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Carbide Grades for PM Tooling

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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**

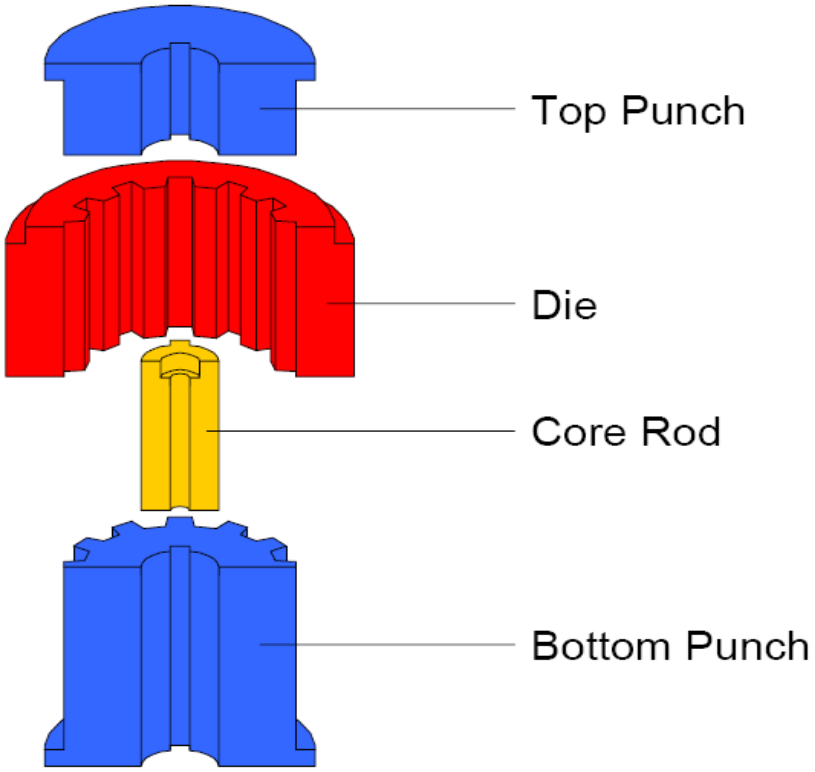
What is Cemented Carbide Grade?

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), **Mo_2C** (Molybdenum Carbide), **TaC** (Tantalum Carbide), **Cr_3C_2** (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.



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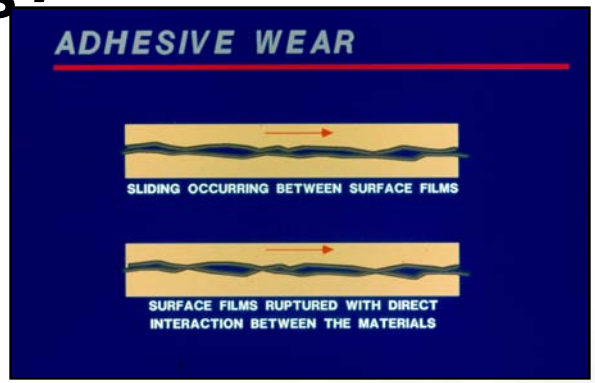
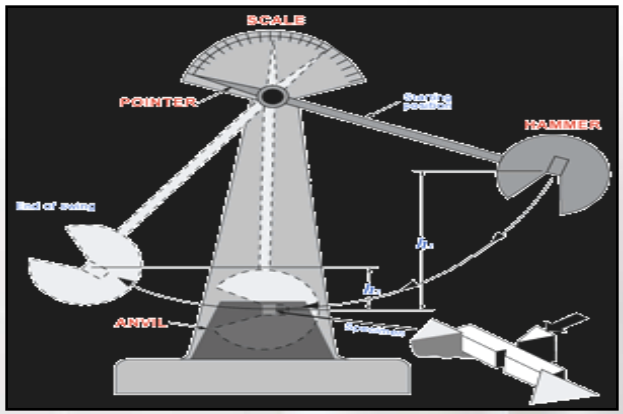
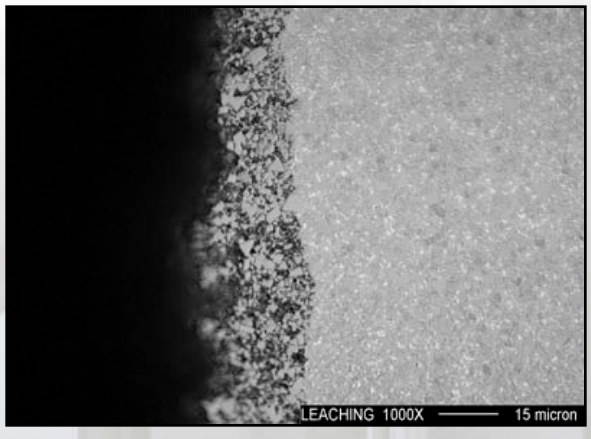
What do PM Tools see under normal working conditions?







