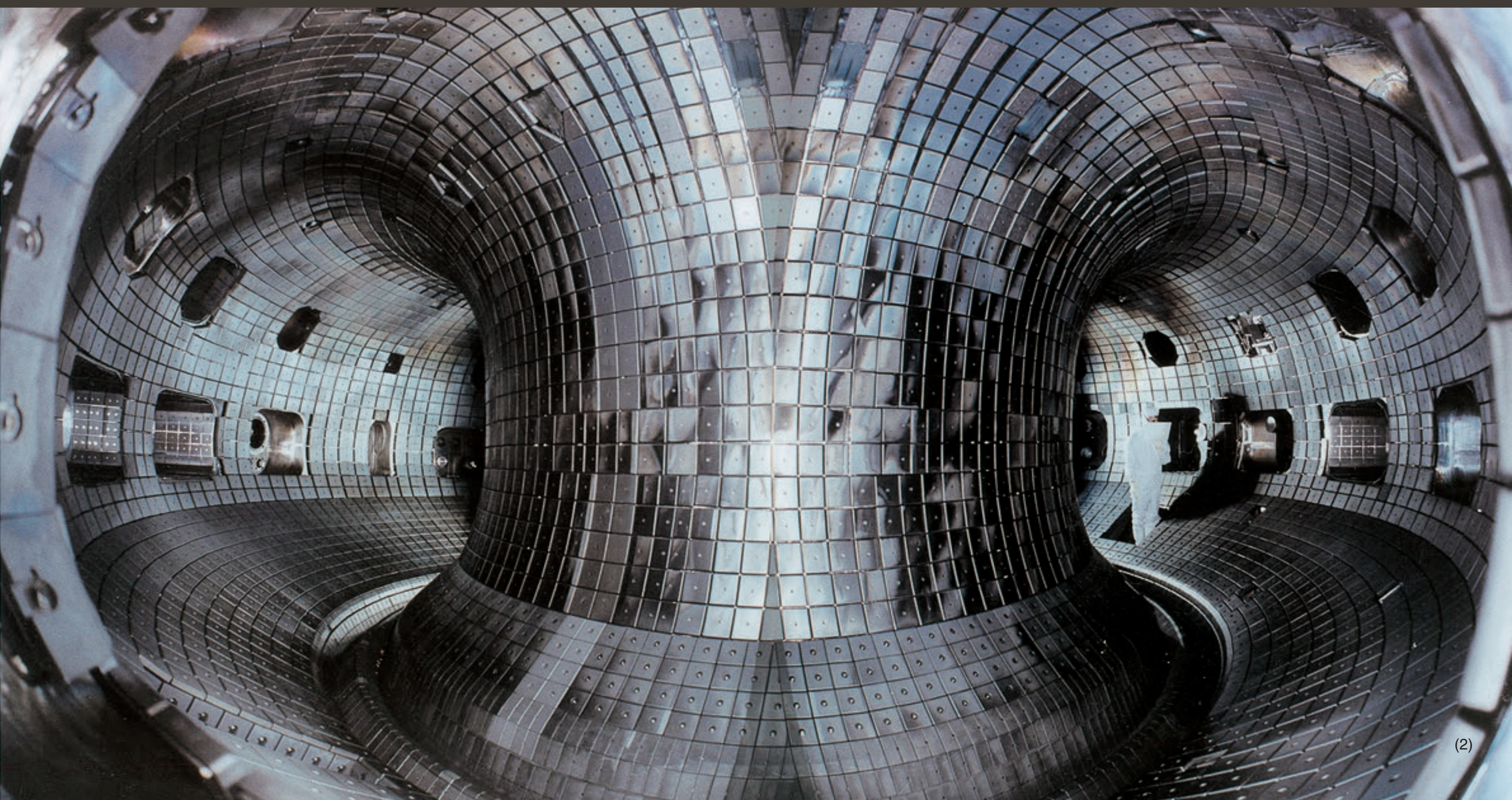
# Special Graphite

(1) Single crystal silicon manufacturing equipment

(2) Critical plasma testing equipment (JT-60)
* Photographs provided by National Institutes for Quantum and Radiological Science and Technology

(1)



(2)

# Features of Special Graphite Products

The demand from the industry over the years has been for carbon with increasingly tighter and stable properties. In this context, Toyo Tanso was the pioneer in our industry in developing "isotropic graphite." This is a graphite material with micro particles and an isotropic structure and properties which created through Cold Isostatic pressing (CIP). Our isotropic graphite products are used across a wide field of industries. These include: the semi-conductor industry, where innovation is rapidly advancing; the environmentally friendly renewable energy industry; the mold industry, where accuracy is such a priority; and the atomic power industry, where high reliability is essential. Our excellence is recognized by our customers, with whom we grow together. The synergistic effect between our exclusive high purity technology and various coating technologies will ensure that in the future too, we use our position as a leading company to continue to unlock the unlimited potential of carbon.



## ■ Isotropic Graphite

Conventional graphite was anisotropic, which limited its use in many applications. However, isotropic graphite in the same cross section direction has no difference in its properties, making a material that is easy to design and use.

