500(inactive) 1400(in vacuo)	2000(inactive) 1700(in vacuo)	1950(inactive) 1800(in vacuo)	1950(inactive) 1800(in vacuo)	1700(inactive) 1500(in vacuo)	1700(inactive) 1500(in vacuo)	1700(inactive) 1500(in vacuo)
Thermal properties	Thermal expansion coefficient	RT～200℃	[$*10^{-6}$/℃]										
Thermal properties	Thermal expansion coefficient	RT～400℃	[$*10^{-6}$/℃]	-0.2	-1.8		5.3					2.1	
Thermal properties	Thermal expansion coefficient	RT～600℃	[$*10^{-6}$/℃]	-0.4	-1.5							2.3	
Thermal properties	Thermal expansion coefficient	RT～800℃	[$*10^{-6}$/℃]	-0.25(1000℃)	-1.4(1000℃)	-0.6(1000℃)	6.0(1000℃)	7.0(1000℃)	4.3(1000℃)	5.4(1000℃)	3.0(1000℃)	2.6(1000℃)	2.0(1000℃)
Thermal properties	Thermal conductivity	20℃	[W/(m·K)]	36	63	60	8	55	66	95	44	47	33
Thermal properties	Thermal conductivity	400℃	[W/(m·K)]		45								
Thermal properties	Thermal conductivity	800℃	[W/(m·K)]		30								
Thermal properties	Specific heat	RT	[J/(kg·K)]	700	800							700	
Thermal properties	Specific heat	400℃	[J/(kg·K)]	1300	1500							1000	
Thermal properties	Specific heat	800℃	[J/(kg·K)]										
Thermal properties	Impact resistance (ΔT)		[℃]	1500	1500							1500	
Electrical characteristics	Dielectric strength		[kV/mm]	25	25	22	19		21	15	21	36	27
Electrical characteristics	Volume resistivity	20℃	[Ω·cm]	$10*10^{15}$	$10*10^{15}$	10^{15}	$0.1*10^{15}$	250～1000μ	10^{14}	10^{14}	10^{14}	$10*10^{15}$	10^{14}
Electrical characteristics	Volume resistivity	500℃	[Ω·cm]	10^4 (1200℃)	10^6 (1200℃)	10^6 (1200℃)	3 (500℃)		10^3 (1200℃)	10^4 (1200℃)	10^6 (1200℃)	10^5 (1200℃)	10^5 (1200℃)
Electrical characteristics	Dielectric constant	1MHz	-	4.0	4.5	4.9	3.0		6.7	7.0	4.9	6.3	4.9
Electrical characteristics	Dielectric constant	3GHz	-										
Electrical characteristics	Dielectric loss	1MHz	[$*10^{-4}$]	8	9	10	13		18	39	24	53	180
Electrical characteristics	Dielectric loss	3GHz	[$*10^{-4}$]										
Anti-corrosion properties	Chemical resistance	hydrochloric acid	WT Loss [mg/cm^2/day]										
Anti-corrosion properties	Chemical resistance	hydrochloric acid	WT Loss [mg/cm^2/day]										
Anti-corrosion properties	Chemical resistance	sulfuric acid	WT Loss [mg/cm^2/day]										
Anti-corrosion properties	Chemical resistance	sulfuric acid	WT Loss [mg/cm^2/day]										
Anti-corrosion properties	Chemical resistance	nitric acid	WT Loss [mg/cm^2/day]										
Anti-corrosion properties	Chemical resistance	nitric acid	WT Loss [mg/cm^2/day]										
Anti-corrosion properties	Chemical resistance	phosphoric acid	WT Loss [mg/cm^2/day]										
Anti-corrosion properties	Chemical resistance	phosphoric acid	WT Loss [mg/cm^2/day]										
Anti-corrosion properties	Chemical resistance	caustic soda (sodium hydroxide)	WT Loss [mg/cm^2/day]										
Anti-corrosion properties	Chemical resistance	caustic soda (sodium hydroxide)	WT Loss [mg/cm^2/day]										
Anti-corrosion properties	Chemical resistance	hydrogen fluoride	WT Loss [mg/cm^2/day]										
	Abrasiveness	Blast abrasion amount	[μm]										
Features & applications				High temperature insulator Setter for firing ceramics Jig for semi-conductor manufacturing equipment Jig for glass casts Crucible for melting Heat-resistive	High temperature insulator Setter for firing ceramics Jig for semi-conductor manufacturing equipment Jig for glass casts Crucible for melting Heat-resistive	High temperature insulator Setter for firing ceramics Jig for semi-conductor manufacturing equipment Jig for glass casts Crucible for melting Heat-resistive	High temperature insulator Setter for firing ceramics Jig for semi-conductor manufacturing equipment Jig for glass casts Crucible for melting Heat-resistive	Metal deposition			High temperature insulator Setter for firing ceramics Jig for semi-conductor manufacturing equipment Jig for glass casts Crucible for melting Heat-resistive	High temperature insulator Setter for firing ceramics Jig for semi-conductor manufacturing equipment Jig for glass casts Crucible for melting Heat-resistive	High temperature insulator Setter for firing ceramics Jig for semi-conductor manufacturing equipment Jig for glass casts Crucible for melting Heat-resistive
Remarks													

