Advancements in Cemented Carbide Products & Processing

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CARBIDES?...

...What do we know about them?

GENERAL CARBIDE.
Agenda

What is a cemented carbide?

Why do we use cemented carbide?

What advancements have been made in:

- processing and manufacturing?
- material grade development?
- failure analysis and troubleshooting?
What is Cemented Carbide?

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), Mo$_2$C (Molybdenum Carbide), TaC (Tantalum Carbide), Cr$_3$C$_2$ (Chromium Carbide), VC (Vanadium Carbide), TiC (Titanium Carbide), etc. or their mixes.
# Carbides: Selected Mechanical Properties

<table>
<thead>
<tr>
<th>Carbide Formula</th>
<th>Vickers (HV) Hardness @ Various Temperatures, °C (°F)</th>
<th>Rockwell Hardness @ Room Temperature, HRa</th>
<th>Ultimate Compressive Strength, MPa (ksi)</th>
<th>Transverse Rupture Strength, MPa (ksi)</th>
<th>Modulus of Elasticity, GPa (10^6 ksi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TiC*</td>
<td>2930 [640]</td>
<td>93</td>
<td>1330-3900 (193-522)</td>
<td>280-400 (40.6-58.0)</td>
<td>370 (52.9)</td>
</tr>
<tr>
<td>HfC*</td>
<td>2860 [ ]</td>
<td>84</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>VC*</td>
<td>2800 [250]</td>
<td>83</td>
<td>620 (89.9)</td>
<td>70 (10.1)</td>
<td>360 (51.4)</td>
</tr>
<tr>
<td>NbC*</td>
<td>2400 [350]</td>
<td>83</td>
<td>1400 (203)</td>
<td>-</td>
<td>270 (38.5)</td>
</tr>
<tr>
<td>TaC*</td>
<td>1570 [800]</td>
<td>82</td>
<td>-</td>
<td>-</td>
<td>470 (68.2)</td>
</tr>
<tr>
<td>Cr₃C₂*</td>
<td>[ ] [ ]</td>
<td>81</td>
<td>100 (14.5)</td>
<td>170-380 ((24.7-55.1)</td>
<td>280 (40.0)</td>
</tr>
<tr>
<td>Mo₂C*</td>
<td>[ ] [ ]</td>
<td>74</td>
<td>2700 (392)</td>
<td>50 (7.3)</td>
<td>375 (53.6)</td>
</tr>
<tr>
<td>WC*</td>
<td>2400 [280]</td>
<td>81</td>
<td>2700-3600 (392-522)</td>
<td>530-560 (76.9-81.2)</td>
<td>665 (95)</td>
</tr>
</tbody>
</table>

*NOTE: TiC-Titanium Carbide; HfC-Hafnium Carbide; VC-Vanadium Carbide; NbC-Niobium Carbide; TaC-Tantalum Carbide; Cr₃C₂ - Chromium Carbide; Mo₂C - Molybdenum Carbide; WC-Tungsten Carbide.
Why Do We Need and Use Cemented Carbide?

...... because of its unique combination of superior physical and mechanical properties!

**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....
# PROPERTIES OF SOME SELECTED WC-Co CEMENTED CARBIDE GRADES

<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)

| Tool Steel (T8)   | 85 (66HRc)    | 2                                 | 575                                       | 600                                      | -                                      | 34                               | 6.5                                      |
| Carbon Steel      | 79 (66HRc)    | 1                                 | -                                         | -                                        | 300                                    | 30                               | -                                        |
| Cast Iron         | -             | 2                                 | 105                                       | -                                        | -                                      | 15-30                            | 9.2                                      |
Room & Hot Hardness of WC-Co Cemented Carbide vs. High Speed Tool Steel

<table>
<thead>
<tr>
<th>Material</th>
<th>Hardness (HRC) @ Various Working Temperatures</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>@ 20 °C (78 °F)</td>
</tr>
<tr>
<td>Cemented Carbide [WC +6%Co]</td>
<td>77 -79</td>
</tr>
<tr>
<td>High Speed Steel --AISI T4 Grade [0.8%C+18%W+4%Cr+1%V+5%Co]</td>
<td>63 - 65</td>
</tr>
</tbody>
</table>
Manufacturing Process of Cemented Carbides

Virgin

Powder Making

Ready Powder

Pressing

Preforms or Billets

Shaping

Shaped Parts

Sintering

Sintered Parts

Rework

Final Treatment: (Grinding, Coating, etc.)