## ■ High Reliability

Isotropic graphite is stronger than conventional graphite due to its micro particle structure. This produces a highly reliable material with a small characteristic variation.

## ■ Ultra Heat Resistance

In an inert atmosphere, stable use is possible even in extremely high temperatures of 2,000°C or more. The material has low thermal expansion and a high coefficient of thermal conductivity, giving it excellent thermal shock resistance and heat distribution properties, with low thermal deformation. It also has a special characteristic whereby its strength increases as the atmospheric temperature gets higher up until 2,500°C.

## ■ Excellent Electrical Conductivity

The high and excellent heat resistance mean graphite is the optimum material for applications such as high temperature heaters.

## ■ Excellent Chemical Resistance

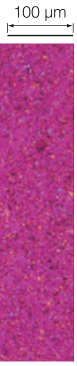
With the exception of some strong oxidizers, it is chemically stable. Graphite can be used stably even in environments that cause some metals to corrode.

## ■ Lightweight and Easy to Machine

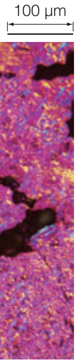
The bulk density is low as compared with metallic materials-enabling a lightweight design. In addition, it has excellent mechanical machining properties-facilitating accurate shaping processes.

## ■ Isotropic Graphite and Anisotropic Graphite

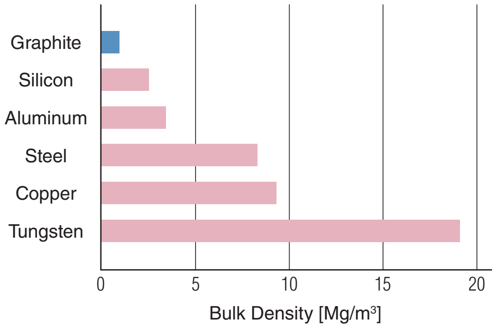
Isotropic High Density Graphite



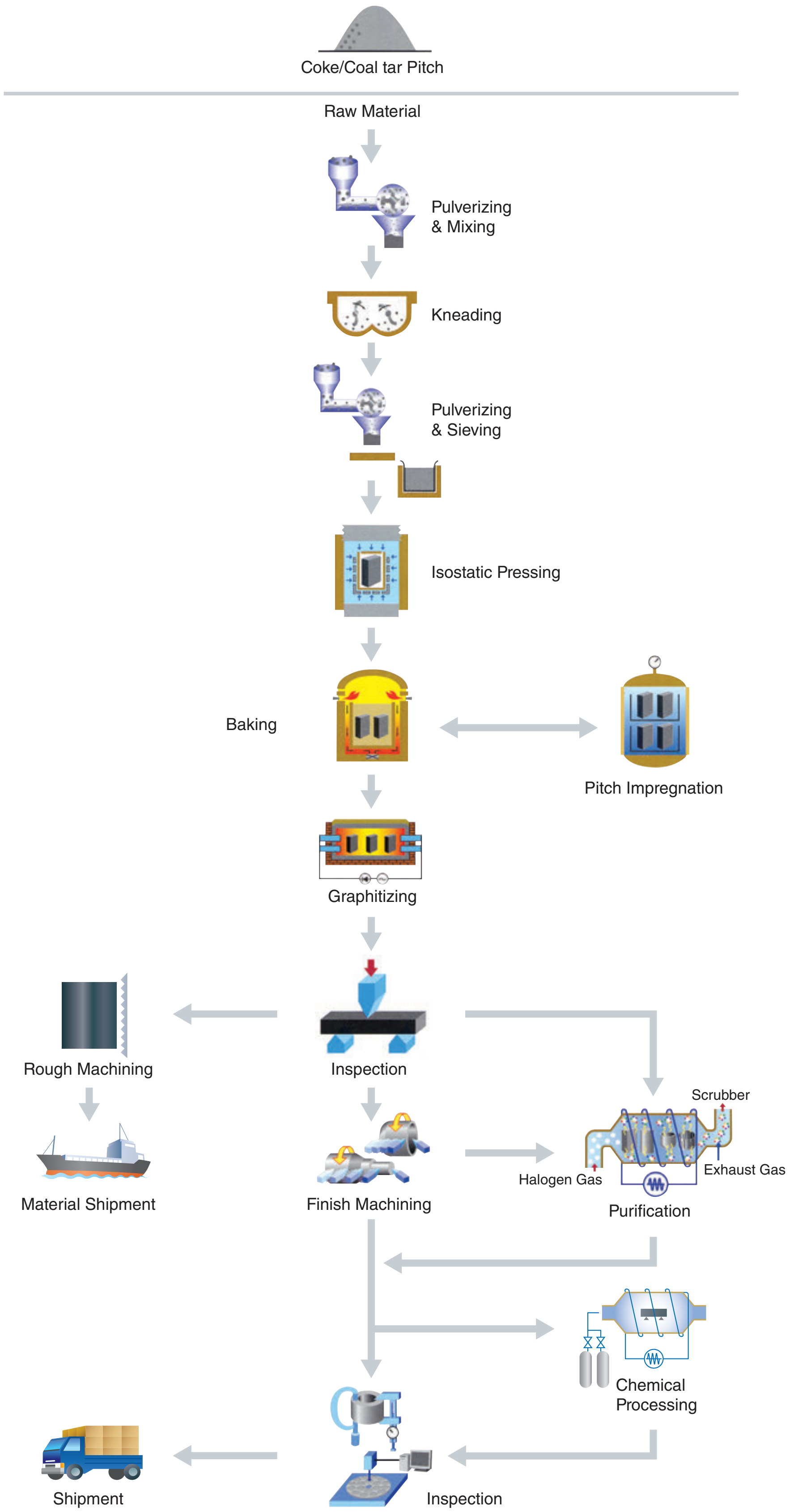

Anisotropic Graphite




Isotropic high density graphite is different from conventional graphite in that it is isotropic and has a micro particle structure, creating a very strong and highly reliable material with a small variation. This isotropic graphite material resolves the problems associate with conventional anisotropic graphite.



# Manufacturing Process



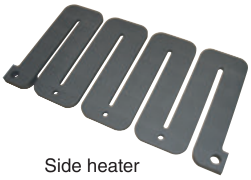