Specific gravity As a base point, the density of water is 1. The larger the bar, the heavier the material.

Compared to metals, ceramics tend to have less than half the density.
Tungsten is heavier than lead and around the same weight as gold,
making it an unusually dense element.
As a result of this, tungsten is often used as radiation shielding.

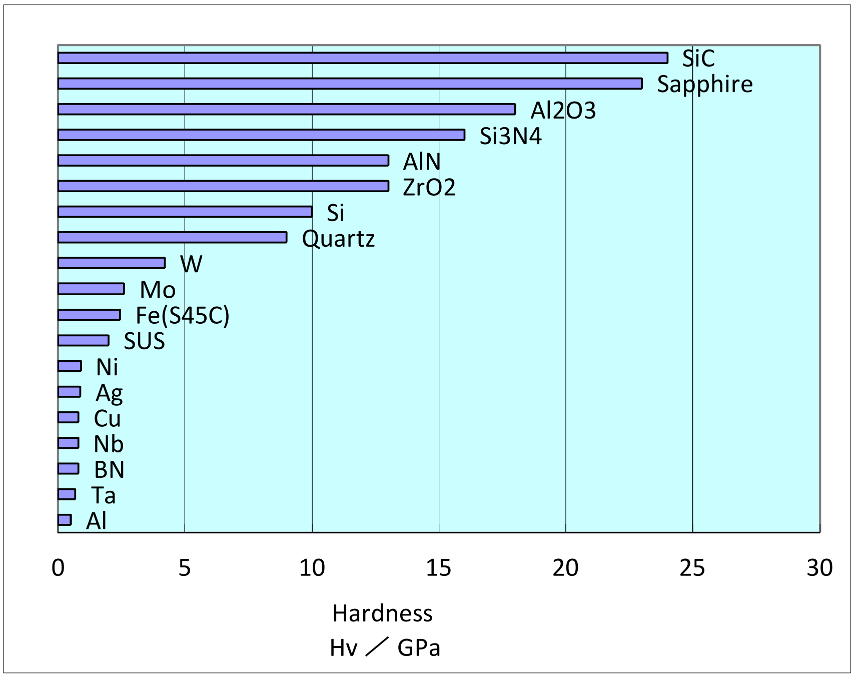
Comparative specific gravity graph



Hardness This graph displays the hardness of various materials. The larger the bar, the harder the material.

Ceramics tend to be much harder than typical metals.
By this, we mean that they resist abrasion and wear. These kinds of materials have many uses.