Finished Parts
Full range of manufacturing capabilities:

- Milling
- Vacuum Drying
- Mechanical pressing
- Spray Drying
- Powder shaping
- Pressure Sintering
Processing Advancements
Preparation of Powder Compositions at General Carbide

Milling

Vacuum Drying

Spray Drying
Mixing / Milling in the Attritor

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.**
Vacuum Drying of Cemented Carbide Powder Blends.

Vacuum drying is ideal for WC-Co materials because it removes moisture while preventing oxidation or explosions that could occur when the milling liquid (solvent) combines with air.
Processing Advancement:
Spray Drying for Carbide Grade Formulations

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.
**Principle of the Spray Drying Process**

**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.
High Quality Cemented Carbide Powder Compositions

Spray-Dried Cemented Carbide Powders

Vacuum-Dried Cemented Carbide Powders

Bulk powder blends after milling and drying processing
Advancements in Thermal [Hot] Consolidation of Cemented Carbides
Methods of Thermal (Hot) Consolidation used in manufacturing Cemented Carbide:

- Vacuum Sintering (less often Atmospheric sintering)
- Hot Isostatic Pressing (HIP)
- Sinter-HIP Processing
- Hot Pressing (anisotropic) under vacuum
Sinter-HIP vs. post-HIP: Pros & Cons...

What do we know?
“Cobalt-Lake” defects that can be found in routine Vacuum Sintering:

During routine sintering of WC-Co cemented carbides, Cobalt (Co) or Co-based liquid eutectic substances frequently generate a defect of the structure known as a “Cobalt Pool” or “Cobalt Lake”. It is a condition where Co is squeezed into a macro-void that might occur within the material at the liquid stage of the sintering operation.
Cobalt lake Defects and Techniques to eliminate them:

- Once a “Co-Lake” defect occurs, it is very difficult to get any amount of WC particles into the affected areas.

- HIP (post sintering) and Sinter-HIP techniques have been developed and applied to achieve better homogeneity of the cemented carbide structure, thereby improving mechanical properties.

- Both processes are performed in special pressure-tight vessels through the simultaneous application of heat and pressure for a pre-determined time.
HIP Technique

Hot Isostatic Pressing, is a technology of isotropic compression and compaction of the material by use of high-temperature and high-pressure gas as a pressure and heat transmitting medium.
Disadvantages of Post-HIP Processing.

- Performed on parts which were already sintered which diminishes productivity.
- Performed at very high pressure in a separate pressure-tight vessel, thereby requiring an extra manufacturing operation and reducing efficiency.
- Can result in grain growth of the microstructure.
Potential for Defects from “Post-HIP” Processing

Due to the fact, that a post-HIP process is performed at the solid-phase diffusion temperature, there is a risk of intensive grain growth of WC particles within the sintered body that could affect the mechanical properties of the final product.
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.
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.
Multiple Sinter-HIP Processing at General Carbide:

Five Sinter-HIP furnaces are used daily on 100% of our products.
Advancements in Grade Development
General Carbide has Discernible Grade Development Capability

Wide variety of grades for many applications:

- WC range: 0.6 to 11 micron
- 12 grades with TaC
- 6 grades with Ni binder
- 6 corrosion resistant grades with Co binder
- Cobalt range: 3.5% to 30%
Premium WC Crystal

Unique and Proprietary crystal structure

Tungsten Carbide grain has a perfect stoichiometric balance of 6.13% carbon throughout
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
Typical corrosion/leaching condition

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

GC-313*

GC-411CT*

*Test conducted in tap water over 48 hours.
Electrolytic Attack

GC-313*

*Test conducted in wire tank for 100 hours.

GC-411CT*

*Test conducted in wire tank for 100 hours.
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
### Grade Specifications

#### Tungsten Carbide Grades with Cobalt Binder

<table>
<thead>
<tr>
<th>Grade</th>
<th>WC</th>
<th>Co</th>
<th>Other</th>
<th>Hardness HRA</th>
<th>Tolerance ±</th>
<th>Sinter HIP Process Guaranteed</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>GC-601</td>
<td>88.13</td>
<td>12</td>
<td>92.7 - 94.2</td>
<td>14.00 ± 2.10</td>
<td>Sinter HIP Process Guaranteed</td>
<td>Sinter HIP Process Guaranteed</td>
<td>Note</td>
</tr>
<tr>
<td>GC-801</td>
<td>65.17</td>
<td>15</td>
<td>98.8 - 98.9</td>
<td>13.79 ± 3.29</td>
<td>Sinter HIP Process Guaranteed</td>
<td>Sinter HIP Process Guaranteed</td>
<td>Note</td>
</tr>
<tr>
<td>GC-801R</td>
<td>65.17</td>
<td>15</td>
<td>98.8 - 98.9</td>
<td>13.79 ± 3.29</td>
<td>Sinter HIP Process Guaranteed</td>
<td>Sinter HIP Process Guaranteed</td>
<td>Note</td>
</tr>
</tbody>
</table>

