Graphite is well adapted for use as continuous casting dies because of its unique physical characteristics:

**Coefficient of Thermal Expansion is important in mold design to compensate for growth as temperature increases.** In order to design a mold to be used at an elevated operating temperature, knowledge of the expansion coefficient is necessary to predict the initial room temperature dimensions.

**High thermal conductivity.**

**Typical Values of Thermal Conductivity**

<table>
<thead>
<tr>
<th>Material</th>
<th>W/m°C</th>
<th>CTE at 900°C</th>
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<tbody>
<tr>
<td>Silver</td>
<td>418</td>
<td>85</td>
</tr>
<tr>
<td>Copper</td>
<td>385</td>
<td>12</td>
</tr>
<tr>
<td>Tungsten</td>
<td>163</td>
<td>1</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>123</td>
<td>1.5</td>
</tr>
<tr>
<td>Nickel</td>
<td>100</td>
<td>2.5</td>
</tr>
<tr>
<td>Iron</td>
<td>90</td>
<td>5</td>
</tr>
<tr>
<td>Graphite for Sintering</td>
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<td>5</td>
</tr>
<tr>
<td>Carbon</td>
<td>42</td>
<td>10</td>
</tr>
<tr>
<td>Brick, Lampblack</td>
<td>0.7</td>
<td>0.3</td>
</tr>
<tr>
<td>Rigid Carbon Insolution Calcarb®</td>
<td>0.3</td>
<td>0.1</td>
</tr>
</tbody>
</table>

**Capable of withstanding molten metal temperatures.** Graphite sublimes at 3,650°C and atmospheric pressure.

**Graphite manufacturing.**

Graphite is easy to machine and to polish.

**Typical Electrical Resistivity vs Temperature**

- **Graphite**
- **Molybdenum**
- **Nickel**
- **Iron**
- **Copper**
- **Tungsten**
- **Carbon**
- **Aluminium**
- **Silver**

**MELTING AND BOILING POINTS**

- **Graphite**
- **Aluminium**
- **Iron**
- **Copper**
- **Gold**
- **Silver**
- **Nickel**
- **Molybdenum**
- **Tungsten**
- **Boron**
- **Tin**
- **Silicium**
- **Tin**
- **Silver**
- **Brick, Lampblack**
- **Rigid Carbon Insolution Calcarb®**

**A WORLD EXPERT in materials and solutions for high temperature processes**

**A GLOBAL PLAYER**

Global expert in materials and solutions for extreme environments as well as in the safety and reliability of electrical equipment. Mersen designs innovative solutions to address its clients specific needs to enable them to optimize their manufacturing process in sectors such as energy, transportation, electronics, chemical, pharmaceutical and process industries.

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215 Stackpole Street
St. Marys, PA 15857-1488 USA
Tel. : +1 814 781 12 34
Fax : +1 814 781 85 70

**Contact for Asia**
MERSEN Kunshan Co. Ltd.
No. 29 South Taihu Road,
Kunshan, Jiangsu Province 215334, CHINA
Tel.: +86 512 5763 98 08
Fax: +86 512 5763 98 11

**www.mersen.com**
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Mersen materials combine high thermal conductivity with low coefficients of thermal expansion, resulting in the dimensional stability required for ceramic molds.

...depends largely on the environmental conditions and process parameters in which the graphite will be used. Grade 2020 is used in diamond segment die bodies and punches where relatively high electrical conductivity is required or to shorten the time required to reach operating temperatures.

Grade 2191 is used where properties similar to 2020 are required, but higher thermal conductivity is desired.

Grade 2124 is used where strength and density requirements of the application are at the highest.

Diamond dressing rollers require a contour machined on the inner diameter of a cylinder. Diamonds are hand set on this diameter and the inside is filled with a metal matrix. The body of the dressing roll can be made by sintering, infiltrating, or reverse plating techniques. Both 2020 and 2191 will work because they are able to be machined to tight tolerances with good surface finish.