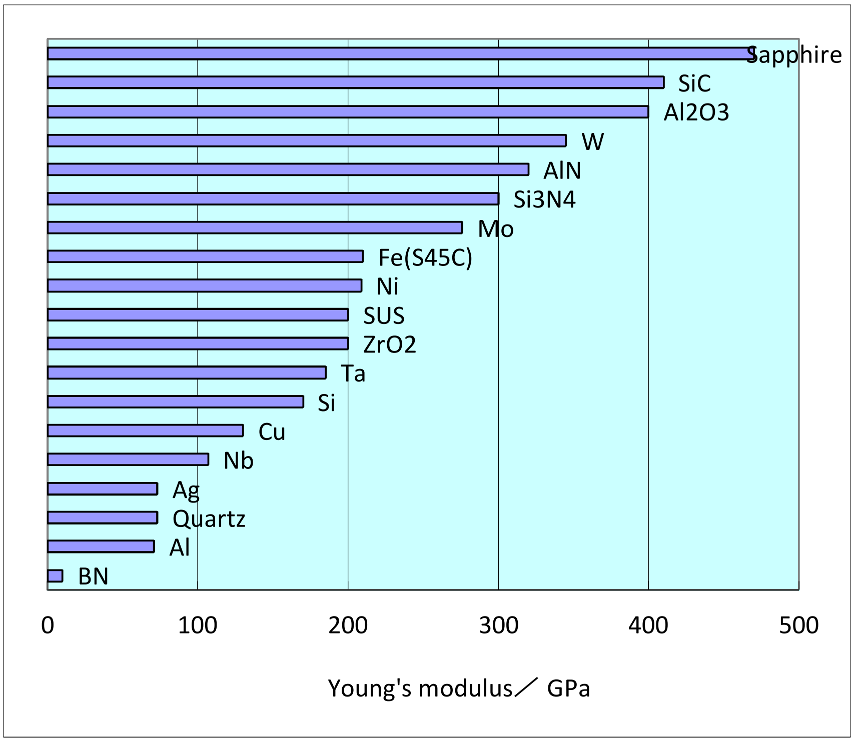
Comparative hardness graph



Young's modulus Resilience to stress is an important commodity. The larger the bar, the stiffer the material.

Ceramics, tungsten and molybdenum, when compared to other metals, have a very high Young`s modulus.

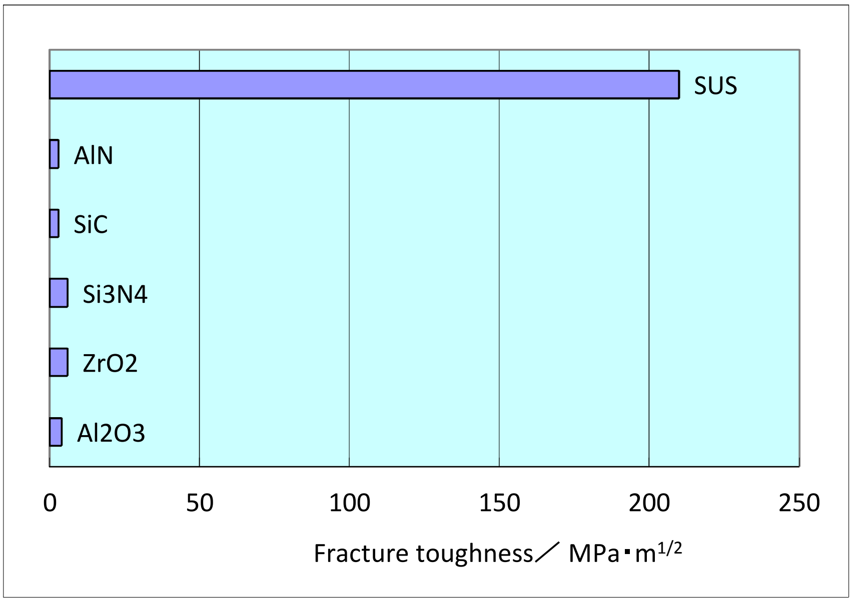
Young's modulus comparative graph



Fracture toughness Fracture toughness can be defined as resistance to cracks. The larger the bar, the harder a material is to break.

Ceramics are extremely brittle.
As zirconia is especially resilient, it is often used in kitchen knives, scissors and wrecking balls.

