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# Advancements in Cemented Carbide Products & Processing


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# CARBIDES?...

...What do we know about them?

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# 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), **$Mo_2C$** (Molybdenum Carbide), **TaC** (Tantalum Carbide), **$Cr_3C_2$** (Chromium Carbide), **VC** (Vanadium Carbide), **TiC** (Titanium Carbide), etc. or their mixes.

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# Carbides: Selected Mechanical Properties

| Carbide Formula | Vickers (HV) Hardness @ Various Temperatures, °C (°F) | | Rockwell Hardness @ Room Temperature, HRa | Ultimate Compressive Strength, MPa (ksi) | Transverse Rupture Strength, MPa (ksi) | Modulus of Elasticity, GPa ($10^6$ ksi) |
|---|---|---|---|---|---|---|
| | 20 °C (78 °F) | 730 °C (1350 °F) | | | | |
| TiC* | 2930 | 640 | 93 | 1330-3900 (193-522) | 280-400 (40.6-58.0) | 370 (52.9) |
| HfC* | 2860 | - | 84 | - | - | - |
| VC* | 2800 | 250 | 83 | 620 (89.9) | 70 (10.1) | 360 (51.4) |
| NbC* | 2400 | 350 | 83 | 1400 (203) | - | 270 (38.5) |
| TaC* | 1570 | 800 | 82 | - | - | 470 (68,2) |
| $Cr_3C_2$* | - | - | 81 | 100 (14.5) | 170-380 ((24.7-55.1) | 280 (40.0) |
| $Mo_2C$* | - | - | 74 | 2700 (392) | 50 (7.3) | 375 (53.6) |
| WC* | 2400 | 280 | 81 | 2700-3600 (392-522) | 530-560 (76.9-81.2) | 665 (95) |

*NOTE: TiC-Titanium Carbide; HfC-Hafnium Carbide; VC-Vanadium Carbide; NbC-Niobium Carbide; TaC-Tantalum Carbide; $Cr_3C_2$ - Chromium Carbide; $Mo_2C$ - 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….***

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# PROPERTIES OF SOME SELECTED WC-Co CEMENTED CARBIDE GRADES

| Composition, wt. % | Hardness, HRa | Abrasion Resistance, 1/vol.loss $cm^3$ | Transverse Rupture Strength, 1,000 lb/$in^2$ | Ultimate Compression Strength, 1,000 lb/$in^2$ | Ultimate Tensile Strength, 1,000 lb/$in^2$ | Modulus of Elasticity, $10^6$ lb/$in^2$ | Thermal Expansion, @75 $^oC$-400 $^oC$ Cal/ (s·$^oC$ ·cm) |
|---|---|---|---|---|---|---|---|
| WC-6%Co | 92.8 | 35-60 | 335 | 860 | 160 | 92 | 2.9 |
| WC-9%Co | 89.5 | 10-13 | 425 | 660 | - | 87 | 2.7 |
| WC-13%Co | 88.2 | 4-8 | 500 | 600 | - | 81 | 3.0 |
| Other Materials (for comparison & consideration) | | | | | | | |
| Tool Steel (T8) | 85 (66HRc) | 2 | 575 | 600 | - | 34 | 6.5 |
| Carbon Steel (AISI 1095) | 79 (66HRc) | 1 | - | - | 300 | 30 | - |
| Cast Iron | - | 2 | 105 | - | - | 15-30 | 9.2 |

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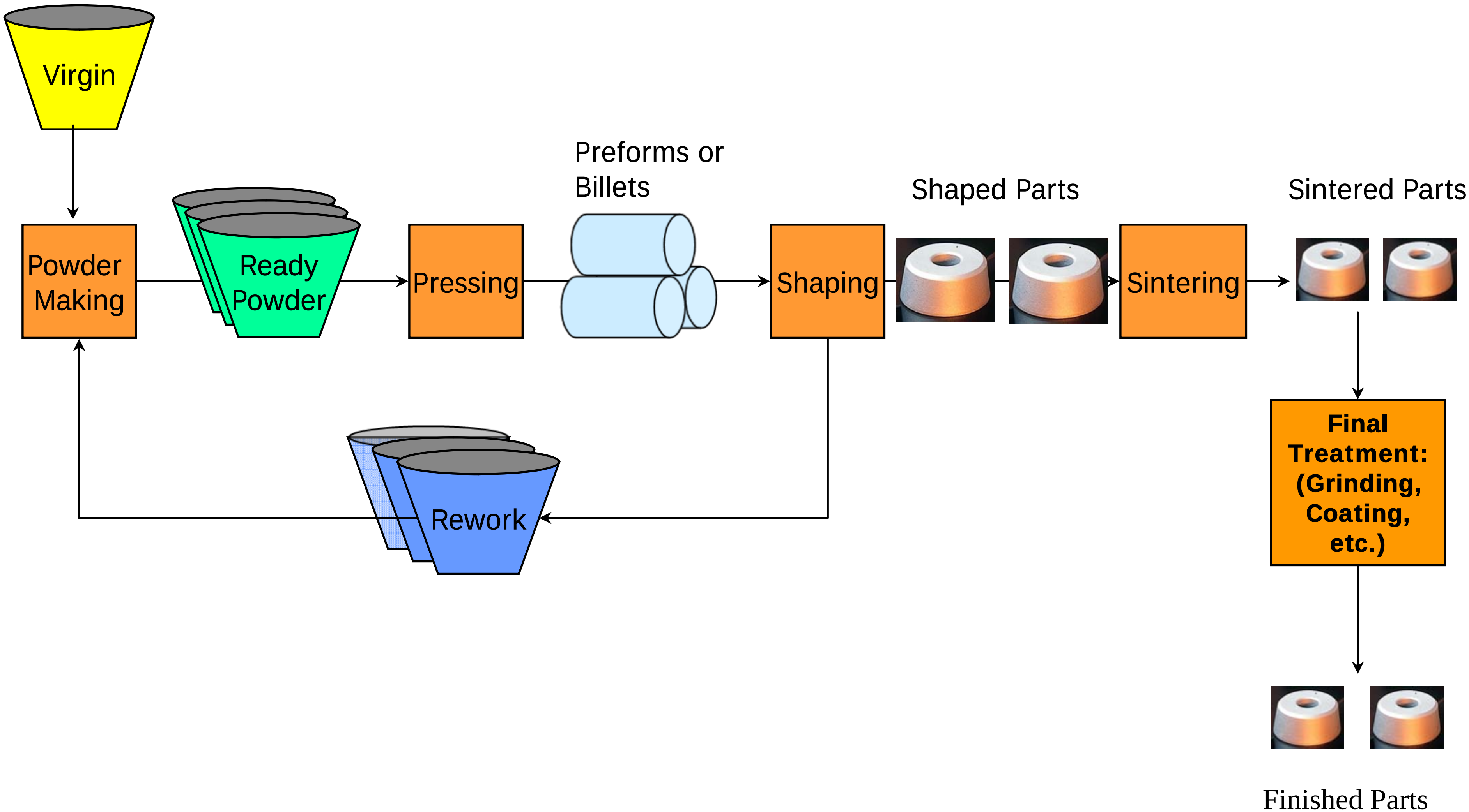
# Room & Hot Hardness of WC-Co Cemented Carbide vs. High Speed Tool Steel

| Properties / Material | Hardness ( HRC) @ Various Working Temperatures | | |
|---|---|---|---|
| | @ 20 °C ( 78 °F) | @ 760 °C (1400 °F) | @ 1093 °C (2000 °F) |
| **Cemented Carbide** [WC +6%Co] | 77 -79 | 27 - 29 | 21 - 23 |
| **High Speed Steel --AISI T4 Grade** [0.8%C+18%W+4%Cr+1%V+5%Co] | 63 - 65 | 17 - 19 | N/A |