# Application

Toyo Tanso's special graphite products are highly regarded for their excellent performance and reliability and are used across a wide range of fields that are essential in our everyday lives. In the environmental and energy industry, our products are used for solar cell manufacturing, atomic power and aerospace applications. In the electronics industry, we provide materials for various manufacturing process such as polycrystalline silicon and single crystal silicon, white LEDs, and high-frequency device. Basic applications of our products include industrial furnaces, continuous casting dies such as those for copper alloys, optical fibers, and EDM electrodes for mold manufacture.



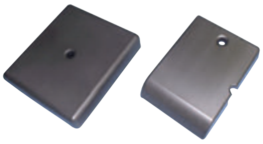
## ■ Environment and Energy

- Solar Cell and Wafer Manufacturing
- Atomic Power: High Temperature Gas Cooled Reactor, Nuclear Fusion
- Fluorine Electrolysis
- Fuel Cells
- Aerospace

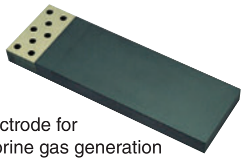


Side heater

Core component for High Temperature Gas-cooled Reactor
* Photographs provided by the Japan Atomic Energy Agency



Nuclear Fusion Reactor Plasma First Wall
* Photographs provided by National Institutes for Quantum and Radiological Science and Technology



Electrode for fluorine gas generation

## ■ Electronics

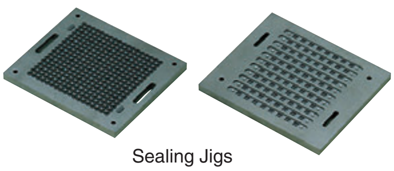
- Silicon Semi-conductor Manufacturing Applications
  - Polycrystalline silicon manufacture
  - Single crystal silicon manufacturing equipment
  - Susceptors for epitaxial growth
  - Plasma CVD electrodes
  - Ion implantation
  - Hermetic sealing jigs

Single crystal silicon manufacturing equipment

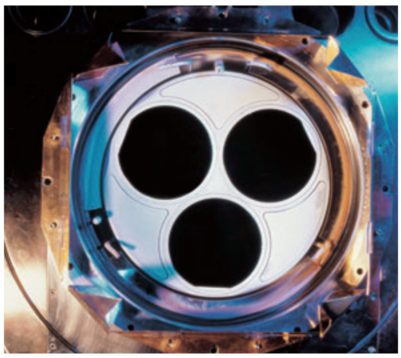
Crucible

Reflector

Heater



Sealing Jigs



## Electronics

- **Compound Semi-conductor Manufacturing Applications**
  Crystal Manufacturing Equipment Parts
  MOCVD Susceptors

- **LCD Panel Manufacturing Applications**
  Heater Panels
  Electrode for plasma Etching

- **Hard Disk Manufacturing Applications**
  Sputtering Targets

MOCVD susceptor

Pancake susceptor

## Metallurgical

- **Continuous Casting**
  Dies
  Mandrels

- **Hot Press**
  Dies
  Punch
  Sleeves
  Spacers

- **Industrial Furnace**
  Heaters
  Trays

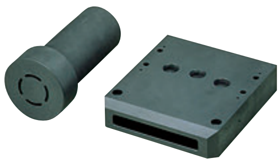
- **Vacuum Evaporation Crucibles**

- **Gas Analysis Crucibles**

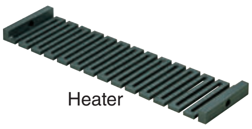
- **Optical Fiber Manufacturing Applications**
  Heaters
  Muffle Tube

- **EDM Electrodes**

Hot Press Mold
(Cut Model)