Diamond tools inserts, armor plates, and spuittering targets are all classic “punch and die” hot pressing applications. Where very large cross section dies are required, grade 2020 will be the material of choice. For high strength parts, grades 2124 and 2333 are often chosen.

Grades 2715 and 2720, with their high electrical resistivity, are recommended for many resistance heating applications. High operating temperatures can be achieved in shorter times using high resistance grades for the mold components carrying the current.

In many cases, the best way to select an optimal grade is through actual trials. Throughout the world, Mersen maintains local sales offices where our experienced customer service and engineering staffs are always available to help you find the most suitable grade for your application.

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The selection of the best graphite grade for your application...

**Recommended grades**

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
<th>2191</th>
<th>2124</th>
<th>2715</th>
<th>2720</th>
<th>2333</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>g/cm³</td>
<td>1.75</td>
<td>1.77</td>
<td>1.84</td>
<td>1.92</td>
<td>1.80</td>
</tr>
<tr>
<td>Porosity</td>
<td>%</td>
<td>12</td>
<td>9</td>
<td>8</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Hardness</td>
<td>Rockwell</td>
<td>80 (S)</td>
<td>85 (S)</td>
<td>89 (H)</td>
<td>100 (H)</td>
<td>05 (S)</td>
</tr>
<tr>
<td>Flexural strength</td>
<td>MPa</td>
<td>64.00</td>
<td>65.00</td>
<td>58.00</td>
<td>55.00</td>
<td>53.00</td>
</tr>
<tr>
<td>Compressive strength</td>
<td>MPa</td>
<td>97</td>
<td>14,100</td>
<td>14,200</td>
<td>124</td>
<td>121</td>
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<tr>
<td>Coefficient of thermal expansivity</td>
<td>x 10⁻⁶/°C</td>
<td>4.2</td>
<td>5.5</td>
<td>3.1</td>
<td>2.6</td>
<td>3.3</td>
</tr>
<tr>
<td>Electrical resistivity</td>
<td>µΩ.cm</td>
<td>1.00</td>
<td>3.00</td>
<td>1.55</td>
<td>1.14</td>
<td>2.30</td>
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<td>Linear thermal expansion</td>
<td>µin/°F</td>
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<td>0.00005</td>
<td>0.00043</td>
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<td>Average grain size</td>
<td>µm</td>
<td>15</td>
<td>15</td>
<td>12</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>Standard block size</td>
<td>mm</td>
<td>ø 14 x 72</td>
<td>ø 643 x 1,830</td>
<td>ø 24 x 72</td>
<td>ø 356 x 1,830</td>
<td>ø 14 x 72</td>
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<td>99</td>
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<td>121</td>
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<td>45</td>
<td>58</td>
<td>55</td>
<td>53</td>
<td></td>
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<td>Thermal conductivity</td>
<td>W/m°C</td>
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<td>85</td>
<td>112</td>
<td>56</td>
<td>60</td>
</tr>
<tr>
<td>Electrical conductivity</td>
<td>Ω cm</td>
<td>80 (L)</td>
<td>95 (L)</td>
<td>80 (H)</td>
<td>100 (H)</td>
<td>85 (L)</td>
</tr>
<tr>
<td>Thermal resistance factor</td>
<td>67</td>
<td>49</td>
<td>65</td>
<td>32</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>Thermal expansion /°C</td>
<td>545 x 545 x 1,830</td>
<td>530 x 635 x 1,830</td>
<td>308 x 620 x 1,830</td>
<td>308 x 620 x 915</td>
<td>305 x 305 x 915</td>
<td></td>
</tr>
<tr>
<td>Density g/cm³</td>
<td>1.77</td>
<td>1.80</td>
<td>1.82</td>
<td>1.80</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bulk density</td>
<td>1.77</td>
<td>1.80</td>
<td>1.82</td>
<td>1.80</td>
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<td></td>
</tr>
<tr>
<td>Strength of the material</td>
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<td>1.80</td>
<td>1.82</td>
<td></td>
<td></td>
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<td>1.82</td>
<td>1.80</td>
<td>1.82</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thermal and electrical conductivity</td>
<td>1.80</td>
<td>1.82</td>
<td>1.80</td>
<td>1.82</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Typical characteristics**

...is substantially determined by the properties of the materials the dies are to be made from, in particular the graphite. The standard graphite material used by Mersen is graphite 2020.