# Manufacturing Process of Cemented Carbides



# Full range of manufacturing capabilities:

Milling

Mechanical pressing

Vacuum Drying

Spray Drying

Powder shaping

Pressure Sintering

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# Processing Advancements

# Preparation of Powder Compositions at General Carbide

**Milling**

**Vacuum Drying**

**Spray Drying**

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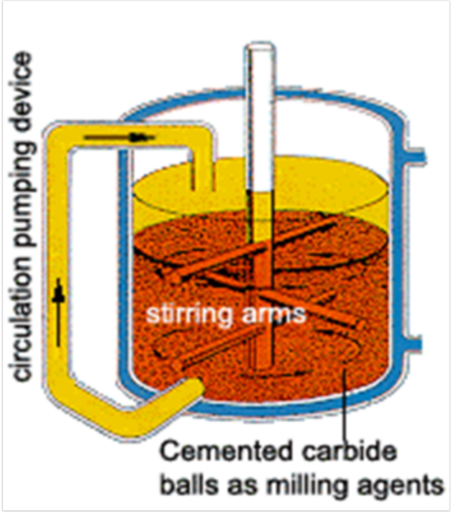
# Mixing / Milling in the Attritor




**Attritor Mill**

**Milling**

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

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 Dryer at General Carbide**

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.

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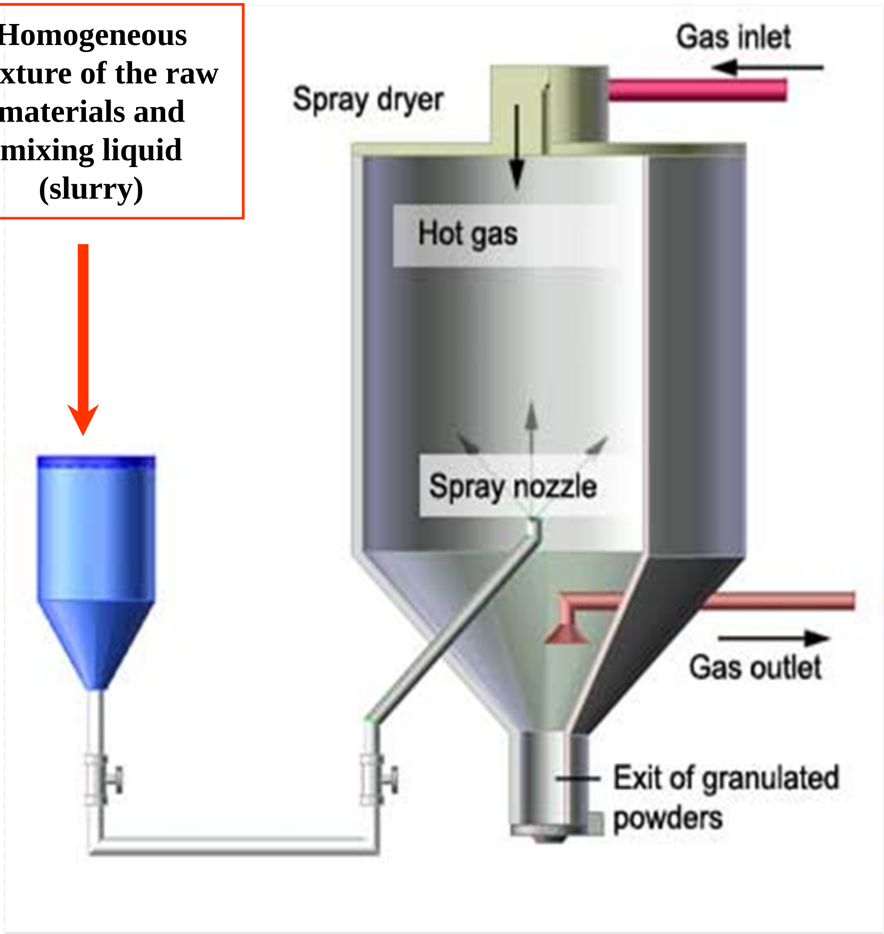
# Principle of the Spray Drying Process

Homogeneous mixture of the raw materials and mixing liquid (slurry)




**<u>Granulation via Spray Drying</u>**

**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**

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# 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?*

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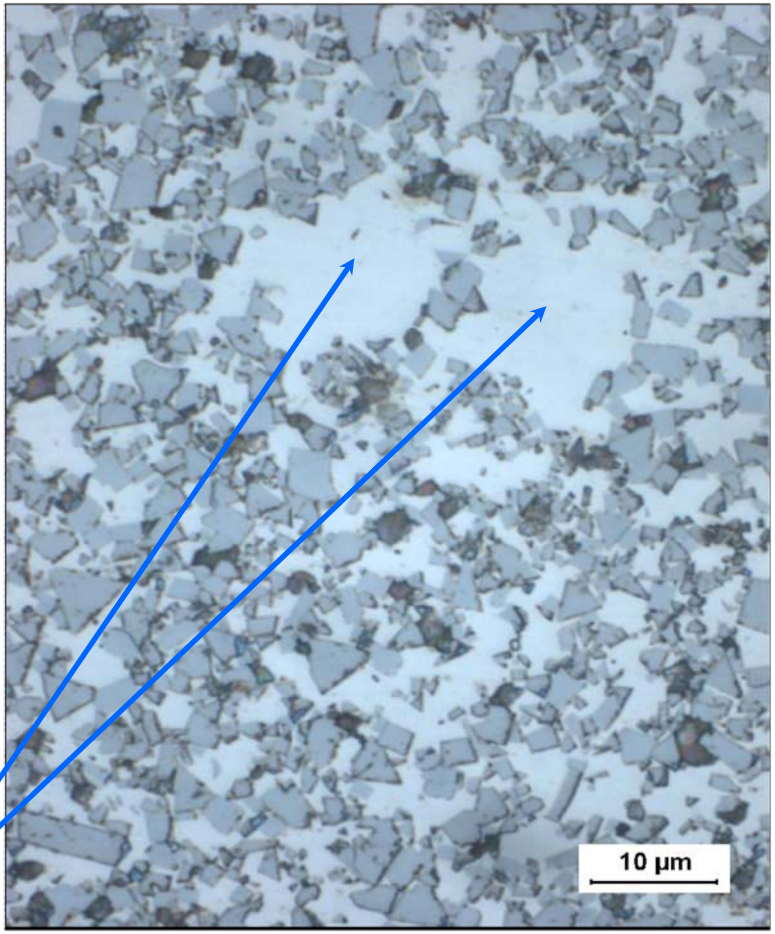
# “Cobalt-Lake” defects that can be found in routine Vacuum Sintering:

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

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# 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

