Carbide Grades for PM Tooling

Mark T. Klingensmith
Manager of Technical Sales and PM Applications

Dr. Leonid Frayman
Chief Metallurgist

Hollywood (Ft. Lauderdale), Florida, USA
Agenda:

- Cemented Carbides: What are they and why use them in PM tooling applications?
- Carbide Materials Selection for PM tooling components.
- What advancements have been made in processing and manufacturing cemented carbides? Grade development?
- Grade Recommendations for PM Tooling.
- Summary
What is Cemented Carbide Grade?

Definition:
Cemented Carbide is a composite material of a soft binder metal usually either Cobalt (Co) or Nickel (Ni) or Iron (Fe) or a mixture thereof and hard carbides like WC (Tungsten Carbide), Mo₂C (Molybdenum Carbide), TaC (Tantalum Carbide), Cr₃C₂ (Chromium Carbide), VC (Vanadium Carbide), TiC (Titanium Carbide), etc. or their mixes.
Why should cemented carbide be used for PM Tooling?
Typical Tooling Elements for Rigid Die Compaction /Sizing of Powdered Material Components.
What do PM Tools see under normal working conditions?

Therefore, tools should efficiently resist wear, corrosion and impact…
# PROPERTIES OF SOME SELECTED WC-Co CEMENTED CARBIDE GRADES vs. OTHER TOOL MATERIALS.

<table>
<thead>
<tr>
<th>Composition, wt.%</th>
<th>Hardness, HRa</th>
<th>Abrasion Resistance, 1/vol.loss cm³</th>
<th>Transverse Rupture Strength, 1,000 lb/in²</th>
<th>Ultimate Compression Strength, 1,000 lb/in²</th>
<th>Ultimate Tensile Strength, 1,000 lb/in²</th>
<th>Modulus of Elasticity, 10⁶ lb/in²</th>
<th>Thermal Expansion, @75 °C-400 °C Cal/(s·°C·cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WC-6%Co</td>
<td>92.8</td>
<td>35-60</td>
<td>335</td>
<td>860</td>
<td>160</td>
<td>92</td>
<td>2.9</td>
</tr>
<tr>
<td>WC-9%Co</td>
<td>89.5</td>
<td>10-13</td>
<td>425</td>
<td>660</td>
<td>-</td>
<td>87</td>
<td>2.7</td>
</tr>
<tr>
<td>WC-13%Co</td>
<td>88.2</td>
<td>4-8</td>
<td>500</td>
<td>600</td>
<td>-</td>
<td>81</td>
<td>3.0</td>
</tr>
</tbody>
</table>

**Other Materials (for comparison & consideration)**

<table>
<thead>
<tr>
<th>Tool Steel (T8)</th>
<th>85 (66 HRc)</th>
<th>2</th>
<th>575</th>
<th>600</th>
<th>-</th>
<th>34</th>
<th>6.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Steel (AISI 1095)</td>
<td>79 (66 HRc)</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>300</td>
<td>30</td>
<td>-</td>
</tr>
<tr>
<td>Cast Iron</td>
<td>-</td>
<td>2</td>
<td>105</td>
<td>-</td>
<td>-</td>
<td>15-30</td>
<td>9.2</td>
</tr>
</tbody>
</table>

Copyright 2010
Why Do We Need and Use Cemented Carbide?

... because of its unique combination of superior physical and mechanical properties including:

- **Abrasion Resistance:** Cemented carbide can outlast wear-resistant steel grades by a factor up to **100 to 1**;
- **Deflection Resistance:** Cemented Carbide has a Modulus of Elasticity three times that of steel which translates into one third of deflection when compared to the steel bars of the same geometry and loading;
- **Tensile Strength:** Tensile Strength is varied from **160,000 psi to 300,000 psi**;
- **Compressive Strength:** Compressive Strength is over **600,000 psi**;
- **High Temperature Wear Resistance:** Good wear resistance up to **1,000 °F**.