Diamond dressing rollers hot molded from 2020 die.

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The selection of the best graphite grade for your application is based on considering several parameters:

- **Bulk density**
- **Strength of the material**
- **Coefficient of thermal expansivity**
- **Thermal and electrical conductivity**

Parameters are critical to advanced ceramic applications, such as:

- Ceramic tool inserts, armor plates, and sputtering targets are all classic “punch and die” hot pressing applications. Where very large cross section dies are required, grade 2020 will be the material of choice.
- For high strength parts, grades 2124 and 2333 are often chosen.
- Grades 2715 and 2720, with their high electrical resistivity, are recommended for many resistance heating applications. High operating temperatures can be achieved in shorter times using high resistance grades for the mold components carrying the current.

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**Pressure Sintering**

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---

**Typical Characteristics**

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<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
<th>2191</th>
<th>2020</th>
<th>2124</th>
<th>2715</th>
<th>2720</th>
<th>2333</th>
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<tbody>
<tr>
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<td>14,100</td>
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<td>16,900</td>
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<td>10</td>
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<td>95</td>
<td>100</td>
<td>100</td>
<td>95</td>
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<tr>
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<td>MPa</td>
<td>6,450</td>
<td>6,500</td>
<td>8,410</td>
<td>8,000</td>
<td>7,700</td>
<td>11,000</td>
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<tr>
<td>Compressive strength MPa</td>
<td></td>
<td>100</td>
<td>100</td>
<td>124</td>
<td>118</td>
<td>117</td>
<td>117</td>
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<tr>
<td>Coefficient of thermal expansion /°C</td>
<td></td>
<td>-2.5</td>
<td>-2.0</td>
<td>-5.5</td>
<td>-6.0</td>
<td>-5.0</td>
<td>-5.0</td>
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<tr>
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<td>4.5</td>
<td>4.0</td>
<td>3.8</td>
<td>3.6</td>
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<td>3.0</td>
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<tr>
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<td></td>
<td>5,000</td>
<td>5,000</td>
<td>1,510</td>
<td>1,430</td>
<td>1,240</td>
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<td>%</td>
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<td>124</td>
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<td>Average grain size</td>
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<td>ø 356</td>
<td>ø 219</td>
<td>ø 219</td>
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<tr>
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<td>100</td>
<td>95</td>
</tr>
<tr>
<td>Flexural strength</td>
<td>MPa</td>
<td>6,450</td>
<td>6,500</td>
<td>8,410</td>
<td>8,000</td>
<td>7,700</td>
<td>11,000</td>
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<td>Compressive strength MPa</td>
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<td>124</td>
<td>118</td>
<td>117</td>
<td>117</td>
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<tr>
<td>Coefficient of thermal expansion /°C</td>
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<td>-2.5</td>
<td>-2.0</td>
<td>-5.5</td>
<td>-6.0</td>
<td>-5.0</td>
<td>-5.0</td>
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<tr>
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<td>4.5</td>
<td>4.0</td>
<td>3.8</td>
<td>3.6</td>
<td>3.0</td>
<td>3.0</td>
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<tr>
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<td></td>
<td>5,000</td>
<td>5,000</td>
<td>1,510</td>
<td>1,430</td>
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<tr>
<td>Porosity</td>
<td>%</td>
<td>97</td>
<td>97</td>
<td>124</td>
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<td>ø 356</td>
<td>ø 356</td>
<td>ø 219</td>
<td>ø 219</td>
<td>ø 219</td>
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<tr>
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**Recommended Grades**