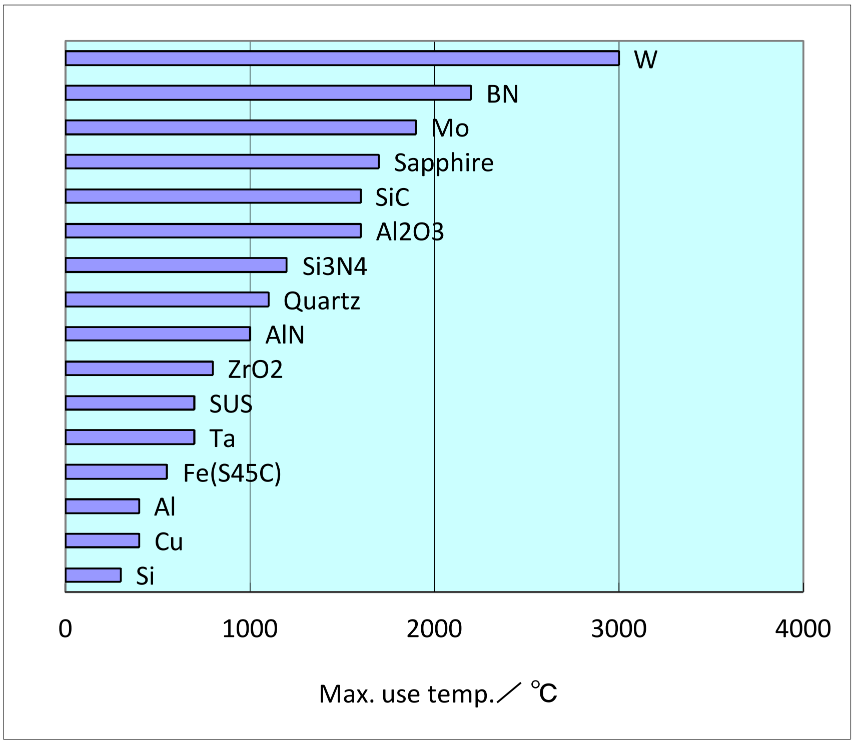
Comparative fracture toughness graph



Max. use temp. A temperature range in which material possible to use (it varies depending on atmosphere).

High melting point metals such as tungsten and molybdenum, as well as ceramic, have many uses, for example furnace materials, crucible, and heat shielding.

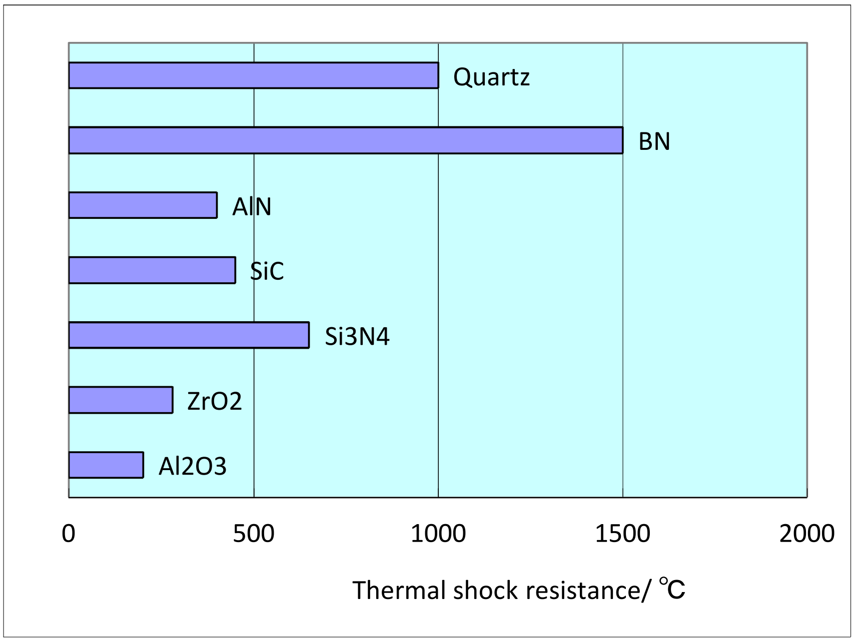
Comparative maximum use temperature graph



Thermal shock resistance Temperature range that can withstand rapid changes in temperature.
The higher the temperature, the harder a material is to brake.

Glass and ceramics are easy to break with abrupt temperature change but boron nitride, quartz, and silicon nitride have a very high thermal shock resistance. These materials tend to be used in parts that experience extreme swings in temperature.