...thus, Cemented Carbide is often the best material choice for particularly tough applications providing the most cost-effective solution to a challenging problem...
Analysis of Applicability of Cemented Carbides for Tool Members within PM Tool Die Set:

...based on Tool Members Functions...
Powder Compaction Schematic in Rigid Tool Set:

“Green” Compact.

With various motions, PM tools sustain various types of thermo-mechanical stresses
Considerations for PM Compacting Tools
Material Selection:

- Tool members within PM die set during compaction or sizing are subjected to pretty high compaction pressure being frequently as high as 690-900 MPa (approximately 50 -- 65 tsi)

- The whole PM tooling must be robust enough to last from several hundred press strokes to more than a million cycles without any damage or wear while keeping proper dimensions and tolerances.

- The initial cost of PM tooling depends upon the level of complexity of the powder component to be produced as well as on the robustness and durability of the tool members themselves.
Key Tool Elements of PM Compaction Die Set Assembly

- Top Punch
- Die
- Core Rod
- Bottom Punch

Separate Tool Members
Requirements of each separate tool element within a Compacting / Sizing Tool Die Assembly....

- The whole **Die Set** must be able to withstand to sizable radial pressure during compaction or sizing operations to hold the tolerances in the horizontal cross-section of the component to be formed.

- **The Die** (**Die Insert**) experiences sliding wear and quite often abrasion wear patterns during either compaction or sizing, especially along its internal circumferential surface. It also sees adhesive wear through friction because of the ejection motion of the “green” compact when the part is leaving the **Die**.

**Therefore, Cemented Carbide Die Inserts are frequently used due to their high wear resistance**
...Requirements of Each Separate Tool Element within the Compacting / Sizing Tool Die Assembly...

- Both **Bottom Punch** and **Upper Punch** should be able to resist expansion under repeated compaction / sizing cycles. Therefore, punches must have high compressive yield strength as well as sustainable toughness and high fatigue strength frequently linked to high wear resistance.

*Note: Cemented Carbide Punch Inserts ensure both high wear resistance and favorable fatigue stress distribution.*
...Requirements of each separate tool element within Compacting / Sizing Tool

Die Assembly:

- **Core Rods** and **Pins** should possess high hardness and wear resistance, and for this reason, they are mainly fabricated from Cemented Carbides. Also, **Core Rods** and **Pins** are subjected to cyclic dynamic loads during compaction /sizing, especially challenging when they have thin cross-section and/or are of a complex shape by design.
Carbide Materials Selection & Consideration for PM Tool Needs…
How do we recommend or create a grade for a specific PM application?

What considerations are there in producing a certain grade?
Grain Size VS Cobalt Content:

**GC-411CT**
- Hardness: 88.0 - 89.0
- TRS: 490,000 psi
- Average grain size: 4.5 micron
- Galling Resistance: Moderate
- Corrosion Resistance: High
- Wear resistance: Good

**GC-010**
- Hardness: 91.4 - 92.2
- TRS: 550,000 psi
- Average grain size: 0.8 micron
- Galling Resistance: Low
- Corrosion Resistance: Low
- Wear resistance: High
Effect of Grain Size

- **ultrafine**: 0.5 µm
- **submicron**: 0.8 µm
- **medium**: 1-2 µm
- **coarse**: >= 3 µm

Wear Resistance

Shock Resistance/Toughness
Constant binder content - varying grain size

4 µm

2 µm

1500x

0.8 µm

0.5 µm
Fine grain formulation:

What does it do for Cemented Carbide?

A finer grain material can achieve higher hardness with a given cobalt binder but has a lower transverse rupture strength value.

GC-010
Effect of Binder Content.

- Wear Resistance

- Shock Resistance/Toughness

- < 4%
- 4% - 10%
- 10% - 16%
- > 16%
Constant grain size/varying binder content

6% 10%

16% 24%
Processing Advancements...