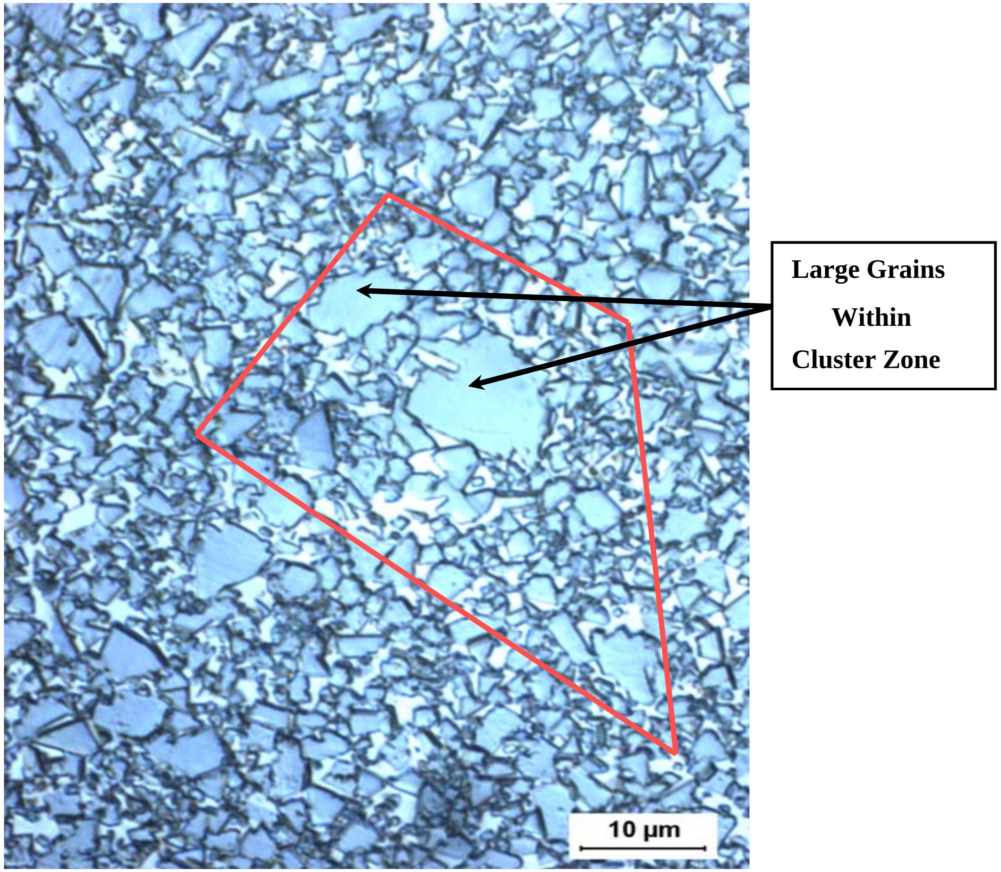
**Hot Isostatic Pressing**, is a technology of isotropic compression and compaction of the material by use of high-temperature and high-pressure gas as a pressure and heat transmitting medium.

# 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.**

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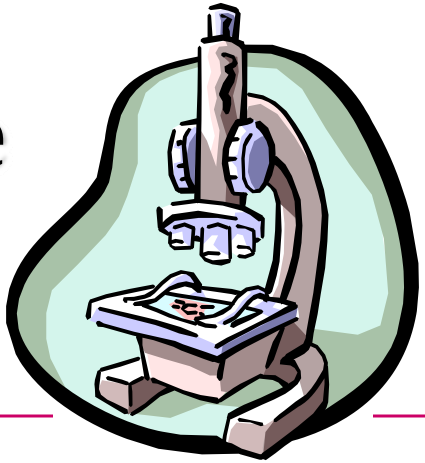
# Multiple Sinter-HIP Processing at General Carbide:


**Five Sinter-HIP furnaces are used daily on 100% of our products.**

# Advancements in Grade Development

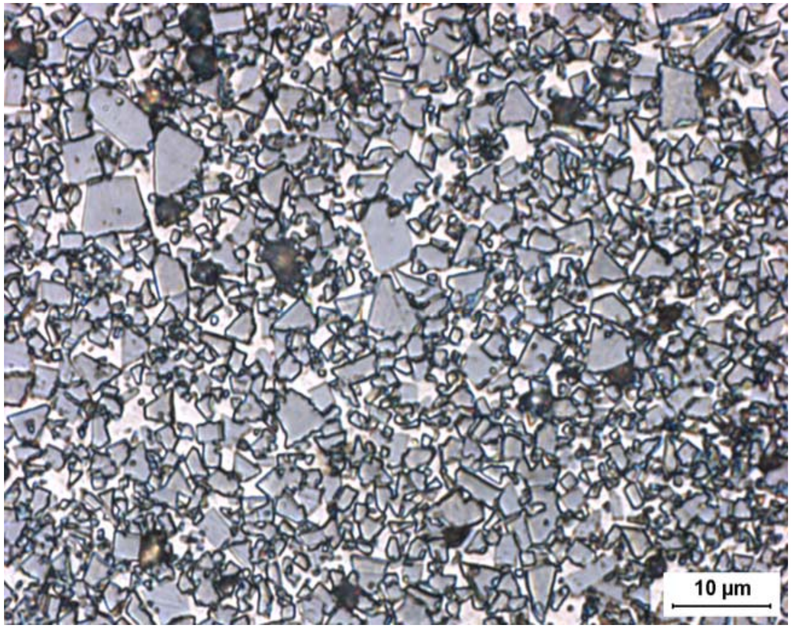
# General Carbide has Discernible Grade Development Capability



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




GC-411CT

GC-613CT

GC-618T

GC-813CT

GC-712C

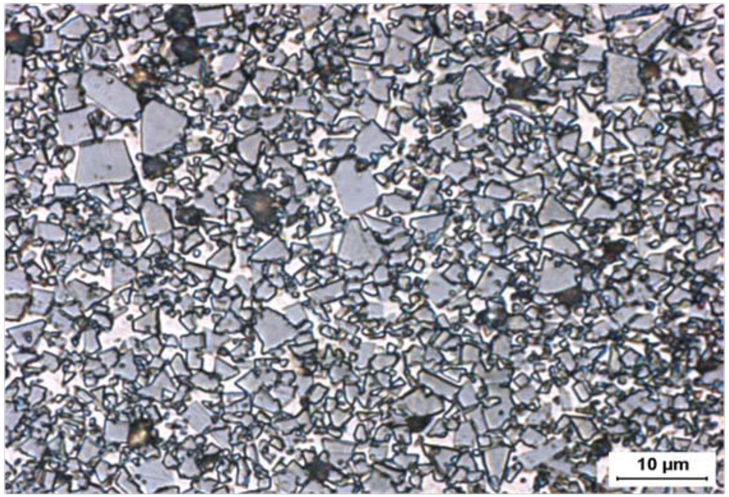
Unique and Proprietary crystal structure

Tungsten Carbide grain has a perfect stoichiometric balance of 6.13 % carbon throughout

# Tantalum Carbide (TaC) Additions:

## *What does it do for Cemented Carbide ?*

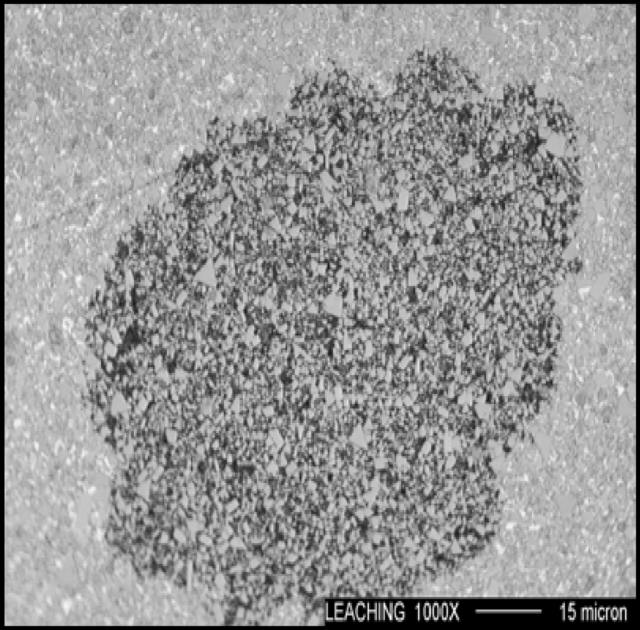
- Anti-galling agent
- Reduces friction between the work material and die wall
- Acts as an internal built-in lubricant