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<table>
<thead>
<tr>
<th>Grade</th>
<th>Description</th>
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<tbody>
<tr>
<td>2191</td>
<td>Diamond dress rolls</td>
</tr>
<tr>
<td>2020</td>
<td>Ceramic tool inserts</td>
</tr>
<tr>
<td>2124</td>
<td>Ceramic tool inserts</td>
</tr>
<tr>
<td>2715</td>
<td>Ceramic tool inserts</td>
</tr>
<tr>
<td>2720</td>
<td>Ceramic tool inserts</td>
</tr>
<tr>
<td>2333</td>
<td>Ceramic tool inserts</td>
</tr>
</tbody>
</table>
```

---

**Parameters Critical to Advanced Ceramic Applications are:***

- Bulk density
- Strength of the material
- Coefficient of thermal expansion
- Thermal and electrical conductivity

---

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---

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(Photograph courtesy of CITCO Division, Western Atlas)

---

**Single and multi-point dressing tools**

(Photograph courtesy of CITCO Division, Western Atlas)

---

**Diamond dressing rollers hot molded from 2020 A6.**

(Photograph courtesy of CITCO Division, Western Atlas)
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Diamond dressing rollers hot molded from 2020 die.

(Photograph courtesy of CITCO Division, Western Atlas)

Recommended Grades

<table>
<thead>
<tr>
<th>Property Unit</th>
<th>2191</th>
<th>2020</th>
<th>2124</th>
<th>2715</th>
<th>2720</th>
<th>2333</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density, g/cc</td>
<td>1.75</td>
<td>1.77</td>
<td>1.04</td>
<td>1.02</td>
<td>1.01</td>
<td>1.86</td>
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<tr>
<td>Hardness, Rockwell</td>
<td>90-95</td>
<td>90-95</td>
<td>80-85</td>
<td>80-85</td>
<td>80-85</td>
<td>80-85</td>
</tr>
<tr>
<td>Flexural strength, MPa</td>
<td>46</td>
<td>64.50</td>
<td>6.55</td>
<td>6.49</td>
<td>6.39</td>
<td>7.00</td>
</tr>
<tr>
<td>Porosity,</td>
<td>48</td>
<td>50</td>
<td>55</td>
<td>50</td>
<td>53</td>
<td>76</td>
</tr>
<tr>
<td>Coefficient of thermal expansion, 10⁻⁶/°C</td>
<td>2.4</td>
<td>3.1</td>
<td>3.5</td>
<td>3.1</td>
<td>3.5</td>
<td>3.6</td>
</tr>
<tr>
<td>Coefficient of thermal conductivity, W/m°C</td>
<td>1.09</td>
<td>1.50</td>
<td>1.55</td>
<td>1.40</td>
<td>1.40</td>
<td>1.50</td>
</tr>
<tr>
<td>Electrical resistivity, Ω cm</td>
<td>6.4 x 10⁸</td>
<td>5.0 x 10⁸</td>
<td>3.0 x 10⁸</td>
<td>3.5 x 10⁸</td>
<td>3.0 x 10⁸</td>
<td>5.0 x 10⁸</td>
</tr>
<tr>
<td>Electrical resistivity, mΩ m</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Average grain size, 10⁻³ in</td>
<td>0.00005</td>
<td>0.00005</td>
<td>0.00005</td>
<td>0.00005</td>
<td>0.00005</td>
<td>0.00005</td>
</tr>
<tr>
<td>Standard block size, nominal</td>
<td>ø 12.7 x 24.5 x 38.1</td>
<td>ø 25.4 x 50.8 x 76.2</td>
<td>ø 25.4 x 50.8 x 76.2</td>
<td>ø 25.4 x 50.8 x 76.2</td>
<td>ø 25.4 x 50.8 x 76.2</td>
<td>ø 25.4 x 50.8 x 76.2</td>
</tr>
</tbody>
</table>

Parameters critical to advanced ceramic applications are:

- Bulk density
- Strength of the material
- Coefficient of thermal expansion
- Thermal and electrical conductivity

Typical characteristics

Diamond dressing rollers hot molded from 2020 die.

(Photograph courtesy of CITCO Division, Western Atlas)

Single and multi-point dressing tools. (Photograph courtesy of CITCO Division, Western Atlas)

"Graphite is the mold designer’s material of choice, and our experienced engineering staff will help you find the right material for your application."
Coefficient of Thermal Expansion is important in mold design to compensate for growth as temperature increases. In order to design a mold to be used at an elevated operating temperature, knowledge of the expansion coefficient is necessary to predict the initial room temperature dimensions.