...or how to make superior quality with cemented carbide material....
Manufacturing Process of Cemented Carbides

1. **Virgin**
2. **Powder Making**
3. **Ready Powder**
4. **Pressing**
5. **Preforms or Billets**
6. **Shaping**
7. **Sintering**
8. **Shaped Parts**
9. **Sintered Parts**
10. **Final Treatment:** (Grinding, Coating, etc.)
11. **Finished Parts**

**Steps:**
- Powder Making
- Pressing
- Shaping
- Sintering
- Final Treatment
- Finished Parts
Key Manufacturing Operations:

- Milling
- Vacuum Drying
- Mechanical pressing
- Spray Drying
- Powder shaping
- Sinter-HIP Thermal Processing
- Cold Isostatic Pressing
In the process of **attrition milling**, a milling media (e.g. cemented carbide balls) is introduced into the milling attritor together with special milling liquid. During this process agglomerates of the basic materials are destroyed and a **homogeneous mix is achieved.**
Spray Dry processing of Cemented Carbides provides uniform particle size and weight, uniform lubricant wax distribution and uniform carbon balance within bulk material.

Spray Drying ensures excellent particle flow in the die cavity. At General Carbide, spray drying is routinely used to dry and granulate the attritor-milled cemented carbide suspension.
Granulation via Spray Drying

By means of granulation, fine particles of the different basic materials are agglomerated to larger grains.

To achieve this, paraffin is added at a previous milling operation into the “slurry“ which is vaporized in small drops via this process.

The drops rise in the spray dryer and hit upon an inverted stream of hot gas. The liquid parts of the mixing and milling agent evaporate and the solid particles agglomerate under the stabilizing effect of the paraffin to produce spheroidized grains.
Advancements in Thermal Consolidation of Cemented Carbides
Methods of Thermal Consolidation Used in Manufacturing of Cemented Carbides:

- Vacuum Sintering
- Atmospheric Sintering (less frequently used);
- Hot Isostatic (Isotropic) Pressing [HIP];
- Sinter-HIP Processing;
- Hot Pressing (Anisotropic) under Vacuum.
Sinter-HIP vs. Post-HIP: Cost-Efficient and Productive Alternative...

• Sinter-HIP requires 10-15 times less pressure than post-HIP processing.
• Sinter-HIP - the overall time of applied pressure is 4-6 times less compared to post-HIP processing.
• Sinter-HIP reduces Argon-gas consumption by 90% vs. post-HIP process.
Sinter-HIP Advantage:

Sinter-HIP processing combines both Sintering and HIP into ONE single processing operation at the last consolidation stage while the whole operation is performed in one furnace.
Cemented Carbide Grades - Design & Development
New Materials Lab:
For Mechanical Strength

Examples:

PM dies and punches, sizing dies.....
Palmqvist Fracture Toughness Test:

Schematic of Palmqvist Test with Vickers indentation.

- Palmqvist Toughness ($W_G$)

\[ W_G = \frac{P}{T}, \text{where} \]

- Palmqvist fracture toughness ($W_K$)

\[ W_K = A \times \sqrt{HV} \times \sqrt{W_G} \]

Where $A$-constant; HV-Vickers Hardness
## Important Mechanical Properties for Selected Carbide Grades:

Table 1. Palmqvist Fracture Toughness ($W_K$) for Selected Carbide Grades

<table>
<thead>
<tr>
<th>Grade ID</th>
<th>$W_K$ MN * (m^(-3/2))</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>GC-313 *</td>
<td>18</td>
<td>3</td>
</tr>
<tr>
<td>GC-613CT</td>
<td>23</td>
<td>3</td>
</tr>
<tr>
<td>GC-411CT</td>
<td>17</td>
<td>1</td>
</tr>
<tr>
<td>GC-415CT</td>
<td>21</td>
<td>3</td>
</tr>
</tbody>
</table>

* Denotes C-12 Grade
Material Design: Premium WC Crystals:

Unique and proprietary crystal structure
Tungsten Carbide grain has a perfect stoichiometric balance of 6.13% carbon throughout

...can be alloyed with Tantalum Carbide and Corrosion Additives

GC-411CT
GC-613CT
GC-415CT
GC-813CT
For Adhesive Wear ......