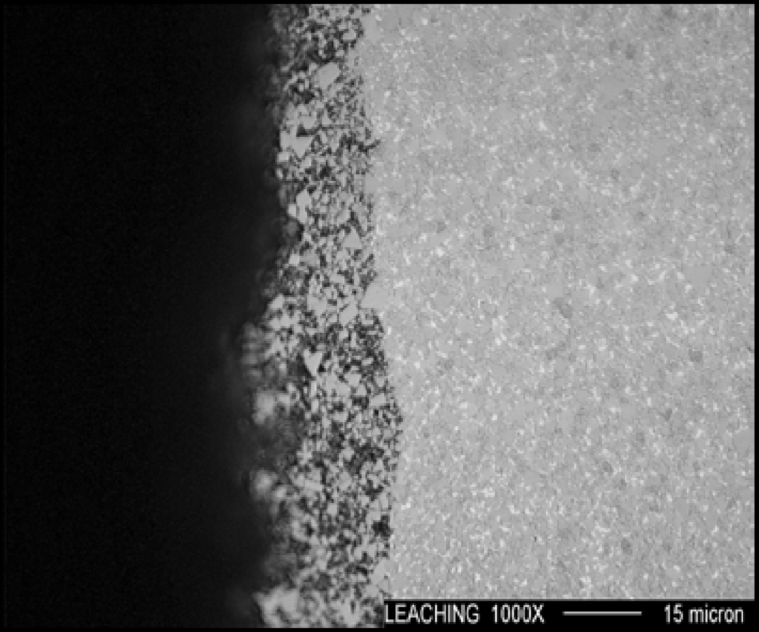



GC-613CT

# Typical corrosion/leaching condition

The selective dissolution of the binder from the cemented carbide microstructure.

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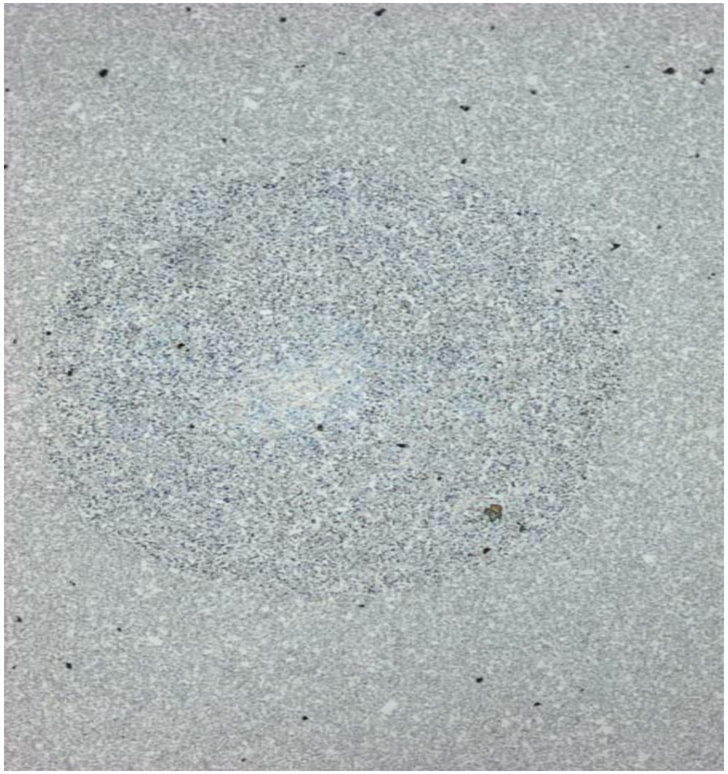
# Corrosion resistance of GC-411CT

| GC-313* | GC-411CT* |
|---|---|
|  |  |

*Test conducted in tap water over 48 hours.

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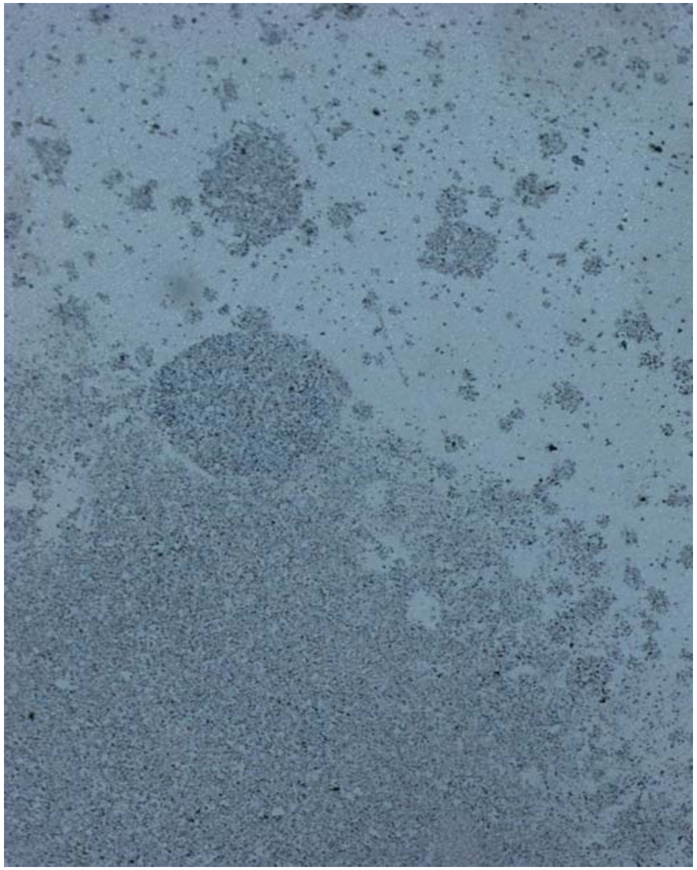
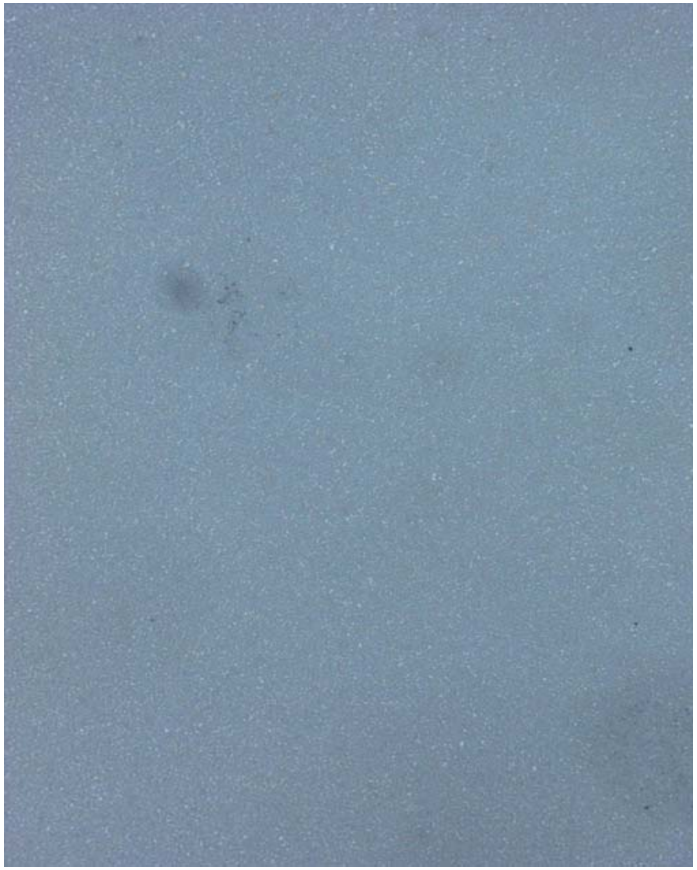
# Electrolytic Attack

**GC-313***



*Test conducted in wire tank for 100 hours.