#### Corrosion Resistant Specialty Grades

<table>
<thead>
<tr>
<th>Grade</th>
<th>WC</th>
<th>Co</th>
<th>TaC</th>
<th>Other</th>
<th>Hardness HRA</th>
<th>Tolerance ±</th>
<th>Sinter HIP Process Guaranteed</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>GC-901P</td>
<td>89.10</td>
<td>15</td>
<td>92.9 - 94.2</td>
<td>14.00 ± 2.10</td>
<td>Sinter HIP Process Guaranteed</td>
<td>Sinter HIP Process Guaranteed</td>
<td>Note</td>
<td></td>
</tr>
<tr>
<td>GC-1001P</td>
<td>89.10</td>
<td>15</td>
<td>92.9 - 94.2</td>
<td>14.00 ± 2.10</td>
<td>Sinter HIP Process Guaranteed</td>
<td>Sinter HIP Process Guaranteed</td>
<td>Note</td>
<td></td>
</tr>
<tr>
<td>GC-101CP</td>
<td>89.10</td>
<td>15</td>
<td>92.9 - 94.2</td>
<td>14.00 ± 2.10</td>
<td>Sinter HIP Process Guaranteed</td>
<td>Sinter HIP Process Guaranteed</td>
<td>Note</td>
<td></td>
</tr>
</tbody>
</table>

#### WC/Co Grades with Tantalum Carbide

<table>
<thead>
<tr>
<th>Grade</th>
<th>WC</th>
<th>Co</th>
<th>TaC</th>
<th>Other</th>
<th>Hardness HRA</th>
<th>Tolerance ±</th>
<th>Sinter HIP Process Guaranteed</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>GC-901</td>
<td>89.10</td>
<td>7</td>
<td>92.9 - 94.2</td>
<td>14.00 ± 2.10</td>
<td>Sinter HIP Process Guaranteed</td>
<td>Sinter HIP Process Guaranteed</td>
<td>Note</td>
<td></td>
</tr>
<tr>
<td>GC-1001</td>
<td>89.10</td>
<td>7</td>
<td>92.9 - 94.2</td>
<td>14.00 ± 2.10</td>
<td>Sinter HIP Process Guaranteed</td>
<td>Sinter HIP Process Guaranteed</td>
<td>Note</td>
<td></td>
</tr>
<tr>
<td>GC-101C</td>
<td>89.10</td>
<td>7</td>
<td>92.9 - 94.2</td>
<td>14.00 ± 2.10</td>
<td>Sinter HIP Process Guaranteed</td>
<td>Sinter HIP Process Guaranteed</td>
<td>Note</td>
<td></td>
</tr>
</tbody>
</table>

#### WC/Fe Grades

<table>
<thead>
<tr>
<th>Grade</th>
<th>WC</th>
<th>Ni</th>
<th>Mo2C</th>
<th>Other</th>
<th>Hardness HRA</th>
<th>Tolerance ±</th>
<th>Sinter HIP Process Guaranteed</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>GC-901</td>
<td>89.10</td>
<td>6</td>
<td>92.9 - 94.2</td>
<td>14.00 ± 2.10</td>
<td>Sinter HIP Process Guaranteed</td>
<td>Sinter HIP Process Guaranteed</td>
<td>Note</td>
<td></td>
</tr>
<tr>
<td>GC-1001</td>
<td>89.10</td>
<td>6</td>
<td>92.9 - 94.2</td>
<td>14.00 ± 2.10</td>
<td>Sinter HIP Process Guaranteed</td>
<td>Sinter HIP Process Guaranteed</td>
<td>Note</td>
<td></td>
</tr>
</tbody>
</table>

#### WC/Co Grades

<table>
<thead>
<tr>
<th>Grade</th>
<th>WC</th>
<th>Co</th>
<th>Other</th>
<th>Hardness HRA</th>
<th>Tolerance ±</th>
<th>Sinter HIP Process Guaranteed</th>
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<tbody>
<tr>
<td>GC-901</td>
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<td>Sinter HIP Process Guaranteed</td>
<td>Sinter HIP Process Guaranteed</td>
<td>Note</td>
</tr>
<tr>
<td>GC-1001</td>
<td>89.10</td>
<td>15</td>
<td>92.9 - 94.2</td>
<td>14.00 ± 2.10</td>
<td>Sinter HIP Process Guaranteed</td>
<td>Sinter HIP Process Guaranteed</td>
<td>Note</td>
</tr>
<tr>
<td>GC-101C</td>
<td>89.10</td>
<td>15</td>
<td>92.9 - 94.2</td>
<td>14.00 ± 2.10</td>
<td>Sinter HIP Process Guaranteed</td>
<td>Sinter HIP Process Guaranteed</td>
<td>Note</td>
</tr>
</tbody>
</table>

Note: All grades are manufactured in accordance with the latest specifications and standards.