Continuous Casting Dies



Heater

Vacuum Evaporation
Crucibles

EDM Electrodes

# Property Data

## ■ Typical Properties

| Grade | Bulk Density | Hardness | Electrical Resistivity | Flexural Strength | Compressive Strength | Tensile Strength | Young's Modulus | Coefficient of Thermal Expansion | Thermal Conductivity | Standard Size |
|---|---|---|---|---|---|---|---|---|---|---|
| | Mg/m³ | HSD | μΩ·m | MPa | MPa | MPa | GPa | $10^{-6}$/K | W/(m·K) | (mm) |
| IG-11 | 1.77 | 51 | 11.0 | 39 | 78 | 25 | 9.8 | 4.5 | 120 | 305 x 620 x 1000  ø585 x 1050 |
| IG-12 | 1.78 | 55 | 12.5 | 39 | 88 | 28 | 10.8 | 4.7 | 100 | 305 x 620 x 1000  ø585 x 1050 |
| IG-15 | 1.90 | 60 | 9.5 | 54 | 103 | 29 | 11.8 | 4.8 | 140 | 230 x 620 x 1000 |
| IG-19 | 1.75 | 60 | 17.0 | 38 | 88 | 25 | 9.5 | 4.6 | 80 | ø400 x 900  305 x 620 x 1000 |
| IG-43 | 1.82 | 55 | 9.2 | 54 | 90 | 37 | 10.8 | 4.8 | 140 | 300 x 540 x 850 |
| IG-45 | 1.88 | 55 | 9.0 | 60 | 110 | 40 | 12.0 | 4.9 | 140 | 300 x 540 x 850 |
| IG-56 | 1.77 | 57 | 12.2 | 43 | 88 | 27 | 10.3 | 4.7 | 100 | 1050 x 1050 x 450  ø740 x 730 |
| IG-70 | 1.83 | 58 | 10.0 | 47 | 103 | 31 | 11.8 | 4.6 | 130 | 305 x 620 x 1000  ø460 x 1050 |
| ISEM-1 | 1.68 | 45 | 13.5 | 36 | 69 | 20 | 8.8 | 4.2 | 90 | 305 x 620 x 1000 |
| ISEM-2 | 1.78 | 55 | 11.0 | 41 | 83 | 25 | 9.8 | 4.6 | 120 | 305 x 620 x 1000 |
| ISEM-3 | 1.85 | 60 | 10.0 | 49 | 103 | 29 | 11.8 | 5.0 | 130 | 305 x 620 x 1000 |
| ISEM-8 | 1.78 | 63 | 13.4 | 52 | 106 | 34 | 10.1 | 5.6 | 90 | 305 x 620  x 1050 |
| ISO-63 | 1.78 | 76 | 15.0 | 65 | 135 | 46 | 12.0 | 5.6 | 70 | 230 x 540 x 1000 |
| ISO-68 | 1.82 | 80 | 15.5 | 76 | 172 | 54 | 13.2 | 5.6 | 70 | 230 x 540 x 1000 |
| TTK-4 | 1.78 | 72 | 14.0 | 73 | 135 | 49 | 10.9 | 5.0 | 90 | 210 x 510 x 950 |
| TTK-5 | 1.78 | 80 | 15.5 | 80 | 150 | 53 | 11.6 | 5.7 | 80 | 210 x 510 x 950 |
| TTK-8 | 1.77 | 78 | 15.0 | 80 | 155 | 55 | 12.0 | 5.3 | 80 | 100 x 400 x 700 |
| TTK-9 | 1.77 | 90 | 18.0 | 92 | 180 | 67 | 13.0 | 5.8 | 70 | 100 x 400 x 700 |
| SIC-6 | 1.85 | 60 | 10.0 | 49 | 103 | 29 | 11.8 | 5.0 | 130 | 305 x 620 x 1000 |
| SIC-12 | 1.77 | 65 | 14.1 | 47 | 93 | 29 | 10.8 | 5.0 | 80 | 305 x 620 x 1000 |
| HPG-51 | 1.78 | 73 | 14.3 | 75 | 140 | 50 | 11.0 | 5.1 | 90 | 210 x 510 x 950 |
| HPG-53 | 1.78 | 81 | 15.7 | 80 | 156 | 55 | 11.8 | 5.8 | 80 | 210 x 510 x 950 |
| HPG-59 | 1.91 | 88 | 13.5 | 100 | 210 | 74 | 12.7 | 5.7 | 95 | 100 x 500 x 950 |
| HPG-81 | 1.77 | 80 | 15.1 | 83 | 161 | 58 | 12.2 | 5.2 | 80 | 100 x 400 x 700 |
| HPG-83 | 1.77 | 92 | 18.2 | 96 | 187 | 70 | 13.3 | 5.9 | 70 | 100 x 400 x 700 |

* The figures above are typical values, and are not guaranteed.
* The measurement temperature range for the coefficient of thermal expansion is 350 to 450°C.
* Unit conversion: μΩ·m=μΩ·cm x 0.01  MPa=kgf/cm² x 0.098  GPa=kgf/mm² x 0.0098  W/(m·K)=kcal/h·m·°C x 1.16
* There are other product sizes in addition to those described above. Contact Toyo Tanso for details.