**GC-411CT***



*Test conducted in wire tank for 100 hours.

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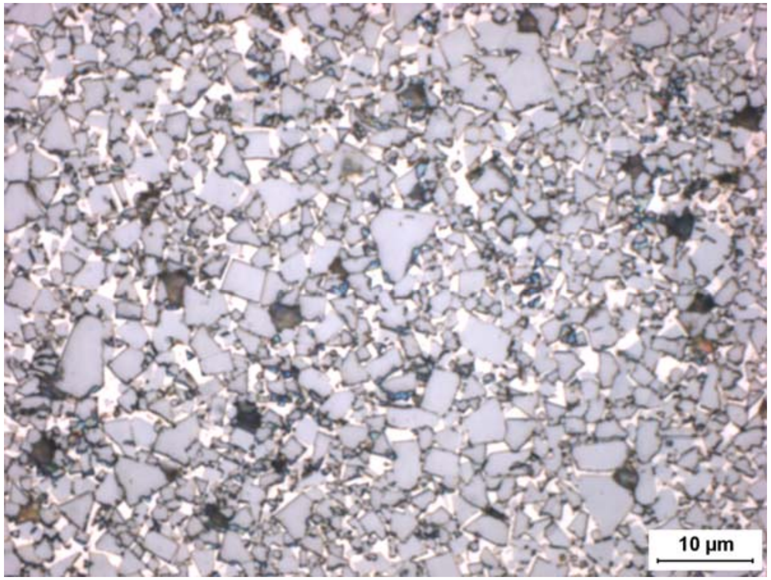
# Grain Size vs. Cobalt Content:




**GC-411CT**

**Hardness: 88.0 - 89.0**

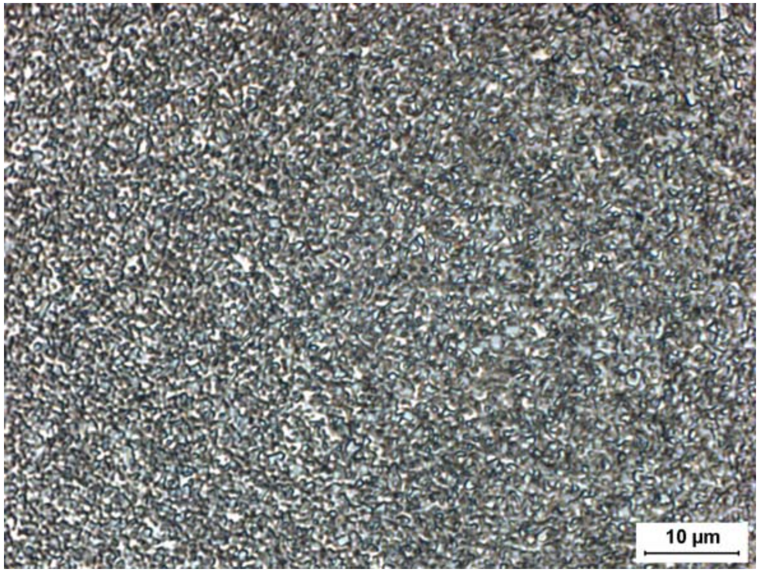
**TRS: 490,000 psi**

**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**

GENERAL CARBIDE PRODUCTS ARE MADE IN THE USA

# Grade Specifications

GENERALCARBIDE.

| | Chemical Composition Weight Percent WC | Co | Other | Hardness HRA | Density g/cm³ | Average Transverse Rupture Strength (psi) |
|---|---|---|---|---|---|---|
| **Tungsten Carbide Grades with Cobalt Binder** | | | | | | |
| **0.6 micron** | | | | | | |
| GC-012F* | 88 | 12 | | 92.2 - 93.2 | 14.08 - 14.20 | 520,000 |
| GC-015F* | 85 | 15 | | 90.8 - 91.8 | 13.79 - 13.92 | 605,000 |
| **0.8 micron ("submicron")** | | | | | | |
| GC-005 | 94.5 | 5.5 | | 93.4 - 94.2 | 14.88 - 14.97 | 500,000 |
| GC-010* | 90 | 10 | | 91.4 - 92.2 | 14.39 - 14.51 | 550,000 |
| GC-010CR* | 89 | 10 | 1 | 92.3 - 93.3 | 14.25 - 14.35 | 590,000 |
| GC-015* | 85 | 15 | | 89.3 - 90.3 | 13.89 - 14.03 | 600,000 |
| GC-015CR* | 84 | 15 | 1 | 90.4 - 91.4 | 13.74 - 13.86 | 650,000 |
| **1.0 micron** | | | | | | |
| GC-103 | 96.3 | 3.7 | | 92.7 - 93.5 | 15.12 - 15.21 | 480,000 |
| GC-106 | 94 | 6 | | 91.9 - 92.7 | 14.86 - 14.97 | 510,000 |
| GC-109 | 91 | 9 | | 91.0 - 91.8 | 14.54 - 14.66 | 520,000 |
| **2.0 micron** | | | | | | |
| GC-206 | 94 | 6 | | 91.2 - 92.2 | 14.86 - 14.97 | 500,000 |
| GC-209 | 91 | 9 | | 90.2 - 91.2 | 14.53 - 14.65 | 505,000 |
| GC-211* | 89 | 11 | | 89.4 - 90.4 | 14.33 - 14.45 | 530,000 |
| **3.0 micron** | | | | | | |
| GC-310* | 90 | 10 | | 89.3 - 90.3 | 14.46 - 14.58 | 515,000 |
| GC-313* | 87 | 13 | | 88.1 - 89.1 | 14.15 - 14.27 | 530,000 |
| GC-315* | 85 | 15 | | 87.5 - 88.5 | 13.95 - 14.09 | 540,000 |
| GC-320* | 80 | 20 | | 85.6 - 86.6 | 13.46 - 13.64 | 525,000 |
| GC-325* | 75 | 25 | | 83.5 - 84.7 | 13.03 - 13.23 | 520,000 |
| GC-330* | 70 | 30 | | 81.6 - 82.9 | 12.61 - 12.82 | 500,000 |
| **6.0 micron** | | | | | | |
| GC-618* | 82 | 18 | | 85.2 - 86.2 | 13.67 - 13.81 | 465,000 |
| GC-712* | 88 | 12 | | 87.7 - 88.7 | 14.25 - 14.37 | 510,000 |
| GC-950* | 85 | 15 | | 86.4 - 87.4 | 13.95 - 14.09 | 480,000 |
| **11.0 micron** | | | | | | |
| GC-915* | 85 | 15 | | 85.6 - 86.6 | 13.95 - 14.09 | 470,000 |
| **1.0 and 6.0 micron (mixed structure)** | | | | | | |
| GC-606M | 94 | 6 | | 90.4 - 91.4 | 14.89 - 15.00 | 480,000 |
| GC-608M | 92 | 8 | | 89.8 - 90.8 | 14.66 - 14.78 | 490,000 |
| GC-610M | 90 | 10 | | 88.8 - 89.8 | 14.46 - 14.58 | 500,000 |
| GC-612M | 88 | 12 | | 88.2 - 89.2 | 14.25 - 14.37 | 505,000 |

*Available in Wire EDM Grade

Note: Micron sizes refer to the nominal grain size for all grades

**SinterHIP Process Guaranteed**

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GENERAL CARBIDE PRODUCTS ARE MADE IN THE USA

# Grade Specifications

GENERALCARBIDE.