Comparative thermal shock resistance graph

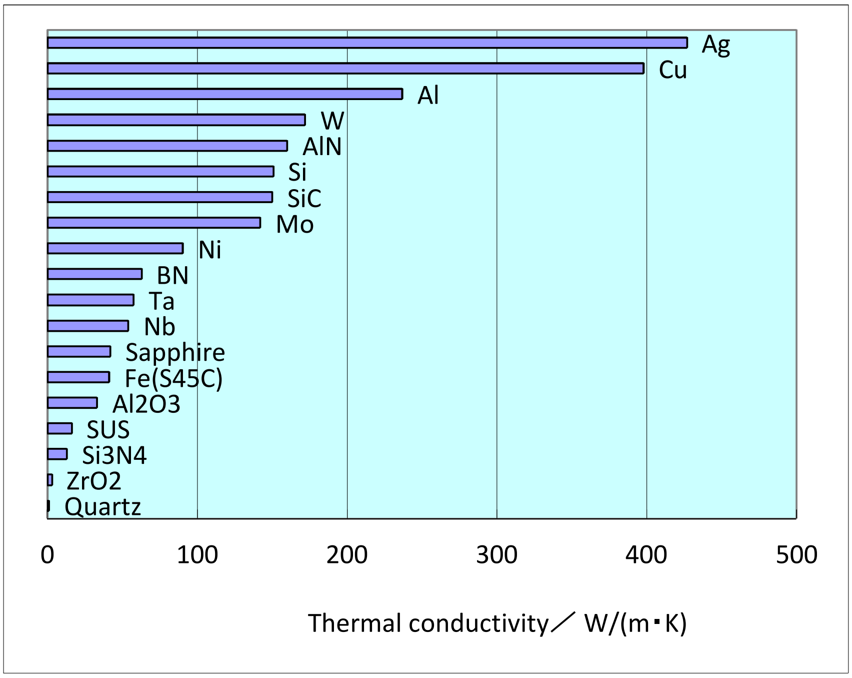


Thermal conductivity

This graph displays the heat conduction rate for different materials.
A larger bar indicates that heat travels easily through the material.

Certain ceramics like aluminum nitride and silicon carbide have high conductivity rates but others such as zirconia have very low conduction.
Tungsten and molybdenum have a comparatively high conductivity rate.

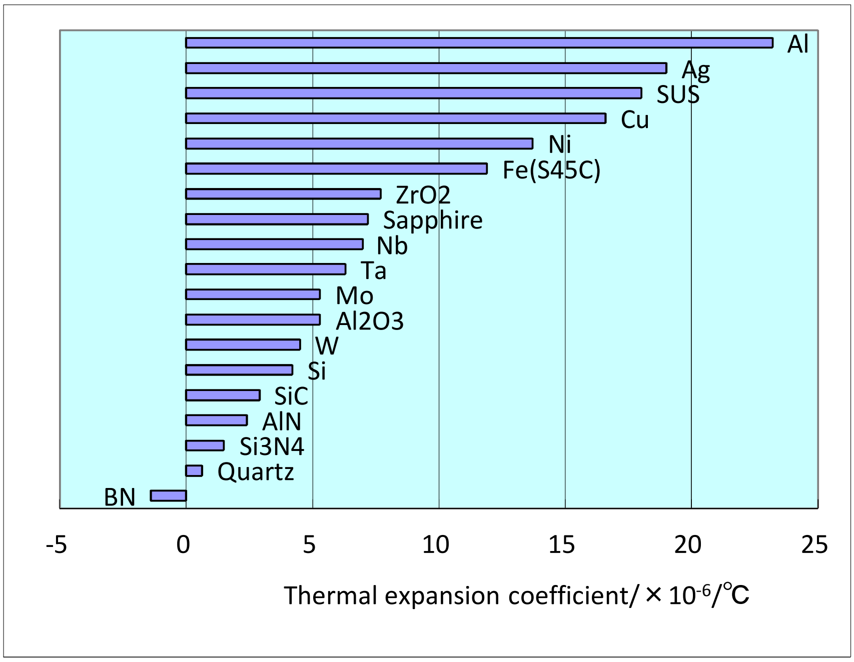
Thermal conductivity comparison graph



Thermal expansion coefficient

Rate of expansion of the materials in response to change of temperature.
The larger the bar the greater the rate of expansion.
Ceramics, tungsten and molybdenum, having a low rate of thermal expansion, undergo for little change of shape in response to changes in temperature.