Examples:
PM dies and punches, sizing dies.....
Tantalum Carbide (TaC) Additions:

What does it do for Cemented Carbide?

- Anti-galling agent
- Reduces friction between the work material and die wall
- Acts as an internal built-in lubricant

GC-613CT
Grade Attributes: The coarse structure coupled with medium binder content provides a grade with good wear resistance and the capability to withstand moderate impact loads. The tantalum carbide adds lubricity and exceptional resistance to galling in all wear areas. For PM applications, ejection forces during powder compaction are sizably less versus conventional carbide grades.

The presence of corrosion-resistant additive provides moderate resistance to environmental corrosion.

Typical Applications: Powder Metal Dies (Wire EDM), sizing and PM punches, WEDM blocks.
For Abrasive Wear ....

Examples:
PM dies and punches.....
Grade Attributes: The unique mixed particle sizes of the tungsten carbide, coupled with the intermediate binder content, provides an excellent wear resistant grade with resistance to impact. The tantalum carbide addition provides resistance to galling as often experienced in cold rolled steel and stainless steel stamping, as well as thermal edge deformation resistance. Enhanced ejection force for metallic powders cold compaction dies. The corrosion resistant additive provides resistance to corrosion in the EDM process, from lubrication, and from atmospheric corrosion on stored dies.

Typical Applications: All lamination tooling, large EDM blocks, stamping punches and dies, powder metal tooling, including dies and punches.
Examples:

Negative influence of residual lubricants that may remain on the working surfaces of tools being stored in tooling premises for future usage.

...especially, when lubricants may contain Chlorine- or Sulfur radicals within it....
Typical corrosion/leaching conditions:

The selective dissolution of the Co-binder from regular WC-Co cemented carbide microstructure.
Corrosion resistance of GC-411CT

GC-313*  GC-411CT*

*Test conducted in tap water over 48 hours.
Grade Attributes: A relatively coarse carbide particle grains size being coupled with medium binder content provides a wear resistant grade with moderate withstanding to impact. The tantalum carbide ensures sufficient resistance to galling. Good sliding wear characteristics for PM compaction tool applications. The corrosion-resistant additive exhibits high resistance to binder leaching at the EDM processing as well as prevents from the negative influence of residual lubricants that may remain on the working surfaces of tools being stored in tooling premises for future usage.

Typical Applications: Powder metal dies, wire EDM blocks, heavy stamping and lamination punches and dies, pierce punches and dies.

Composition:
- Tungsten Carbide: (4.5 micron) 86.0%
- Cobalt: 11.0%
- Tantalum Carbide: 2.0%
- Other: 1.0%

Physical properties:
- Hardness, HRA (ASTM B294): 88.5-89.5.5
- Density, g/cc (ASTM B311): 14.19 -14.31
- Aver. Transv. Rupture Strength, psi (ASTM B406): 490,000
- Typical Porosity (ASTM B276): A02-B00-C00
Electrolytic Attack

GC-313*

GC-411CT*

*Test conducted in wire tank for 100 hours.
General Recommendations to Resist Corrosion:

• WC with lower binder and finer grain size is better.
• WC grades with corrosion resistant Nickel-based binder and/or chrome carbide additives are superior to regular carbide grades.
EDM Serviceability: Effect of Alloying Concept

**GC-411CT**
WEDM Cut Edge Area:
Clean cut without cracks and minimal re-cast zone.

**GC-313**
WEDM Cut Edge Area:
Regular Carbide Grade provides rough cut with the presence of micro-crack type defects on the cut edge and large re-cast zone.
For Significant Impact Sustainability and Efficient Wear Resistance:

Examples:

PM and sizing dies, sizing punches.....
# High Performance Grades for PM Tools

## Grade Specifications

### GC-415CT

**Composition:**
- Tungsten Carbide (4.5 micron): 81.0%
- Cobalt: 16.0%
- Tantalum Carbide: 2.0%
- Other: 1.0%

**Physical Properties:**
- Hardness, HRA (ASTM B294): 87.4 - 88.4
- Density, g/cc (ASTM B311): 13.72 - 13.82
- Average Transverse Rupture Strength, psi (ASTM B406): 450,000
- Typical Porosity (ASTM B276): A02-B00-C00

**Performance Characteristics:**
- Wear Resistance: Moderate
- Impact Resistance: High
- Galling Resistance: High
- Corrosion Resistance: Mod / High

**Grade Attributes:** The relatively coarse carbide particle grains size being coupled with medium binder content provides a wear resistant grade with good resistance to impact. The tantalum carbide ensures efficient withstanding to galling. The corrosion-resistant additive exhibits relatively high resistance to binder leaching at the EDM shape processing as well as its structure prevents from the negative influence of residual lubricants that may remain on the working surfaces of the tools being stored in the tooling premises for future usage.

**Typical Applications:** Wire EDM blocks, punches and dies, powder metal dies, slitters.

### GC-425CT

**Composition:**
- Tungsten Carbide (3-, 4-, and 6-micron WC grains): 70.5%
- Cobalt: 25.0%
- Tantalum Carbide: 4.0%
- Other: 0.5%

**Physical Properties:**
- Hardness, HRA (ASTM B294): 83.5 - 84.5
- Average Transverse Rupture Strength, psi (ASTM B406): 470,000
- Typical Porosity (ASTM B276): A02-B00-C00

**Performance Characteristics:**
- Wear Resistance: Modest
- Impact Resistance: High
- Galling Resistance: High
- Corrosion Resistance: Moderate

**Grade Attributes:** The mixture of intermediate carbide particle grain sizes coupled with the higher binder content provides a grade that can withstand heavy impact and, at the same time, exhibits moderate wear resistance and corrosion resistance. This grade also exhibits relatively good machinability. The tantalum carbide additive ensures high anti-galling properties.

**Typical Applications:** Sizing dies and core pins for powder metal tooling, die inserts for heavy loaded cold heading applications, general metalforming dies, mandrels, and bushings.
Grade Recommendations for PM Tooling
## PM TOOLING GRADES:

<table>
<thead>
<tr>
<th>INDUSTRY CODE</th>
<th>STANDARD</th>
<th>PREMIUM</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>C2/C9</td>
<td>GC-106</td>
<td>GC-0004</td>
<td>HighWear Dies</td>
</tr>
<tr>
<td></td>
<td></td>
<td>GC-010*</td>
<td>Small WEDM Dies &amp; Pins-Excellent</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>for pressing ceramics &amp; large non-EDM liners</td>
</tr>
<tr>
<td></td>
<td></td>
<td>GC-010CR</td>
<td></td>
</tr>
<tr>
<td>C10</td>
<td>GC-209</td>
<td>GC-813CT*</td>
<td>High wear / Fine Teeth/ WEDM Dies &amp; Cores/ Intricate Forms / Excellent for Stainless PM</td>
</tr>
<tr>
<td>C11</td>
<td>GC-211*</td>
<td>GC-313T*</td>
<td>Med. Size WEDM Dies High Toughness Form, Gear Dies &amp; Cores GC-411CT for Stainless PM Excellent Wear Resistance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>GC-313T</td>
<td></td>
</tr>
</tbody>
</table>

* - WEDM Grade
T - Addition of TaC for Lubricity
CT- Grades are Corrosion resistant
<table>
<thead>
<tr>
<th>INDUSTRY CODE</th>
<th>STANDARD</th>
<th>PREMIUM</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>C12</td>
<td>GC-313*</td>
<td>GC-411CT*</td>
<td>Med/ Lg WEDM Dies High Toughness Form, Gear Dies &amp; Cores Excellent Wear</td>
</tr>
<tr>
<td></td>
<td>GC-712C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C13</td>
<td>GC-315*</td>
<td>GC-613CT*</td>
<td>Med/XL WEDM Dies Extreme Toughness Good Wear Complex Internal Shapes</td>
</tr>
<tr>
<td></td>
<td>GC-415CT*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C14</td>
<td>GC-320*</td>
<td>GC-618T*</td>
<td>High Impact Sizing Dies Complex Internal Shapes Excellent Shock &amp; Impact Strength</td>
</tr>
<tr>
<td></td>
<td>GC-425CT*</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* - WEDM Grade  
T - Addition of TaC for Lubricity  
CT- Grades are Corrosion resistant
In Summary: General Carbide offers Distinct Grade Development Capability specifically for the PM Industry….