| | Chemical Composition Weight Percent | | | | Hardness HRA | Nominal Grain Size microns | Density g/cm³ | Average Transverse Rupture Strength (psi) |
|---|---|---|---|---|---|---|---|---|
| **Corrosion Resistant Specialty Grades** | WC | Co | TaC | Other | | | | |
| GC-010CR* | 89 | 10 | | 1 | 92.3 - 93.3 | 0.8 | 14.25 - 14.35 | 590,000 |
| GC-015CR* | 84 | 15 | | 1 | 90.4 - 91.4 | 0.8 | 13.74 - 13.86 | 650,000 |
| GC-813CT* | 86.5 | 10.5 | 2 | 1 | 90.5 - 91.5 | 3.0 | 14.24 - 14.36 | 500,000 |
| GC-411CT* | 86 | 11 | 2 | 1 | 88.5 - 89.5 | 4.0 | 14.19 - 14.31 | 490,000 |
| **WC/Co Grades with Tantalum Carbide** | WC | Co | TaC | Other | | | | |
| GC-0004* | 89 | 7 | 4 | | 91.7 - 92.7 | 1.0 | 14.72 - 14.83 | 450,000 |
| GC-813CT* | 86.5 | 10.5 | 2 | 1 | 90.5 - 91.5 | 3.0 | 14.24 - 14.36 | 500,000 |
| GC-313T* | 85 | 13 | 2 | | 88.5 - 89.5 | 3.0 | 14.14 - 14.26 | 510,000 |
| GC-0014* | 73 | 13 | 14 | | 88.3 - 89.3 | 3.0 | 14.02 - 14.14 | 485,000 |
| GC-315T* | 83 | 15 | 2 | | 87.5 - 88.5 | 3.0 | 13.93 - 14.07 | 525,000 |
| GC-320T* | 77 | 20 | 3 | | 85.8 - 86.8 | 3.0 | 13.44 - 13.62 | 500,000 |
| GC-325T* | 72 | 25 | 3 | | 83.7 - 84.9 | 3.0 | 13.01 - 13.21 | 490,000 |
| GC-411CT* | 86 | 11 | 2 | 1 | 88.5 - 89.5 | 4.0 | 14.19 - 14.31 | 490,000 |
| GC-613T* | 84 | 13 | 3 | | 87.4 - 88.4 | 6.0 | 14.13 - 14.25 | 465,000 |
| GC-618T* | 79 | 18 | 3 | | 85.3 - 86.3 | 6.0 | 13.65 - 13.79 | 480,000 |
| **WC/Ni Grades** | WC | Ni | | $Mo_2C$ | | | | |
| GC-N061 | 92.5 | 6 | | 1.5 | 91.2 - 92.0 | 1.0 | 14.72 - 14.83 | 480,000 |
| GC-N101 | 88.5 | 10 | | 1.5 | 89.2 - 90.0 | 1.0 | 14.30 - 14.42 | 495,000 |
| GC-N121 | 86.5 | 12 | | 1.5 | 88.1 - 89.1 | 1.0 | 14.11 - 14.23 | 500,000 |
| **WC/Ni/Co Grades** | WC | Ni | Co | $Cr_3C_2$ | | | | |
| GC-N129 | 86 | 10 | 2 | 2 | 88.6 - 89.7 | 3.0 | 13.92 - 14.04 | 490,000 |
| GC-N176 | 80 | 14.5 | 3 | 2.5 | 85.2 - 86.3 | 6.0 | 13.33 - 13.48 | 470,000 |
| GC-N256 | 73 | 20 | 5 | 2 | 78.2 - 80.2 | 6.0 | 12.75 - 12.95 | 440,000 |

*Available in Wire EDM Grade

Note: Micron sizes refer to the nominal grain size for all grades

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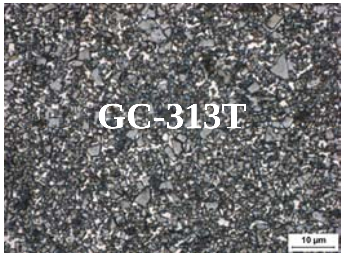
# General Carbide grades commonly used in the Powder Metal Industry

# POWDER METAL TOOLING GRADES

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

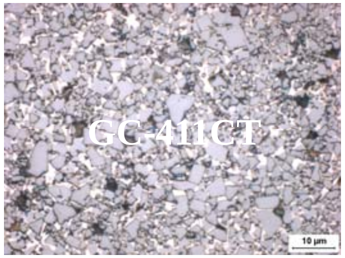


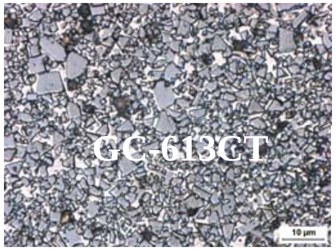



*** - WEDM Grade**
**T - Addition of TaC for Lubricity**
**CT- Grades are Corrosion resistant**

# POWDER METAL TOOLING GRADES

| INDUSTRY CODE | STANDARD | PREMIUM | COMMENTS |
|---|---|---|---|
| C12 | GC-313*<br>GC-712C* | GC-411CT* | Med/ Lg WEDM Dies<br>High Toughness<br>Form, Gear Dies & Cores<br>Excellent Wear |
| C13 | GC-315* | GC-613CT*<br>GC-415CT | Med/XL WEDM Dies<br>Extreme Toughness<br>Good Wear<br>Complex Internal Shapes |
| C14 | GC-320* | GC-618T* | High Impact Sizing Dies<br>Complex Internal Shapes<br>Excellent Shock &<br>Impact Strength |





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

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# 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



*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), $Cr_3C_2$ (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.