See www.generalcarbide.com for .pdf download
General Carbide grades commonly used in the Powder Metal Industry
# POWDER METAL 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 for pressing ceramics &amp; large non-EDM liners</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</td>
</tr>
<tr>
<td></td>
<td></td>
<td>GC-411CT*</td>
<td>High Toughness Form, Gear Dies &amp; Cores GC-411CT for Stainless PM Excellent Wear</td>
</tr>
</tbody>
</table>

* - WEDM Grade
T - Addition of TaC for Lubricity
CT - Grades are Corrosion resistant

See [www.generalcarbide.com](http://www.generalcarbide.com) for .pdf download
# Powder Metal Tooling Grades

<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</td>
</tr>
<tr>
<td></td>
<td>GC-712C*</td>
<td></td>
<td>High Toughness</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Form, Gear Dies &amp; Cores</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Excellent Wear</td>
</tr>
<tr>
<td>C13</td>
<td>GC-315*</td>
<td>GC-613CT*</td>
<td>Med/XL WEDM Dies</td>
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<tr>
<td></td>
<td></td>
<td>GC-415CT</td>
<td>Extreme Toughness</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Good Wear</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Complex Internal Shapes</td>
</tr>
<tr>
<td>C14</td>
<td>GC-320*</td>
<td>GC-618T*</td>
<td>High Impact Sizing Dies</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Complex Internal Shapes</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Excellent Shock &amp; Impact Strength</td>
</tr>
</tbody>
</table>

* - WEDM Grade
T - Addition of TaC for Lubricity
CT - Grades are Corrosion resistant

See [www.generalcarbide.com](http://www.generalcarbide.com) for .pdf download
Wire EDM Material Specifications

- Proprietary WC Crystal
- Special WEDM Material Recipe
- Magna-flux in “soft” state
- Wire EDM Sinter-Hip Furnace Cycle
- Thermal Stress Relieving
- Vibratory Stress Relieving
- Ultrasonic check for internal cracks
- Semi-Finish Grinding Option (in-house)
- Delivery - 8 working days or less
Designer’s Guide to Tungsten Carbide

Chapter I.... Background of Cemented Carbide
Chapter II.... Unique properties of Cemented Carbide
Chapter III.... Design Considerations
Chapter IV.... Attaching and Assembling Techniques
Chapter V.... Finishing Techniques for Cemented Carbide

See www.generalcarbide.com/articles for .pdf download of all chapters
Research & Development Capabilities
Capabilities in Material Analysis

- WC-Co traditional bi-phase cemented carbide material products;
- Cemented Carbides with Nickel-based binding phase;
- Cemented carbides containing TaC (Tantalum Carbide), Cr$_3$C$_2$ (Chromium Carbide), VC (Vanadium Carbide), NbC (Niobium Carbide);
- Tungsten Carbide Composites (GenTuff Products);
- PVD / CVD Multi-Layer Coatings applied onto Cemented Carbide products;
- Engineered ceramic compositions and special materials.
Failure Analysis & Troubleshooting
Typical Defects and Failures of Cemented Carbide Products / Applications

By its origin, most frequently encountered defects/failures of cemented carbide products can be divided into 4 main groups:

• Processing defects (eta-phase occurrence, large grain cluster formations, powder shaping cracks)
• Fabrication defects (braze cracks, thermal cracks)
• Environmental failures from corrosion, erosion, etc.
• Mechanical failures caused by brittle fracturing, wear, fatigue.....etc.
Carbide Processing Defects

Eta-Phase in Cemented Carbide Materials
Carbide Processing Defects

Large Carbide grains cluster formation

Chipping crack resulting from green carbide shaping operation
Fabrication Defects

EDM Crack

Brazing Crack
Environmental Corrosion & Pitting Defects

Observable pitting

Corrosive attack on binder material
Environmental Failures

The selective dissolution ("leaching") of the binder from the cemented carbide microstructure

Electrolytic Attack*

*Test conducted in wire EDM tank for 100 hours.
Wear Failure Patterns

Abrasive Wear

Galling / Scuffing Wear
Carbide Failure Patterns

Brittle Fracture Defect

Cyclic Fatigue Failure
...ANY QUESTIONS?
OR COMMENTS...
PLEASE...