## ■ Impurity Analysis Example

Unit: mass ppm

| Element | Content | | | Measurement Method |
|---|---|---|---|---|
| | Ultra High Purity Graphite | High Purity Graphite | Regular Graphite | |
| Li | <0.001 | <0.001 | <0.03 | ICP-MS |
| B | 0.10 | 0.15 | 3 | ICP-MS |
| Na | <0.002 | <0.002 | <0.5 | ICP-MS |
| Mg | <0.001 | 0.004 | 0.2 | ICP-MS |
| Al | <0.001 | 0.012 | 14 | ICP-MS |
| Si | <0.1 | <0.1 | 2 | UV |
| K | <0.03 | 0.04 | 2 | FL-AAS |
| Ca | <0.01 | 0.08 | 6 | FL-AAS |
| Ti | <0.001 | <0.001 | 33 | ICP-MS |

| Element | Content | | | Measurement Method |
|---|---|---|---|---|
| | Ultra High Purity Graphite | High Purity Graphite | Regular Graphite | |
| V | <0.001 | 0.018 | 40 | ICP-MS |
| Cr | <0.004 | 0.006 | <0.3 | ICP-MS |
| Mn | <0.001 | <0.001 | <0.2 | ICP-MS |
| Fe | <0.02 | 0.06 | 26 | ICP-MS |
| Co | <0.001 | <0.001 | <0.3 | ICP-MS |
| Ni | <0.001 | 0.006 | 4 | ICP-MS |
| Cu | <0.002 | <0.002 | <1 | ICP-MS |
| Zn | <0.002 | <0.002 | <0.6 | ICP-MS |
| Pb | <0.001 | <0.001 | <1 | ICP-MS |

* The figures above are examples of actual measurement, and are not guaranteed.
* ICP-MS: Inductively Coupled Plasma Mass Spectrometer, FL-AAS: Flameless Atomic Absorption Spectrometer, UV: Absorption Spectrophotometer.
* The impurity content of regular graphite is approximately 400 mass ppm; however, a higher purity is required for applications such as semi-conducting industries. At Toyo Tanso, we can use a high temperature halogen treatment to purify the graphite to the mass ppm levels requested by our customers.

## Chemical Properties

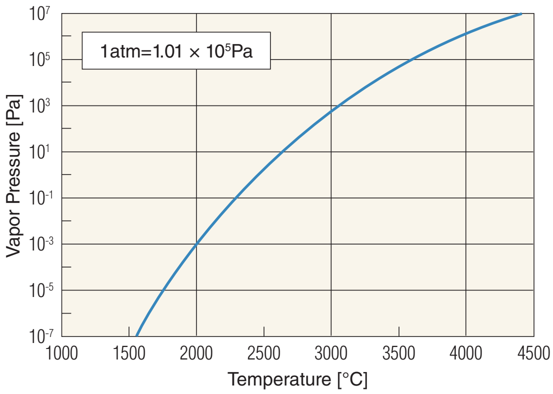
### Initial Reaction Temperatures With Various Substances

* Extracted from other publications

| Reacant | Initial Reaction Temperature | Compound of Reaction |
|---|---|---|
| Aluminum | 800°C | $Al_4C_3$ |
| Boron | 1600°C | $B_4C$ |
| Iron | 600 to 800°C | $Fe_3C$ |
| Sodium | 400 to 450°C | $C_{64}Na$ Intercalation compound (when $O_2$ is present) |
| Cobalt | 218°C | CoC, $Co_3C$ |
| Molybdenum | 700°C | $Mo_2C$ |
| Nickel | 1310°C | Ni Carbonizing in Ni |
| Silicon | 1150°C | SiC |
| Copper | — | |
| Magnesium | — | |
| Lead | — | |
| Tin | — | |
| Tungsten | 1400°C | $W_2C$, WC (in hydrogen) |
| Potassium | 300°C | $C_8K$ Other intercalation compounds |
| Lithium | 500°C | $Li_2C_2$ |
| Beryllium | 900°C | $Be_2C$ (in a vacuum or He) |
| Boron oxide | 1200°C | CO, B |
| Vanadium oxide (V) | 438°C | CO, V |
| Iron oxide (III) | 485°C | CO, Fe |
| Titanium oxide (IV) | 930°C | CO, Ti, TiC |
| Silicon dioxide | 1250°C | CO, Si, SiC |
| Alumina | 1280°C | CO, Al, $Al_4C_3$ |
| Beryllium oxide | 960°C | CO, Be, $Be_2C$ |
| Magnesium oxide | 1350°C | CO, Mg |
| Zirconium oxide (IV) | 1300°C | CO, Zr, ZrC |

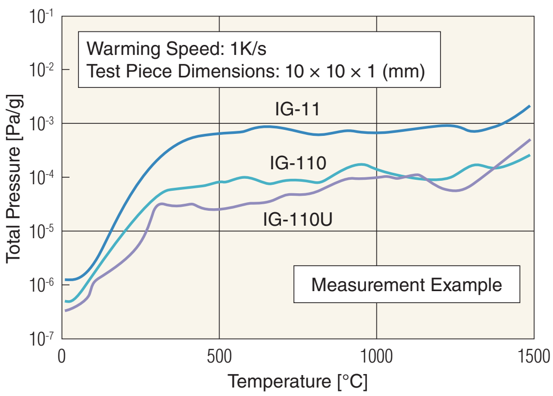
### Vapor Pressure

* Extracted from other publications




Graphite is an extremely stable material in temperatures under 2,200°C. However, the vapor pressure increases in higher temperatures and high vacuums, so caution must be exercised with regard to the accelerated wearing of graphite.