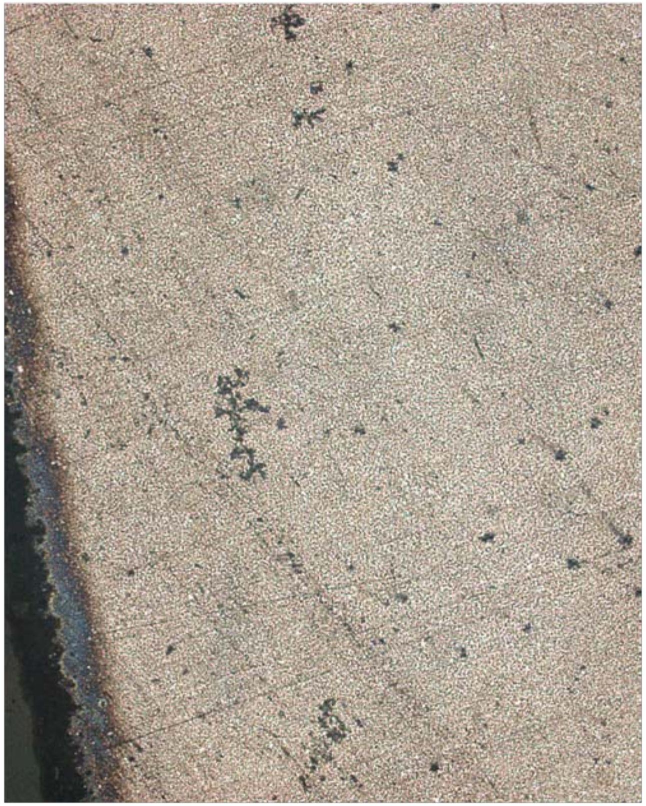
# Failure Analysis & Troubleshooting

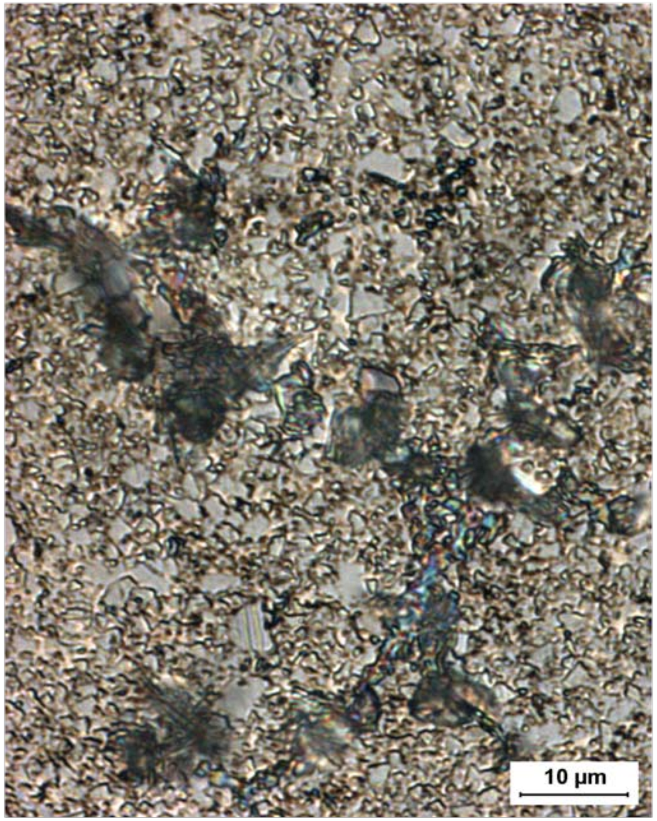
# Typical Defects and Failures of Cemented Carbide Products / Applications

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.**

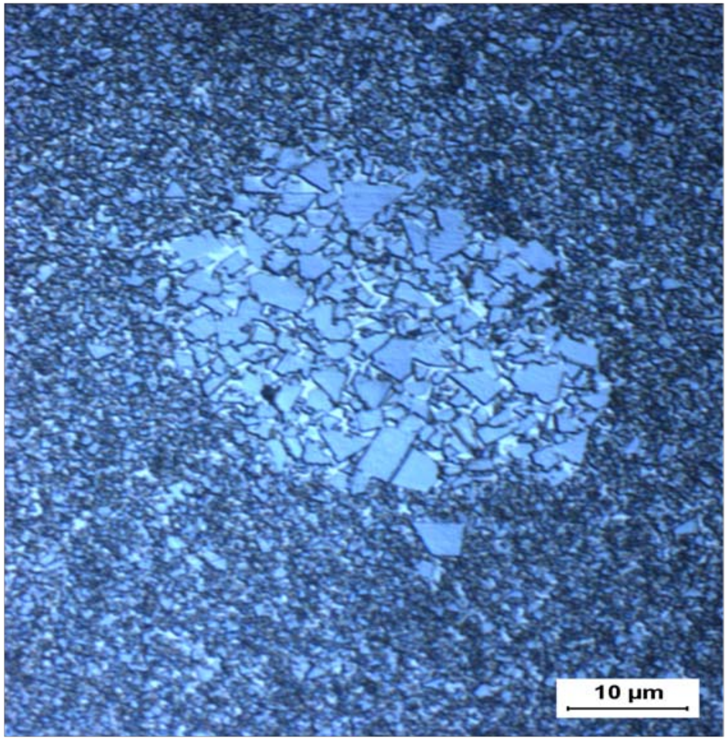
# Carbide Processing Defects



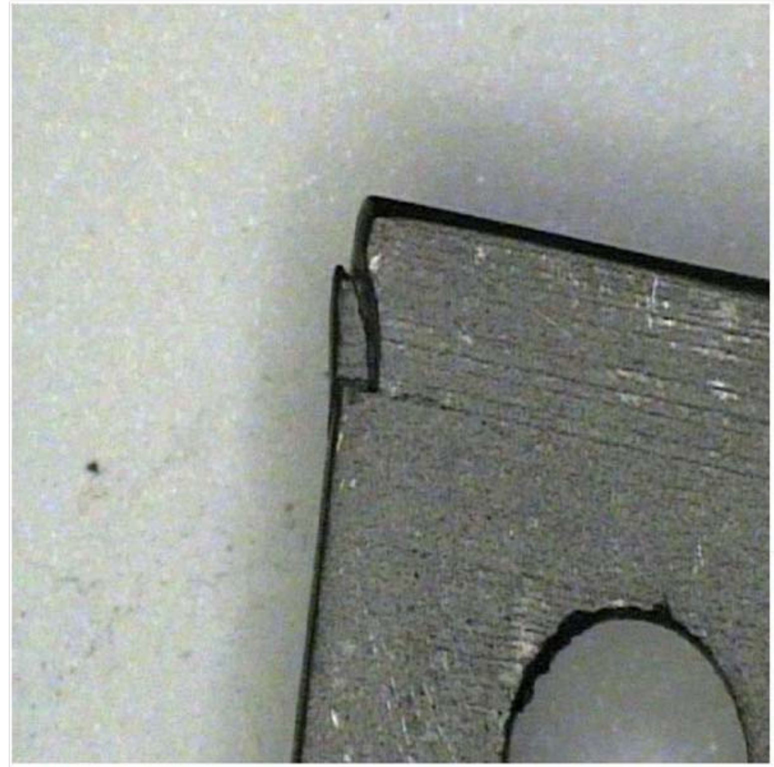



**Eta-Phase in Cemented Carbide Materials**

# Carbide Processing Defects




Large Carbide grains cluster formation



Chipping crack resulting from green carbide shaping operation

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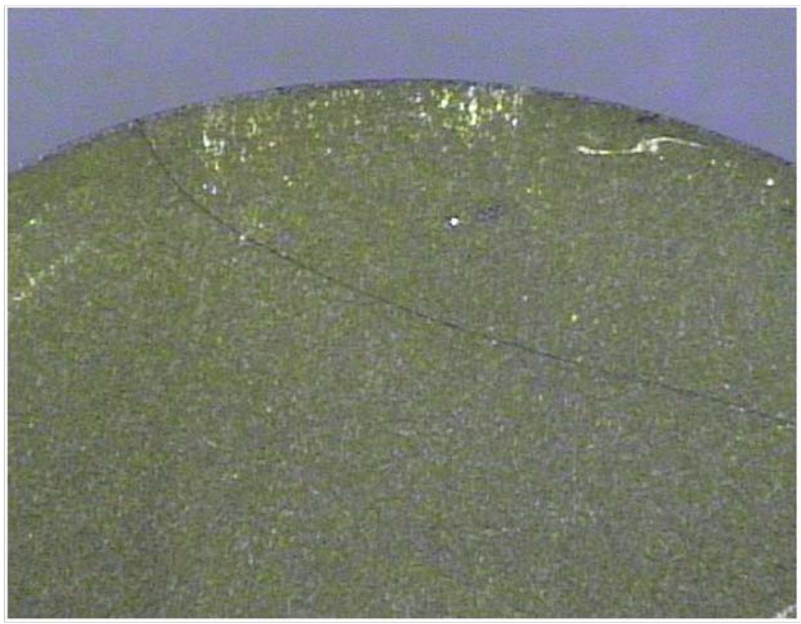
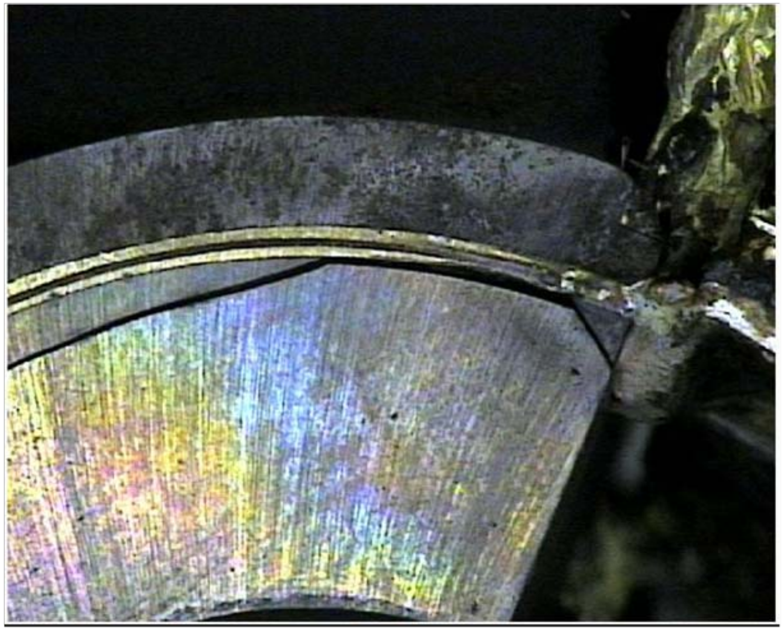
# Fabrication Defects