IMPACT

CORROSIVE WEAR

Therefore, tools should efficiently resist wear, corrosion and impact…

PROPERTIES OF SOME SELECTED WC-Co CEMENTED CARBIDE GRADES vs. OTHER TOOL MATERIALS.

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 °C-400 °C Cal/ (s·°C ·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 (66 HRc)	2	575	600	-	34	6.5
Carbon Steel (AISI 1095)	79 (66 HRc)	1	-	-	300	30	-
Cast Iron	-	2	105	-	-	15-30	9.2

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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;

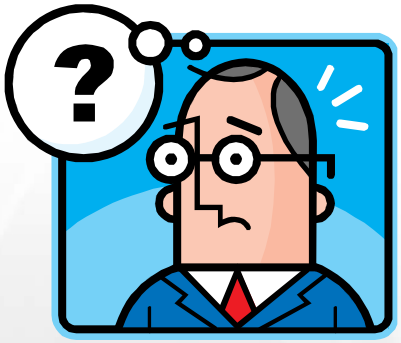
-***Tensile Strength:*** Tensile Strength is varied from **160,000 psi to 300,000 psi**;

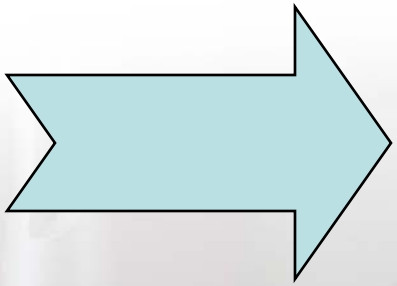
-***Compressive Strength:*** Compressive Strength is over **600,000 psi**;

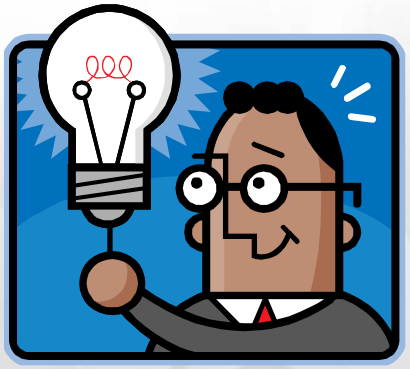
-***High Temperature Wear Resistance:*** Good wear resistance **up to 1,000 ºF**.

…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:

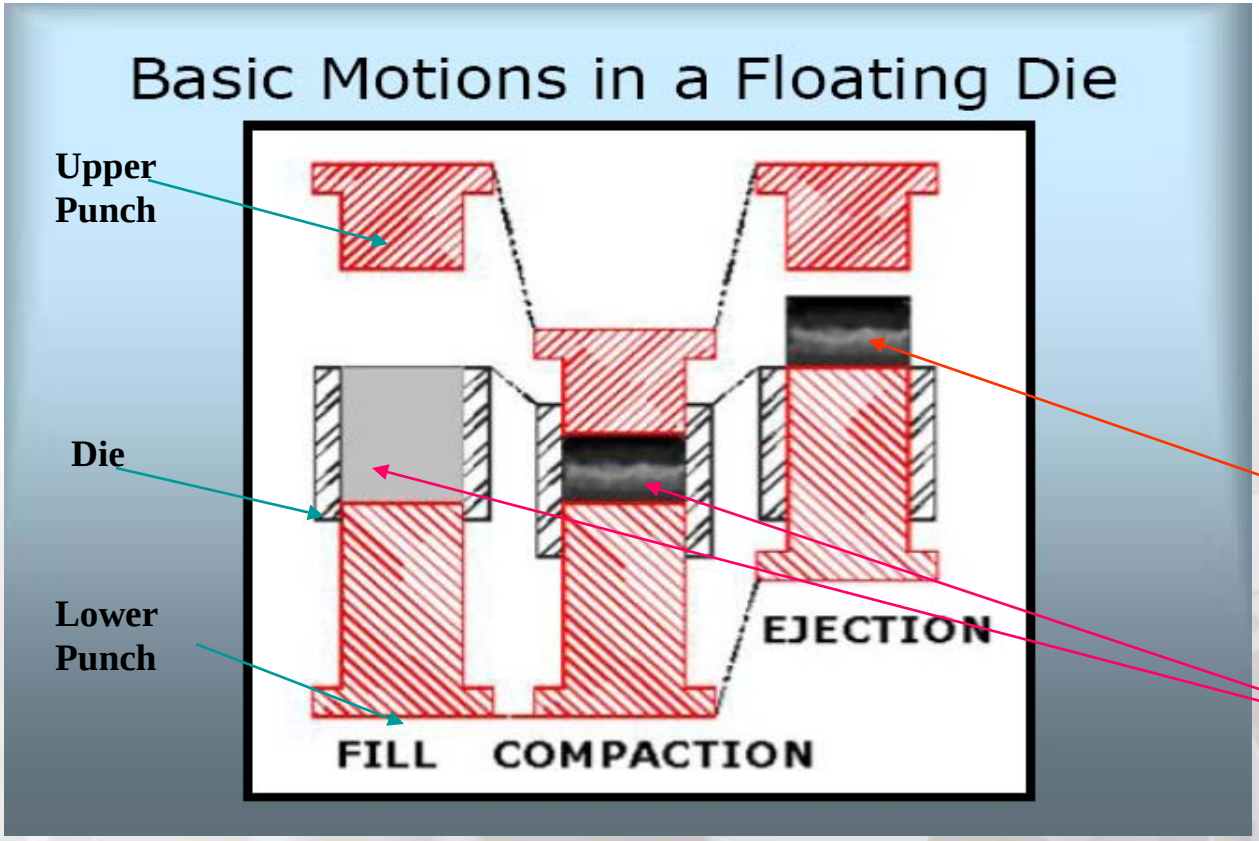






…based on Tool Members Functions…

Powder Compaction Schematic in Rigid Tool Set:



With various motions, PM tools sustain various types of thermo-mechanical stresses

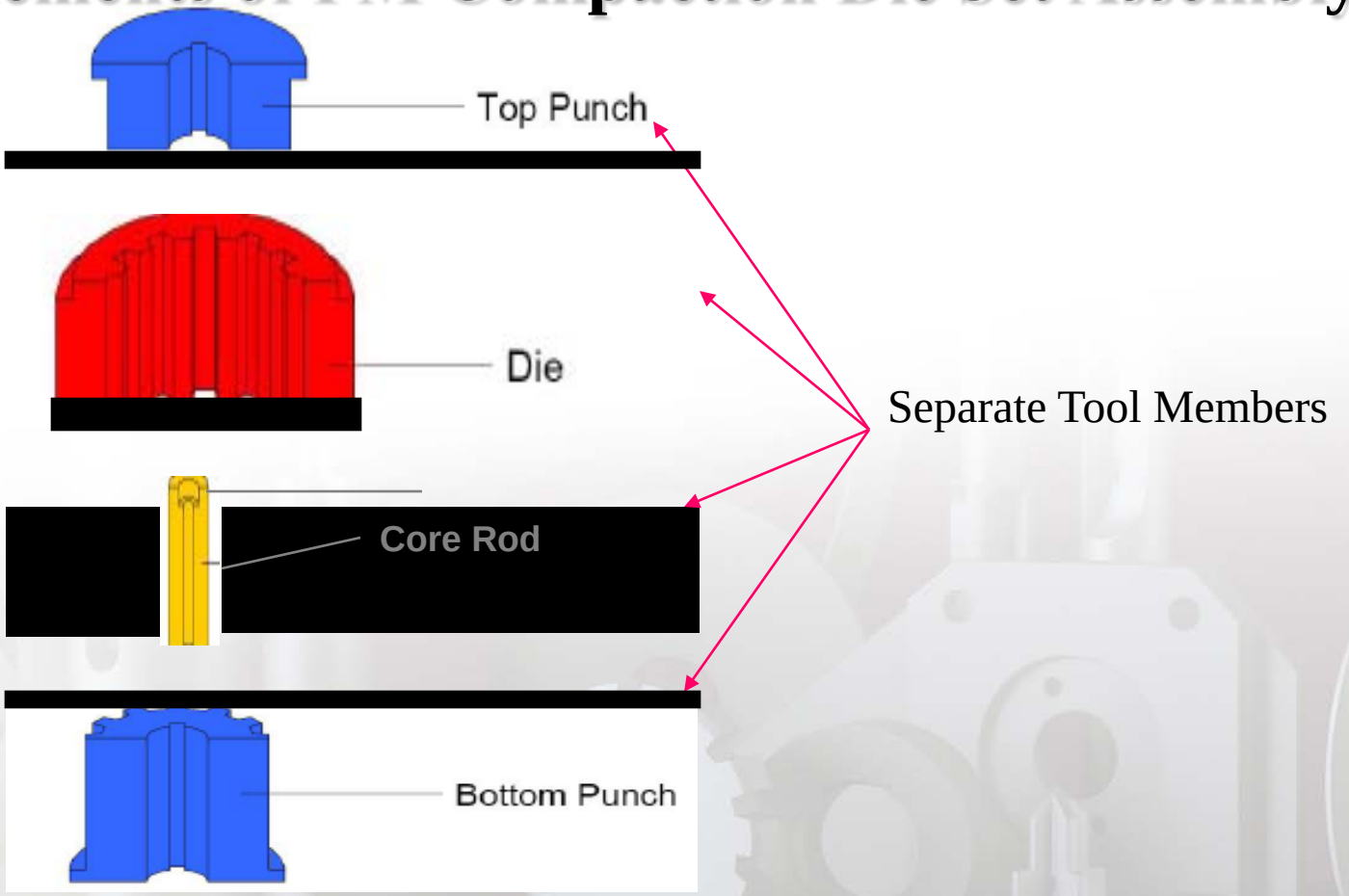
Considerations for PM Compacting Tools Material Selection:

- **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



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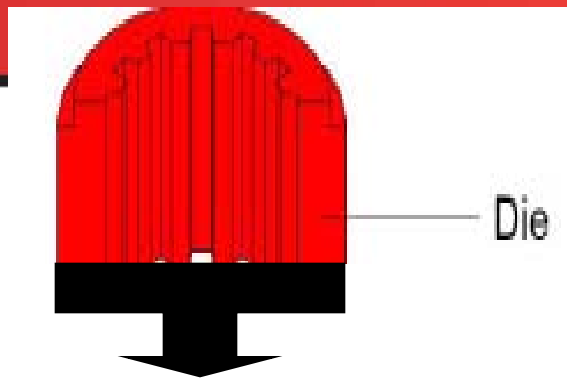
Requirements of each separate tool element within a Compacting / Sizing Tool Die Assembly….



- 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

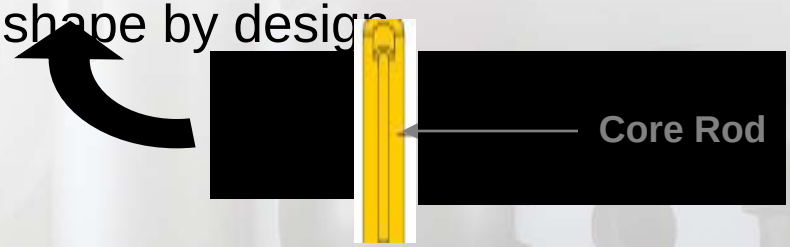
…Requirements of Each Separate Tool Element within the Compacting /Sizing Tool Die Assembly…

- 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.



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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?

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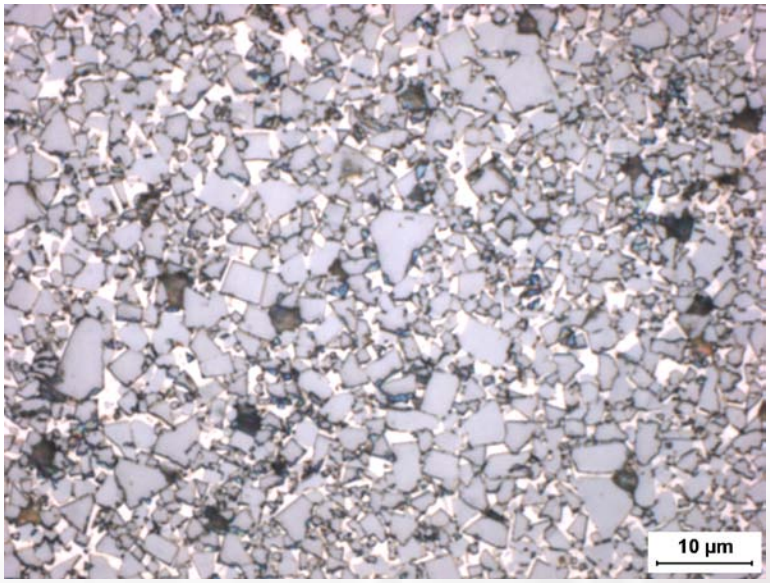
Grain Size VS Cobalt Content:



GC-411CT

Hardness: 88.0 - 89.0

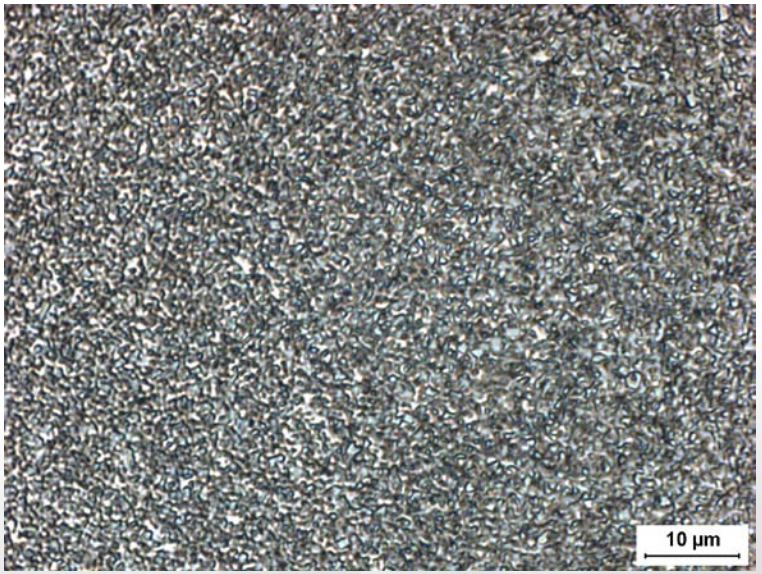
TRS: 490,000 psi

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

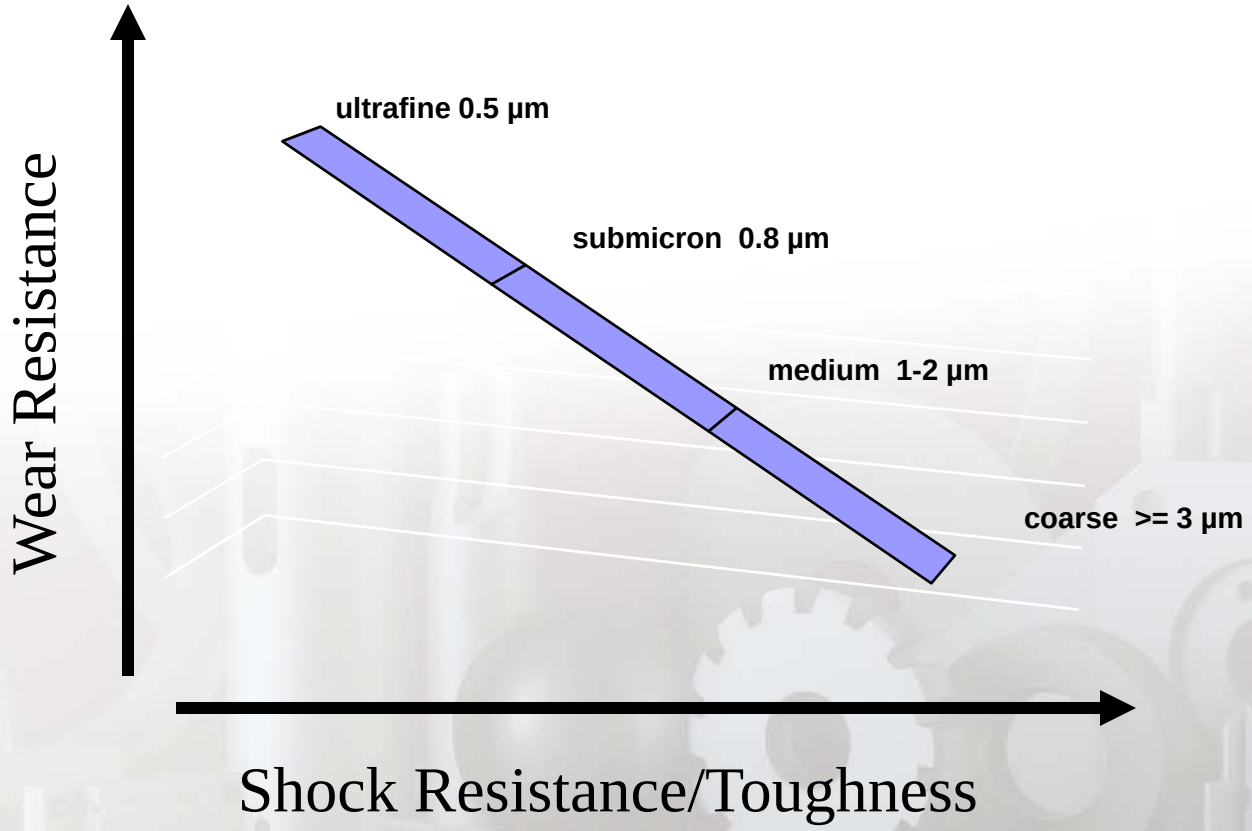
Average grain size: 0.8 micron

Galling Resistance: Low

Corrosion Resistance: Low

Wear resistance: High

Effect of Grain Size



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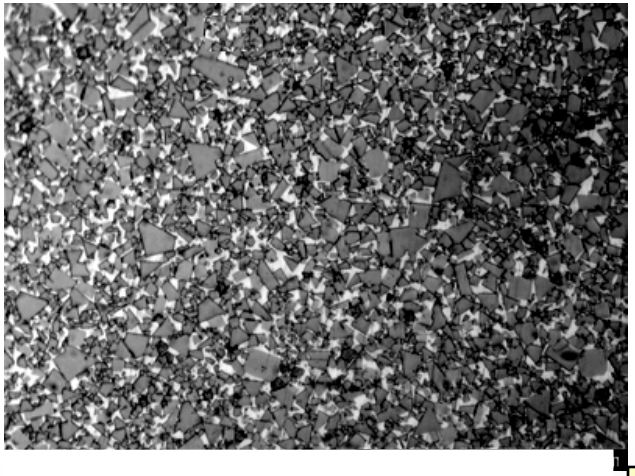
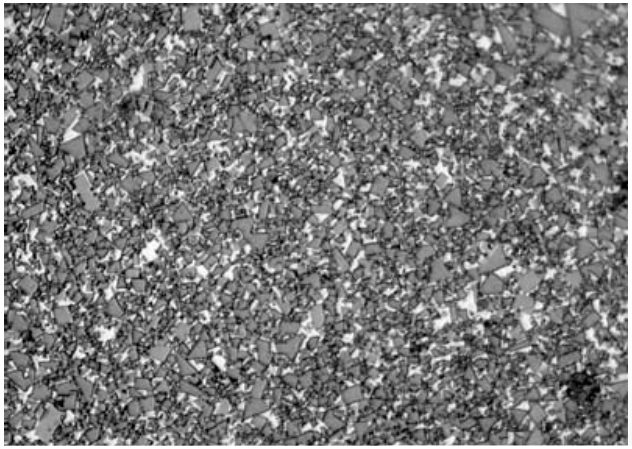
Constant binder content - varying grain size