- **WC** range: 0.6 to 11 micron.
- 12 grades with **TaC**.
- 6 grades with **Ni** - binder (within range 6.0-25.0%).
- 6 corrosion resistant grades with **Co** - binder.
- **Cobalt** range: 3.5% to 30.0%.

Wide variety of grades for many applications …
## Designer’s Guide to Tungsten Carbide

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Background of Cemented Carbide</td>
</tr>
<tr>
<td>II</td>
<td>Unique properties of Cemented Carbide</td>
</tr>
<tr>
<td>III</td>
<td>Design Considerations</td>
</tr>
<tr>
<td>IV</td>
<td>Attaching and Assembling Techniques</td>
</tr>
<tr>
<td>V</td>
<td>Finishing Techniques for Cemented Carbide</td>
</tr>
</tbody>
</table>

See [www.generalcarbide.com/articles](http://www.generalcarbide.com/articles) for PDF download of all chapters.
Summary:

Strong, tough and wear-resistant tool materials, as well as the proper processing techniques, play a crucial role in both tool performance and its associated cost-efficiency.
Thank you for your attention!

Any questions, please?...
Manufacturing process for cemented carbide products:

From APT (Ammonium Para-Tungstate) …to Finished Part / Tool …

APT

Reduction Carburization Weighing Milling Drying

Binder, Cubic Carbides, Press wax, etc.