EDM Crack



Brazing Crack



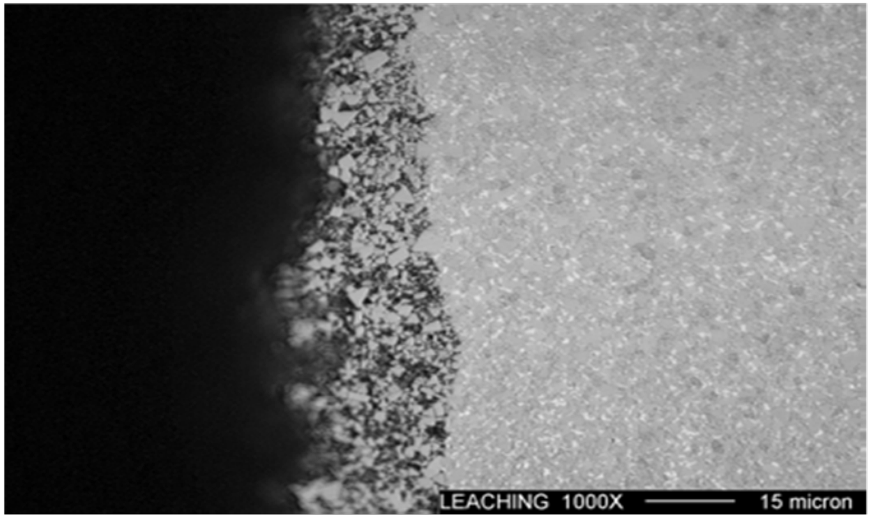
# Environmental Corrosion & Pitting Defects

Observable pitting

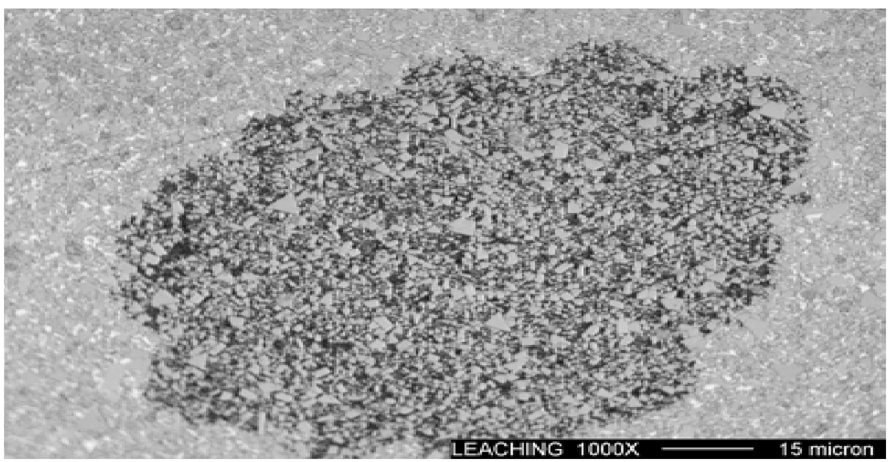
Corrosive attack on binder material

# Environmental Failures

a)

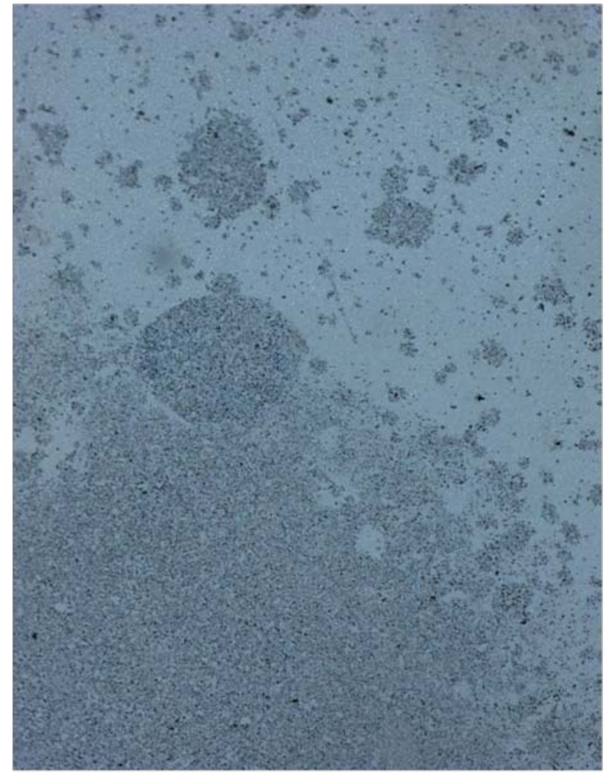



b)




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**

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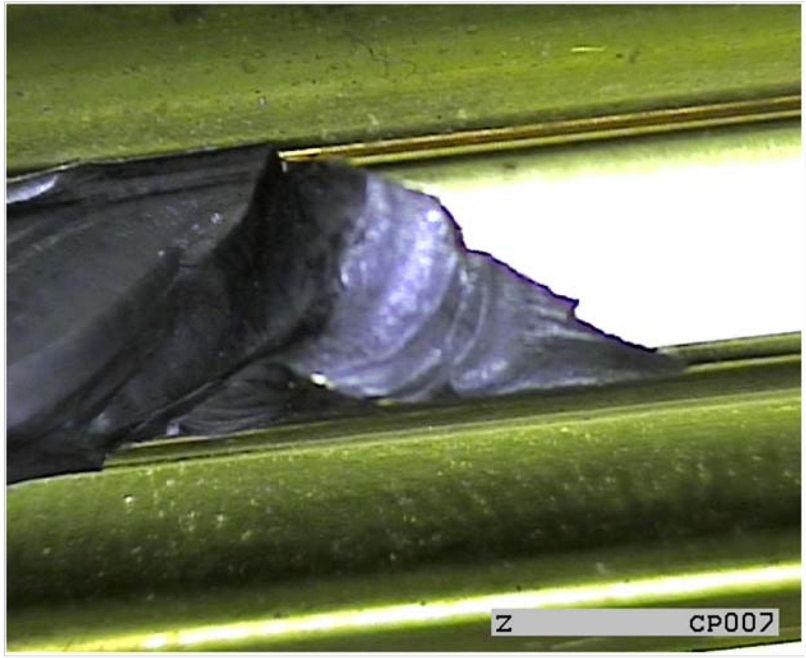
# Carbide Failure Patterns




Brittle Fracture Defect

Cyclic Fatigue Failure

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# …ANY QUESTIONS?

# OR COMMENTS…

# PLEASE…

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