### Thermal Desorption Spectrum (TDS)




Graphite emits absorbed gas when in high temperatures.
Some applications such as semi-conducting industries must use highly purified or ultra highly purified graphite, which emits less gas.

### Reactivity With Various Atmosphere/Gas species

* Extracted from other publications

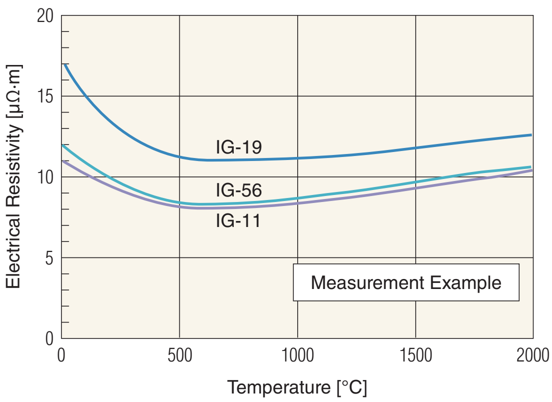
| Atmosphere/ Gaseous species | Initial Reaction Temperatures/ Reaction Temperatures | Genesis phenomenon or Produced Compound | Remarks |
|---|---|---|---|
| Air | 420 to 460°C | Oxidation/CO, $CO_2$ | Approx. 100°C higher in case of high purity graphite |
| Oxygen ($O_2$) | 420 to 460°C | Oxidation/CO, $CO_2$ | React with atomic oxygen at normal temperature |
| Steam ($H_2O$) | Approx. 650°C | Oxidation/CO, $CO_2$, $H_2$ | |
| Carbon dioxide ($CO_2$) | Approx. 900°C | Oxidation/CO | |
| Hydrogen ($H_2$) | Approx. 700°C | Methanation/$CH_4$ | Produce $C_2H_2$, $C_2H_4$, $C_2H_6$ or so at more high temperature |
| Nitrogen ($N_2$) | Inert at more than room temperature | Sublimation | Produce Cyanogen$C_2N_2$ during discharge and in 2700°C high pressure $N_2$ atmosphere |
| Chlorine ($Cl_2$) | Inert at more than room temperature | Sublimation | Produce intercalation compound in a lower temperature than 0°C |
| Fluorine ($F_2$) | 420 to 1900°C | Fluorination/CF | Produce $CF_4$, $C_2F_6$ or so up to temperature |
| Argon (Ar) | Inert at any temperature | Sublimation | |
| Vacuum | — | Sublimation | In the higher temperature and vacuum atmosphere, the easier sublimate |

In an oxidizing atmosphere, graphite reacts with oxygen at a relatively low temperature. However, in a non-oxidizing atmosphere, graphite is chemically and thermally and extremely stable material, enabling a broad range of applications.

# Property Data

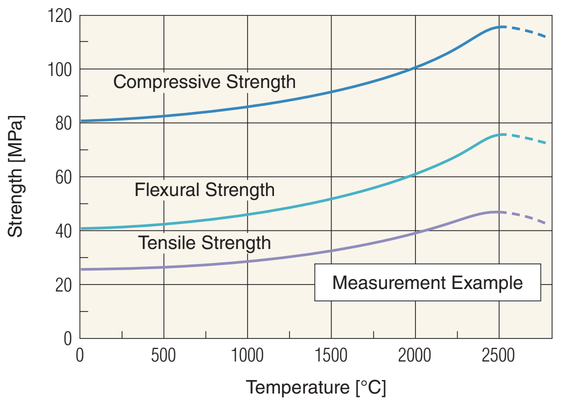
## High Temperature Properties

### Electrical Resistivity



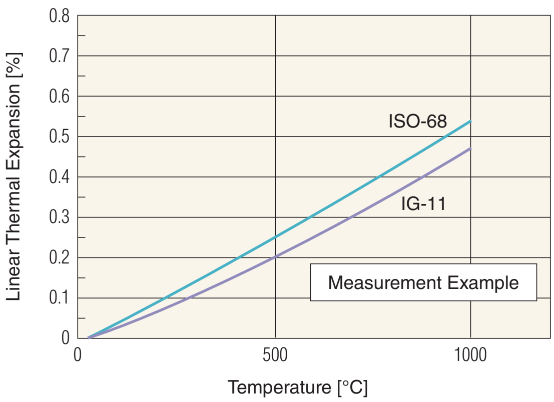

Since thermal characteristics differ from grade to grade, the coefficient of electrical resistivity must be carefully studied when selecting a grade for a heating element.