Ready-to-press

Powder Compaction Shaping Sintering Grinding
### Grade Specifications

#### Tungsten Carbide Grades with Cobalt Binder

<table>
<thead>
<tr>
<th>Grade</th>
<th>Weight Percent WC</th>
<th>Co</th>
<th>Other</th>
<th>Hardness (R3A)</th>
<th>Density (g/cm³)</th>
<th>Average Transverse</th>
<th>Tensile Strength (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GC-012F</td>
<td>86</td>
<td>12</td>
<td>-</td>
<td>92.2</td>
<td>91.2</td>
<td>14.08</td>
<td>14.26</td>
</tr>
<tr>
<td>GC-016F</td>
<td>86</td>
<td>15</td>
<td>-</td>
<td>90.8</td>
<td>91.8</td>
<td>13.79</td>
<td>13.92</td>
</tr>
<tr>
<td>0.8 micron</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GC-010F</td>
<td>95</td>
<td>5</td>
<td>9.3</td>
<td>94.2</td>
<td>34.18</td>
<td>14.97</td>
<td>560,000</td>
</tr>
<tr>
<td>GC-010F</td>
<td>90</td>
<td>10</td>
<td>9.1</td>
<td>92.2</td>
<td>34.51</td>
<td>14.31</td>
<td>550,000</td>
</tr>
<tr>
<td>GC-010FC</td>
<td>89</td>
<td>10</td>
<td>1</td>
<td>92.3</td>
<td>91.3</td>
<td>14.25</td>
<td>14.35</td>
</tr>
<tr>
<td>GC-010FCF</td>
<td>84</td>
<td>15</td>
<td>1</td>
<td>89.1</td>
<td>94.1</td>
<td>13.69</td>
<td>14.03</td>
</tr>
<tr>
<td>GC-015F</td>
<td>94</td>
<td>5</td>
<td>9.4</td>
<td>94.1</td>
<td>33.73</td>
<td>13.86</td>
<td>650,000</td>
</tr>
<tr>
<td>GC-019</td>
<td>99</td>
<td>1</td>
<td>9.1</td>
<td>91.8</td>
<td>14.54</td>
<td>14.66</td>
<td>520,000</td>
</tr>
<tr>
<td>GC-020</td>
<td>99</td>
<td>9</td>
<td>9.0</td>
<td>91.8</td>
<td>14.54</td>
<td>14.66</td>
<td>520,000</td>
</tr>
<tr>
<td>GC-020F</td>
<td>94</td>
<td>9</td>
<td>9.1</td>
<td>92.2</td>
<td>14.18</td>
<td>14.97</td>
<td>560,000</td>
</tr>
<tr>
<td>GC-020FC</td>
<td>89</td>
<td>11</td>
<td>9.4</td>
<td>94.4</td>
<td>14.32</td>
<td>14.45</td>
<td>520,000</td>
</tr>
<tr>
<td>GC-035F</td>
<td>90</td>
<td>10</td>
<td>8.9</td>
<td>90.4</td>
<td>14.46</td>
<td>14.58</td>
<td>515,000</td>
</tr>
<tr>
<td>GC-031F</td>
<td>87</td>
<td>13</td>
<td>8.8</td>
<td>90.1</td>
<td>14.15</td>
<td>14.27</td>
<td>515,000</td>
</tr>
<tr>
<td>GC-031FC</td>
<td>86</td>
<td>15</td>
<td>8.7</td>
<td>90.5</td>
<td>13.95</td>
<td>14.08</td>
<td>515,000</td>
</tr>
<tr>
<td>GC-031F</td>
<td>85</td>
<td>20</td>
<td>8.6</td>
<td>90.6</td>
<td>13.46</td>
<td>13.64</td>
<td>520,000</td>
</tr>
<tr>
<td>GC-035FC</td>
<td>5</td>
<td>25</td>
<td>8.2</td>
<td>84.7</td>
<td>13.02</td>
<td>12.22</td>
<td>520,000</td>
</tr>
<tr>
<td>GC-035F</td>
<td>10</td>
<td>30</td>
<td>8.1</td>
<td>82.9</td>
<td>12.04</td>
<td>12.82</td>
<td>510,000</td>
</tr>
<tr>
<td>3.0 micron</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GC-040F</td>
<td>82</td>
<td>18</td>
<td>8.3</td>
<td>90.2</td>
<td>13.62</td>
<td>13.81</td>
<td>465,000</td>
</tr>
<tr>
<td>GC-040F</td>
<td>88</td>
<td>12</td>
<td>8.7</td>
<td>94.7</td>
<td>13.42</td>
<td>13.57</td>
<td>510,000</td>
</tr>
<tr>
<td>GC-050F</td>
<td>86</td>
<td>15</td>
<td>8.6</td>
<td>87.4</td>
<td>13.79</td>
<td>13.09</td>
<td>480,000</td>
</tr>
<tr>
<td>GC-055F</td>
<td>85</td>
<td>15</td>
<td>8.5</td>
<td>86.6</td>
<td>13.79</td>
<td>14.09</td>
<td>470,000</td>
</tr>
<tr>
<td>10.0 micron</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GC-061F</td>
<td>94</td>
<td>6</td>
<td>9.8</td>
<td>91.4</td>
<td>14.09</td>
<td>13.06</td>
<td>480,000</td>
</tr>
<tr>
<td>GC-067F</td>
<td>92</td>
<td>10</td>
<td>8.8</td>
<td>90.8</td>
<td>14.46</td>
<td>14.28</td>
<td>480,000</td>
</tr>
<tr>
<td>GC-071F</td>
<td>90</td>
<td>10</td>
<td>8.8</td>
<td>90.9</td>
<td>14.46</td>
<td>14.58</td>
<td>500,000</td>
</tr>
</tbody>
</table>