4 µm

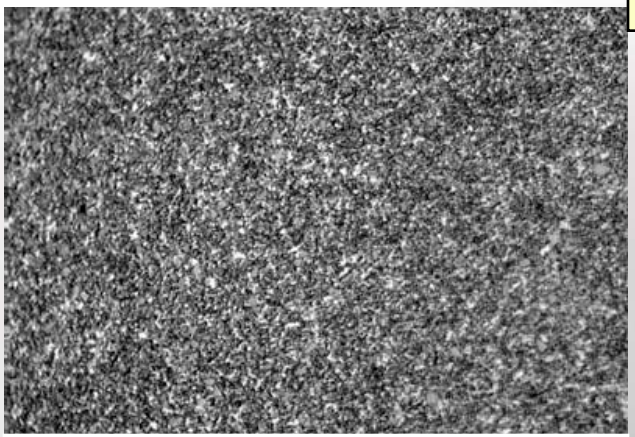


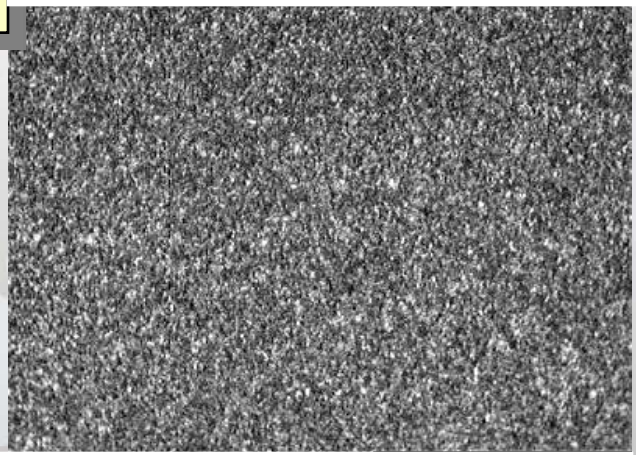


2 µm

1500x

0.8 µm



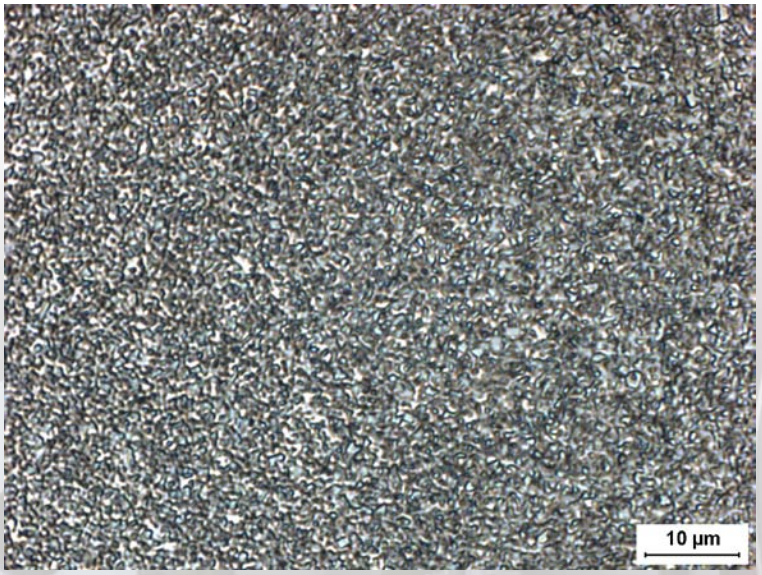


0.5 µm

Fine grain formulation:

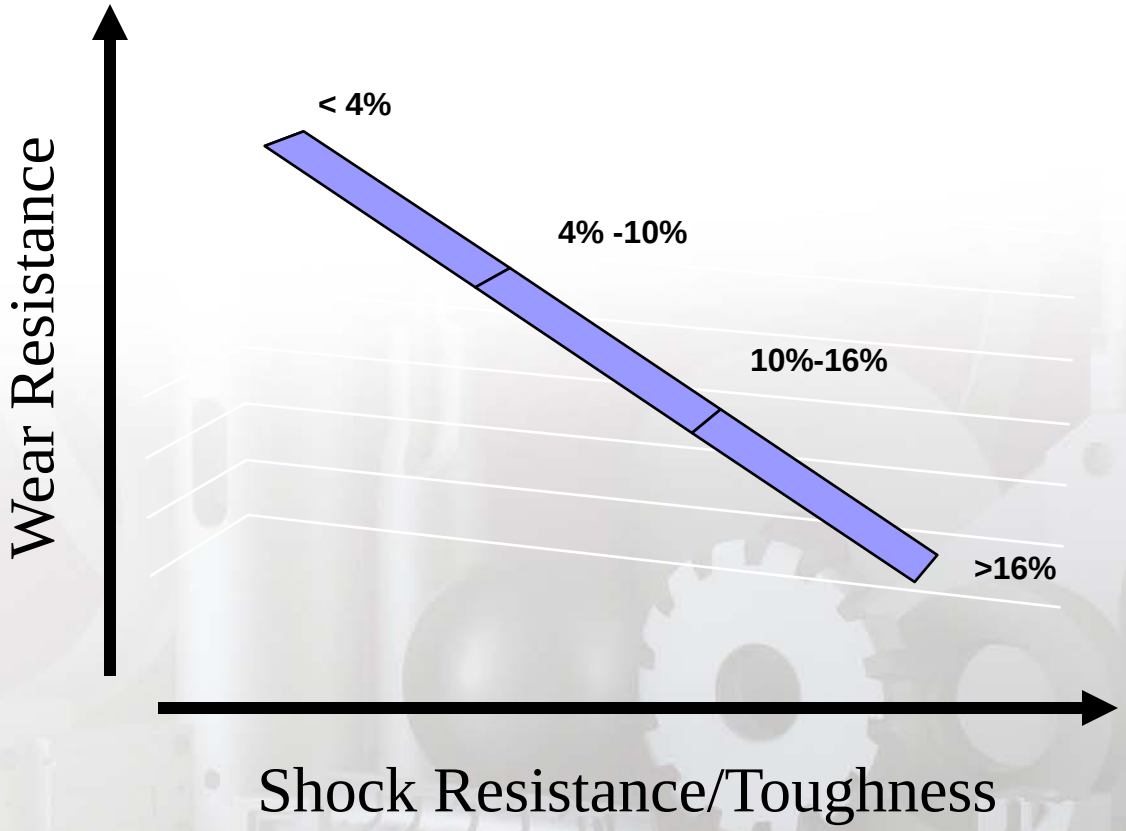
What does it do for Cemented Carbide ?

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.



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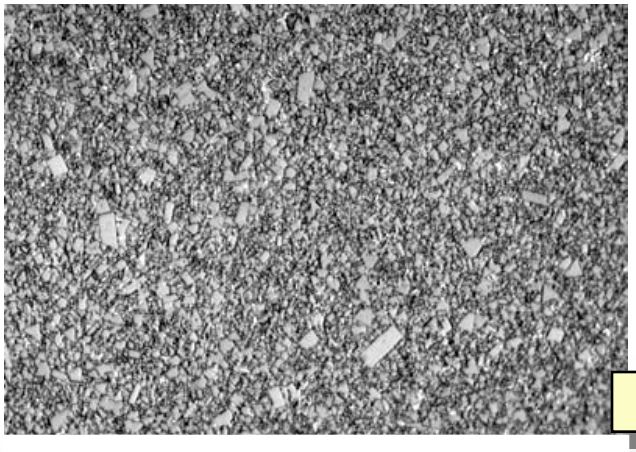
Constant grain size/varying binder content