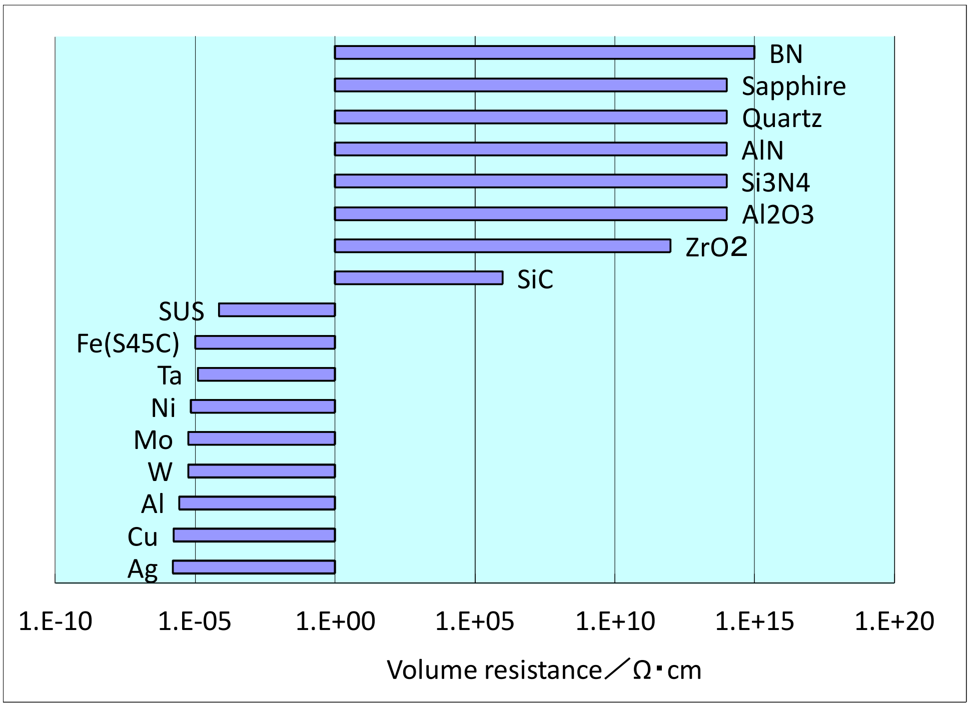
Thermal expansion comparative graph



Volume resistance This property explains how easy or not it is for electricity to pass through a material.
The larger the bar, the greater resistance to electricity.

Ceramics in general are poor conductors of electricity and as a result have a variety of uses as insulators. Some of ceramics have electro conductive properties.

Volume resistance graph



Dielectric constant According to the electrical charge of a material, the amount of energy it can emit is expressed as a coefficient.

Ceramics resist electricity so they are often used as insulators in electrical parts.

Corrosion resistance The appearance or function of a material not being harmed by chemical or biological effects is known as corrosion resistance.

Ceramics excel in this, and as such they are often used in prosthetic limbs.
As corrosion resistive parts they have many different uses.
Tungsten resists acid and alkali in a similar manner.

Electric conductivity In general, fine ceramics are insulators that do not conduct electricity.
Depending on voltage or temperature, some of them can become semiconductors.

Piezoelectricity Piezoelectric are materials, which after applying stress and distortion to their crystals, generate electric charge. It is called piezoelectric effect.
When an electric field is applied, stress and distortion are generated and inverse piezoelectric effect occurs.

Piezoelectric ceramics have polycrystalline substance.
An example of piezoelectric material is lead zirconate titanate (PTZ in short).

Unit conversion charts

◇Stress

GPa	MPa or N/mm^2	kgf/mm^2	kgf/cm^2	10^3lb/in^2
1	1X10^3	1.0197X10^2	1.0197X10^4	1.45X10^2
1X10^{-3}	1	1.0197X10^{-1}	1.0197X10	1.45X10^{-1}
9.807X10^{-3}	9.807	1	1X10^2	1.422
9.807X10^{-5}	9.807X10^{-2}	1X10^{-2}	1	1.422X10^{-2}
6.895X10^{-3}	6.895	7.03X10^{-1}	7.03X10	1

◇Thermal conductivity

W/(m・K)	kcal/(h・m・℃)	cal/(sec・cm・℃)
1	0.86	2.39x10^{-3}
1.163	1	2.78X10^{-3}
4.187X10^2	3.6X10^2	1

◇Specific heat

J /(kg・K)	kcal /(kgf・K)	Btu /(lb・°R)	kgf・m /(kgf・K)	ft-lbf /(lb・°R)
1	2.39X10^{-4}	2.39X10^{-4}	1.0197X10^{-1}	1.8586X10^{-1}
4.1868X10^3	1	1	4.26935X10^2	7.78169X10^2
9.80665	2.342X10^{-3}	2.342X10^{-3}	1	1.82269
5.38032	1.285X10^{-3}	1.285X10^{-3}	5.4864X10^{-1}	1