*Available in W12EDM Grade

### Grade Specifications

#### Corrosion Resistant Specialty Grades

<table>
<thead>
<tr>
<th>Grade</th>
<th>Weight Percent WC</th>
<th>Co</th>
<th>TaC</th>
<th>Other</th>
<th>Hardness (R3A)</th>
<th>Density (g/cm³)</th>
<th>Average Transverse</th>
<th>Tensile Strength (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GC-010F</td>
<td>89</td>
<td>10</td>
<td>1</td>
<td>92.3</td>
<td>91.3</td>
<td>0.8</td>
<td>14.25</td>
<td>14.35</td>
</tr>
<tr>
<td>GC-015F</td>
<td>85</td>
<td>15</td>
<td>1</td>
<td>90.5</td>
<td>91.5</td>
<td>0.8</td>
<td>14.28</td>
<td>14.38</td>
</tr>
<tr>
<td>GC-020F</td>
<td>86</td>
<td>11</td>
<td>1</td>
<td>91.0</td>
<td>91.0</td>
<td>0.8</td>
<td>14.28</td>
<td>14.38</td>
</tr>
</tbody>
</table>

#### WC/Co Grades with Tantalum Carbide

<table>
<thead>
<tr>
<th>Grade</th>
<th>Weight Percent WC</th>
<th>Co</th>
<th>Tantalum Carbide</th>
<th>Other</th>
<th>Hardness (R3A)</th>
<th>Density (g/cm³)</th>
<th>Average Transverse</th>
<th>Tensile Strength (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GC-004F</td>
<td>89</td>
<td>7</td>
<td>4</td>
<td>91.7</td>
<td>92.7</td>
<td>1.0</td>
<td>14.72</td>
<td>14.83</td>
</tr>
<tr>
<td>GC-012F</td>
<td>86</td>
<td>15</td>
<td>2</td>
<td>90.5</td>
<td>91.5</td>
<td>1.0</td>
<td>14.42</td>
<td>14.42</td>
</tr>
<tr>
<td>GC-015F</td>
<td>77</td>
<td>19</td>
<td>3</td>
<td>85.5</td>
<td>86.5</td>
<td>1.0</td>
<td>14.42</td>
<td>14.42</td>
</tr>
<tr>
<td>GC-020F</td>
<td>72</td>
<td>25</td>
<td>5</td>
<td>83.7</td>
<td>84.9</td>
<td>1.0</td>
<td>14.42</td>
<td>14.42</td>
</tr>
<tr>
<td>GC-011F</td>
<td>86</td>
<td>14</td>
<td>1</td>
<td>87.4</td>
<td>88.4</td>
<td>1.0</td>
<td>14.18</td>
<td>14.25</td>
</tr>
<tr>
<td>GC-017F</td>
<td>79</td>
<td>18</td>
<td>1</td>
<td>85.3</td>
<td>86.3</td>
<td>1.0</td>
<td>14.15</td>
<td>14.29</td>
</tr>
</tbody>
</table>

#### WC/Co Grades

<table>
<thead>
<tr>
<th>Grade</th>
<th>Weight Percent WC</th>
<th>Ni</th>
<th>Mo</th>
<th>Other</th>
<th>Hardness (R3A)</th>
<th>Density (g/cm³)</th>
<th>Average Transverse</th>
<th>Tensile Strength (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GC-000F</td>
<td>92</td>
<td>6</td>
<td>1.5</td>
<td>91.2</td>
<td>92.0</td>
<td>1.0</td>
<td>14.72</td>
<td>14.83</td>
</tr>
<tr>
<td>GC-010F</td>
<td>88</td>
<td>6</td>
<td>1.5</td>
<td>92.0</td>
<td>90.9</td>
<td>1.0</td>
<td>14.30</td>
<td>14.42</td>
</tr>
<tr>
<td>GC-011F</td>
<td>88</td>
<td>6</td>
<td>1.5</td>
<td>90.9</td>
<td>89.1</td>
<td>1.0</td>
<td>14.12</td>
<td>14.23</td>
</tr>
</tbody>
</table>

*Available in W12EDM Grade

### SinterHIP Process Guaranteed

See www.generalcarbide.com for .pdf format download