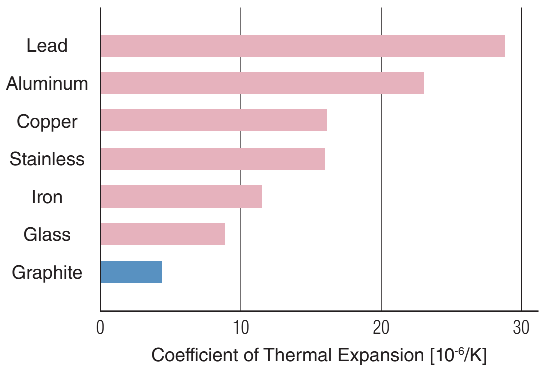
### Strengths (IG-11)




An unparalleled characteristic of graphite, which makes it indispensable in high temperature applications, is that as the temperature rises (up to 2,500°C), the strength also increases. Strength reaches levels approximately double those at room temperature.

### Linear Thermal Expansion

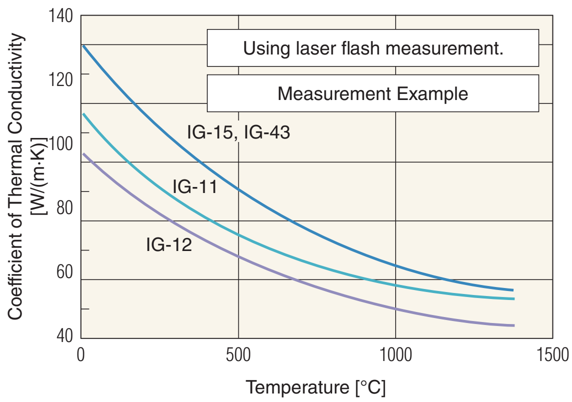


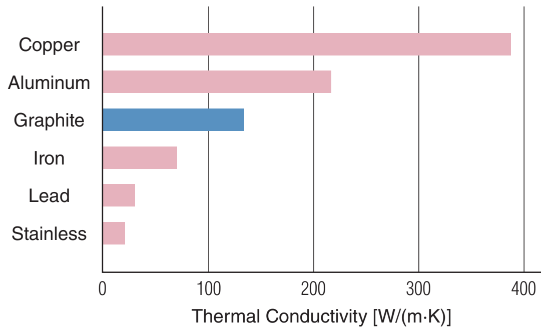




Compared with general metals, the coefficient of thermal expansion for graphite is extremely low. As a result, when used in high temperature applications, the dimensional accuracy is very stable.

Reference: Coefficient of Thermal Expansion $(10^{-6}/K) = \dfrac{\text{Linear Thermal Expansion (\%)} \times 10^{-2}}{\text{Temperature Difference (°C)}}$

### Thermal Conductivity

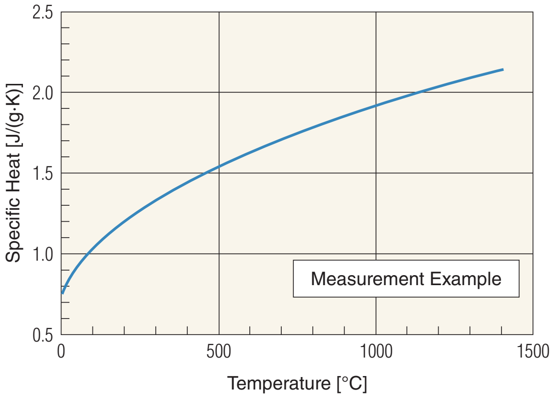



The thermal conductivity of graphite is fairly high, while the coefficient of thermal expansion is very low. These characteristics contribute to its superior thermal shock resistance. The relationship between thermal conductivity and electrical resistivity of graphite in room temperature is indicated below.

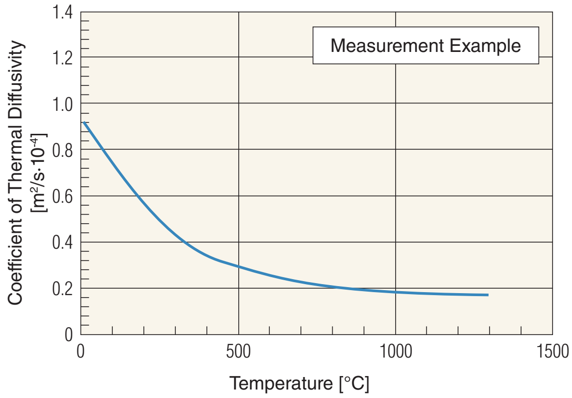
$$\text{Thermal Conductivity [W/(m·K)]} = \frac{0.13 \times 10^4}{\text{Electrical Resistivity (μΩ·m)}}$$

## Specific Heat




Due to the anisotropic nature of its crystals, the specific heat of graphite at room temperature stays at 1/3 of that of general solids. The specific heat value is essential in various thermodynamic functions. At high temperatures, specific heat values are similar regardless of the graphite grades.