◇Density

g/cm^3	kg/m^3
1	1x10^3
1x10^{-3}	1

◇Volume resistance

Ω・cm	μΩ・cm
1	1X10^6
1X10^{-6}	1

Hardness conversion tables

Rockwell hardness C scale HRC	Vickers hardness Hv	Brinell hardness 10mm ball 3000kgf force HB		Shore hardness HS	Tensile strength (approx.) MPa	Rockwell hardness C scale HRC	Vickers hardness Hv	Brinell hardness 10mm ball 3000kgf force HB		Shore hardness HS	Tensile strength (approx.) MPa
		Bogey tube	Tungsten carbide ball					Bogey tube	Tungsten carbide ball		
68	940	—	—	97	—	34	336	319	319	47	1055
67	900	—	—	95	—	33	327	311	311	46	1025
66	865	—	—	92	—	32	318	301	301	44	1000
65	832	—	(739)	91	—	31	310	294	294	43	980
64	800	—	(722)	88	—	30	302	286	286	42	950
63	772	—	(705)	87	—	29	294	279	279	41	930
62	746	—	(688)	85	—	28	286	271	271	41	910
61	720	—	(670)	83	—	27	279	264	264	40	880
60	697	—	(654)	81	—	26	272	258	258	38	860
59	674	—	(634)	80	—	25	266	253	253	38	840
58	653	—	615	78	—	24	260	247	247	37	825
57	633	—	595	76	—	23	254	243	243	36	805
56	613	—	577	75	—	22	248	237	237	35	785
55	595	—	560	74	2075	21	243	231	231	35	770
54	577	—	543	72	2015	20	238	226	226	34	760
53	560	—	525	71	1950	(18)	230	219	219	33	730
52	544	(500)	512	69	1880	(16)	222	212	212	32	705
51	528	(487)	496	68	1820	(14)	213	203	203	31	675
50	513	(475)	481	67	1760	(12)	204	194	194	29	650
49	489	(464)	469	66	1695	(10)	196	187	187	28	620
48	484	451	455	64	1635	(8)	188	179	179	27	600
47	471	442	443	63	1580	(6)	180	171	171	26	580
46	458	432	432	62	1530	(4)	173	165	165	25	550
45	446	421	421	60	1480	(2)	166	158	158	24	530
44	434	409	409	58	1435	0	160	152	152	24	515
43	423	400	400	57	1385	-	150	143	143	22	490
42	412	390	390	56	1340	-	140	133	133	21	455
41	402	381	381	55	1295	-	130	124	124	20	425
40	392	371	371	54	1250	-	120	114	114	-	390
39	382	362	362	52	1215	-	110	105	105	-	-
38	372	353	353	51	1180	-	100	95	95	-	-
37	363	344	344	50	1160	-	95	90	90	-	-
36	354	336	336	49	1115	-	90	86	86	-	-
35	345	327	327	48	1080	-	85	81	81	-	-

Note: Above numbers are for reference only.

Dielectric strength/resistivity

			dielectric strength kv/mm	resistivity Ωcm
Ceramics	Fine ceramics	Alumina	＞10	＞10^{14}
		Zirconia	＞10	＞10^{12}
		Silicon nitride	＞14	＞10^{14}
		Aluminum nitride	＞15	＞10^{14}
		Silicon carbide	—	＞10^{6}
		Cordierite	7	10^{13}
		Mullite	＞10	10^{14}
		Steatite	18	10^{14}
		Calcia	—	—
		Magnesia (compact)	—	＞10^{14}
		Sialon	＞15	＞10^{15}
	Machinable ceramics	Macerite S	＞10	1X10^{15}
		Macerite SP	＞10	2X10^{15}
		Macerite HSP	＞10	5X10^{15}
		Photoveel Ⅱ	35	2.2X10^{15}
		Photoveel Ⅱ -S	30	10^{14}
		M-soft	40	10^{12}
		BN HC	25	10^{15}
		BN N-1	25	10^{15}
		BN NB-1000	22	10^{15}
		BA	21	10^{14}
		SBN	27	10^{14}
	Pottery		—	—
	Porcelain		—	3X10^{14}
	Glass	Universal glass	—	—
		Toughened glass	—	—
		Pyrex, Tempax	—	＞10^{15}
		Neoceram	—	＞10^{13}
		Quartz	＞10	＞10^{14}
		Baycol	—	10^{17}
		Sapphire glass	＞10	＞10^{14}
	Brick	Ordinary brick	—	—
		General purpose furnace material (ceiling use)	—	—
		General purpose furnace material (insulation brick)	—	—
	Cement	Universal cement	—	—
		Fireproof cement	—	—

			dielectric strength kv/mm	resistivity Ωcm
Metals	Metal with high melting point	Tungsten	—	5.5X10^{-6}
		Molybdenum	—	5.7X10^{-6}
		Tantalum	—	12.4X10^{-6}
		Niobium	—	—
	Heat-resistant steel	SUS310S	—	90X10^{-6}
		SUH445	—	60X10^{-6}
		Inconel 600	—	103X10^{-6}
	Universal metal (alloy)	SUS316	—	74X10^{-6}
		SUS304	—	71X10^{-6}
		Iron	—	19.5X10^{-6}
		Aluminum	—	2.7X10^{-6}
		Copper	—	1.7X10^{-6}