High thermal conductivity.

Capable of withstanding molten metal temperatures. Graphite sublimes at 3,650°C and atmospheric pressure.

Easy to machine and to polish.

Typical values of thermal conductivity for sintering materials (W/m·°K):
- Silver: 418
- Copper: 385
- Tungsten: 320
- Molybdenum: 280
- Graphite: 120
- Nickel: 90
- Iron: 75
- Carbon: 42
- Brick: 0.7
- Lampblack: 0.3
- Rigid Carbon Insulation Calcarb®: 0.1

Typical electrical resistivity vs temperature for various materials:
- Silver: 100 Ω·cm
- Copper: 120 Ω·cm
- Tungsten: 140 Ω·cm
- Molybdenum: 150 Ω·cm
- Graphite: 200 Ω·cm

Graphite manufacturing.

Graphite is well adapted for use as continuous casting dies because of its unique physical characteristics:
- Capable of withstanding molten metal temperatures.
- High thermal conductivity.
- Easy to machine and to polish.
- High thermal conductivity.
- Capable of withstanding molten metal temperatures.
- Easy to machine and to polish.

TYPICAL ELECTRICAL RESISTIVITY VS TEMPERATURE

MELTING AND BOILING POINTS

Graphite is well adapted for use as continuous casting dies because of its unique physical characteristics:
- Capable of withstanding molten metal temperatures.
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- Easy to machine and to polish.

Co-efficient of Thermal Expansion

Metal | Coefficient of Thermal Expansion (x10^-6/°C)
--- | ---
Graphite | 0.6
Nickel | 5.7
Iron | 8.5
Copper | 14.5
Tungsten | 16.5
Molybdenum | 19.0
Graphite for Sintering | 20.0

Graphite is well adapted for use as continuous casting dies because of its unique physical characteristics:
- Capable of withstanding molten metal temperatures.
- High thermal conductivity.
- Easy to machine and to polish.

TYPICAL VALUES OF THERMAL CONDUCTIVITY MATERIAL (W/m·°K)

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- Capable of withstanding molten metal temperatures.
- High thermal conductivity.
- Easy to machine and to polish.

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**Coefficient of Thermal Expansion**

- Important in mold design to compensate for growth as temperature increases.
- In order to design a mold to be used at an elevated operating temperature, knowledge of the expansion coefficient is necessary to predict the initial room temperature dimensions.

**Typical Values of Thermal Conductivity**

- **Material (W/m·°K)**
  - Silver: 418
  - Copper: 385
  - Tungsten: 163
  - Molybdenum: 123
  - Graphite for Sintering: 100
  - Nickel: 90
  - Iron: 75
  - Carbon: 42
  - Carbon Brick: 0.7
  - Rigid Carbon Insulation Calcarb®: 0.3
  - Lampblack: 0.1

**Typical Electrical Resistivity vs Temperature**

- **Material (μΩ·cm)**
  - Silver: 418
  - Copper: 385
  - Tungsten: 163
  - Molybdenum: 123
  - Graphite for Sintering: 100
  - Nickel: 90
  - Iron: 75
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**Graphite is well adapted for use as continuous casting dies because of its unique physical characteristics:**

- High thermal conductivity.
- Capable of withstanding molten metal temperatures. Graphite sublimes at 3,650°C and atmospheric pressure.
- Easy to machine and to polish.
- Good thermal conductivity.
- High melting point.

**Specialty Graphite Materials for Sintering**

Global expert in materials and solutions for high temperature processes. Mersen designs innovative solutions to address its clients’ specific needs to enable them to optimize their manufacturing processes in sectors such as energy, transportation, electronics, chemical, pharmaceutical and process industries.

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