## Coefficient of Thermal Diffusivity

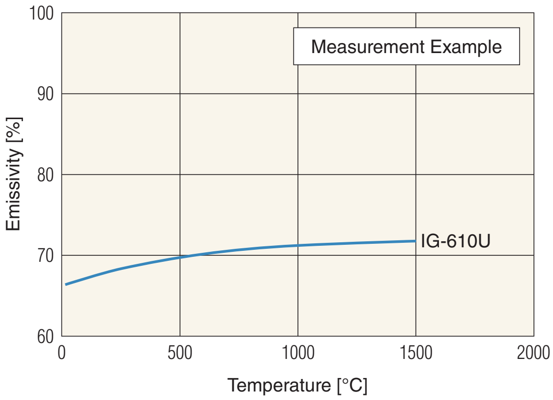



This chart shows that the higher the temperature rises, the faster the heat is transmitted. The thermal diffusivity of graphite is superior to other materials.

Reference:

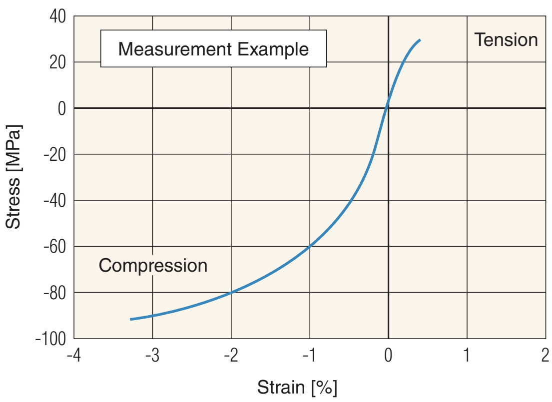
$$\text{Coefficient of Thermal Diffusivity} = \frac{\text{Thermal Conductivity}}{\text{Specific Heat} \times \text{Density}}$$

## Emissivity



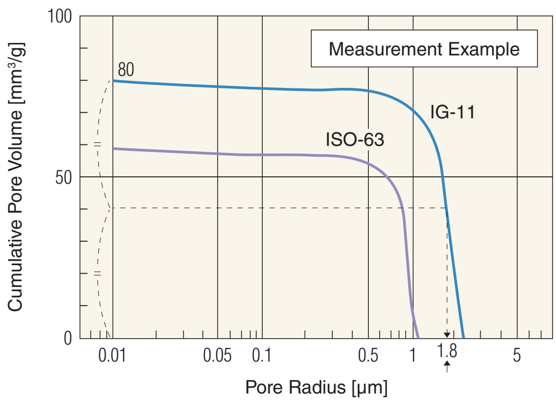

## Physical Properties

## Stress Strain Curve (IG-12)




Graphite generally shows elastic-plastic deformation. The fracture behavior is different under tension and under compression, so caution must be exercised.

## Pore Distribution Curve




This shows the pore distribution through the mercury penetration method. The pore distribution has a close relationship with gas permeability and other unique properties of graphite. The halfway position of the cumulative pore volume indicates the average pore radius.

Example: For IG-11 80/2 = 40 mm³/g→1.8 μm

# Machining

## ■ Surface Roughness Standards

Since carbon products are porous, it is difficult to obtain a surface finish that is equivalent to metal. The table on the right shows the correspondence of the "Surface Finish Symbol" and surface roughness standards, Ry & Ra & Rz.

### ■ Surface Roughness Standards

| Finish Symbol (For reference) | Machining Surface Roughness for Carbon | | | Finishing Method | Machining Surface Roughness for Metal | | |
|---|---|---|---|---|---|---|---|
| | Ry | Ra | Rz | | Ry | Ra | Rz |
| ▽▽▽▽ | √Ry3 | 0.75 | √Rz3 | Honing Lapping | √Ry0.8 | 0.2 | √Rz0.8 |
| ▽▽▽ | √Ry12 | 3.0 | √Rz12 | Grinder, Lathe Miller | √Ry6.3 | 1.6 | √Rz6.3 |
| ▽▽ | √Ry35 | 8.75 | √Rz35 | Lathe Miller | √Ry25 | 6.3 | √Rz25 |
| ▽ | √Ry100 | 25 | √Rz100 | Lathe Miller | √Ry100 | 25 | √Rz100 |
| ～ | No particular standard | | | Saw Machine | No particular standard | | |

* 3.0 means that Ra 3.0 micro miter is the maximum.

## ■ Machining Dimension Tolerance

If the tolerance is not specified on the customer drawing, apply the intermediate grade of JIS B 0405.

### ■ Dimension Tolerance Standards

Unit: mm

| Nominal Dimension Category | | Tolerance |
|---|---|---|
| 0.5 or more | 6 or less | ±0.1 |
| Exceeding 6 | 30 or less | ±0.2 |
| Exceeding 30 | 120 or less | ±0.3 |
| Exceeding 120 | 400 or less | ±0.5 |
| Exceeding 400 | 1000 or less | ±0.8 |
| Exceeding 1000 | 2000 or less | ±1.2 |

* The above information can be applied when graphite is machined by Toyo Tanso in Japan.

Toyo Tanso has a wide range of carbon and graphite grades available to meet your requirements.
Before actually using one of our products, please be sure to contact our sales department to consult on selecting the most appropriate grade.