			dielectric strength kv/mm	resistivity Ωcm
Plastic	Engineering plastic	Polyimide (PI)	23	＞10^{14}
		Poly Benz Imidazol (PBI)	23	2X10^{15}
		Polymide-imide (PAI)	23	2X10^{15}
		Poly Ether Imide (PEI)	24	10^{17}
		Polyacetal (POM)	20	1X10^{14}
		Poly Phenylene Sulfide (PPS)	15	1.6X10^{16}
		Poly Ether Ether Ketone (PEEK)	19	10^{16}
		Poly Tetra Fluoro Ethylene (PTFE)	19	＜10^{18}
		Polymide 6 (PA6)	31	10^{14}
		Ultra-high-molecular-weight polyethylene (UHMWPE)	—	＞10^{13}
	General purpose plastic	Polyethylene	40～50	6X10^{18}
		Polypropylene	31	＞10^{16}
		Vinyl chloride resin	37.5	＞10^{16}
		Polystyrene	20～28	—
		Polyethylene-telephthalate	22	＞10^{16}
		Acrylonitrile butadiene	14～20	1～4.8X10^{14}

Heat-resistant material

			Max. use temp. atmosphere/℃	Normal temp. atmosphere/℃
Ceramics	Fine ceramics	Alumina	1300～1600	—
		Zirconia	1000	—
		Silicon nitride	1200	—
		Aluminum nitride	900	—
		Silicon carbide	1500	—
		Cordierite	1200	—
		Mullite	1200	—
		Steatite	1000	—
		Calcia	1800	—
		Magnesia (compact)	1700	—
		Sialon	1300	—
	Machinable ceramics	Macerite HSP	700	—
		Photoveel Ⅱ	1000	—
		Photoveel Ⅱ-S	1000	—
		M-soft	1000	—
		BN HC	950	—
		BN N-1	950	—
		NB	950	—
		BA	950	—
		SBN	950	—
	Pottery		140～450	—
	Porcelain		110～390	—
	Glass	Universal glass	380	110
		Toughened glass	250	230
		Pyrex, Tempax	500	230
		Neoceram	800	750
		Quartz	1200	900
		Baycol	1200	900
		Sapphire glass	1850	—
	Brick	Ordinary brick	500	—
		General purpose furnace material (ceiling use)	1300～1500	—
		General purpose furnace material (insulation brick)	900～1400	—
	Cement	Universal cement	＜500	—
		Fireproof cement	1100	—

			Max. use temp. non-volatile gas/℃	Normal temp. non-volatile gas/℃	melting temp. ℃	recrystallization temp. ℃
Metals	Metal with high melting point	Tungsten	—	—	3387	1100～1300
		Molybdenum	—	—	2623	800～1200
		Tantalum	—	—	2990	900～1450
		Niobium	—	—	2415	850～1300
	Heat-resistant steel	SUS310S	1150	900	—	—
		SUH445	1200	1000	—	—
		Inconel 600	1050	1050	—	—
	Universal metal (alloy)	SUS316	1000	700	—	—
		SUS304	1000	700	—	—
		Iron	550	—	—	—
		Aluminum	400	—	—	—
		Copper	400	—	—	—

			Max. use temp. atmosphere/℃	Normal temp. atmosphere/℃
Plastic	Engineering plastic	Polyimide (PI)	—	300
		Poly Benz Imidazol (PBI)	—	310
		Polymide-imide (PAI)	—	250
		Poly Ether Imide (PEI)	—	170
		Polyacetal (POM)	—	80
		Poly Phenylene Sulfide (PPS)	—	220
		Poly Ether Ether Ketone (PEEK)	—	250
		Poly Tetra Fluoro Ethylene (PTFE)	—	260
		Polymide 6 (PA6)	—	110～120
		Ultra-high-molecular-weight polyethylene (UHMWPE)	—	80
	General purpose plastic	Polyethylene	—	80～90
		Polypropylene	—	100～140
		Vinyl chloride resin	—	60～80
		Polystyrene	—	80～90
		Polyethylene-telephthalate	—	85～100
		Acrylonitrile butadiene	—	70～100

TOP SEIKO CO., LTD.
1197-4, Hosoe-cho, Nagahama City, Shiga, 526-0105 Japan
Phone : +81-749-51-9021
Fax : +81-749-51-9022
E-mail : info@top-seiko.co.jp
Website : http//www.top-seiko.co.jp