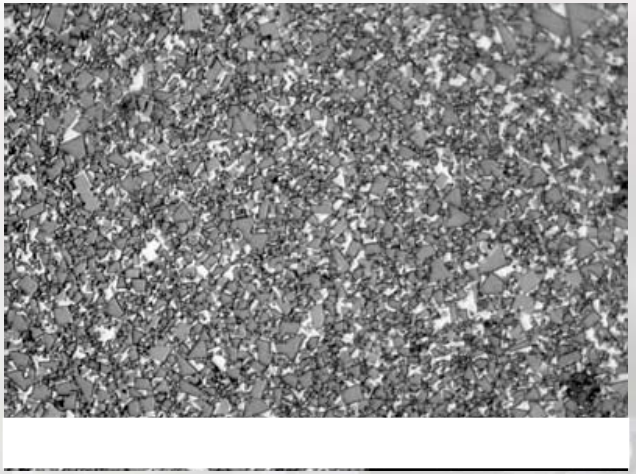
6%

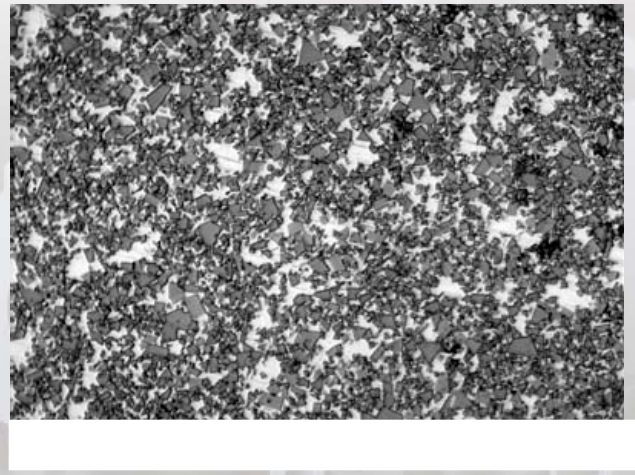


1500x

10%

16%



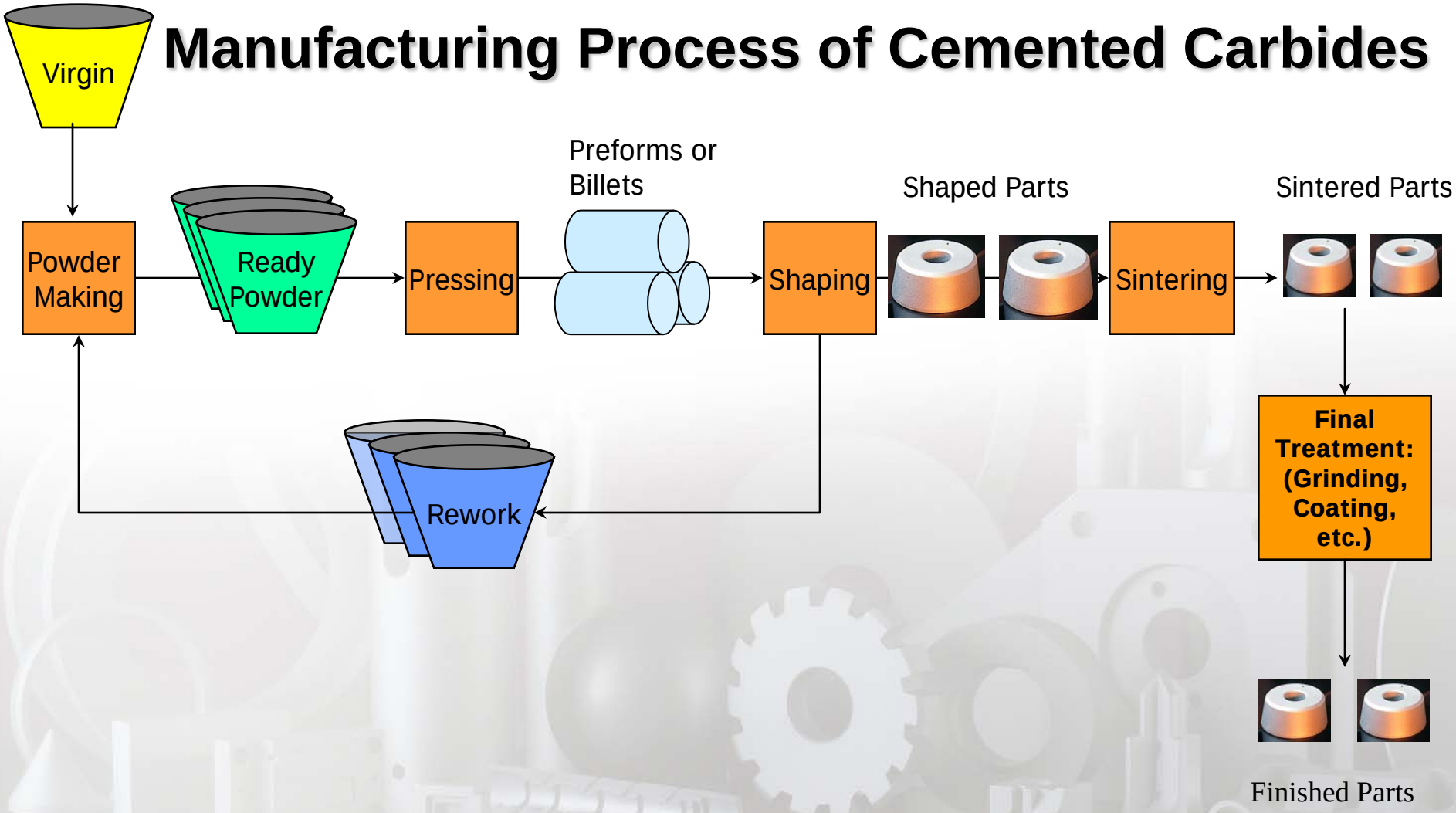


24%

Processing Advancements…

…or how to make superior quality with cemented carbide material….

Manufacturing Process of Cemented Carbides



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Key Manufacturing Operations:

Milling

Vacuum Drying

Mechanical pressing

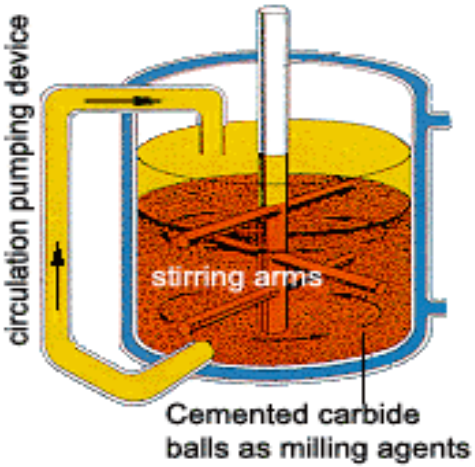
Spray Drying

Cold Isostatic Pressing

Powder shaping

Sinter-HIP Thermal Processing

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.***

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Processing Advancement:

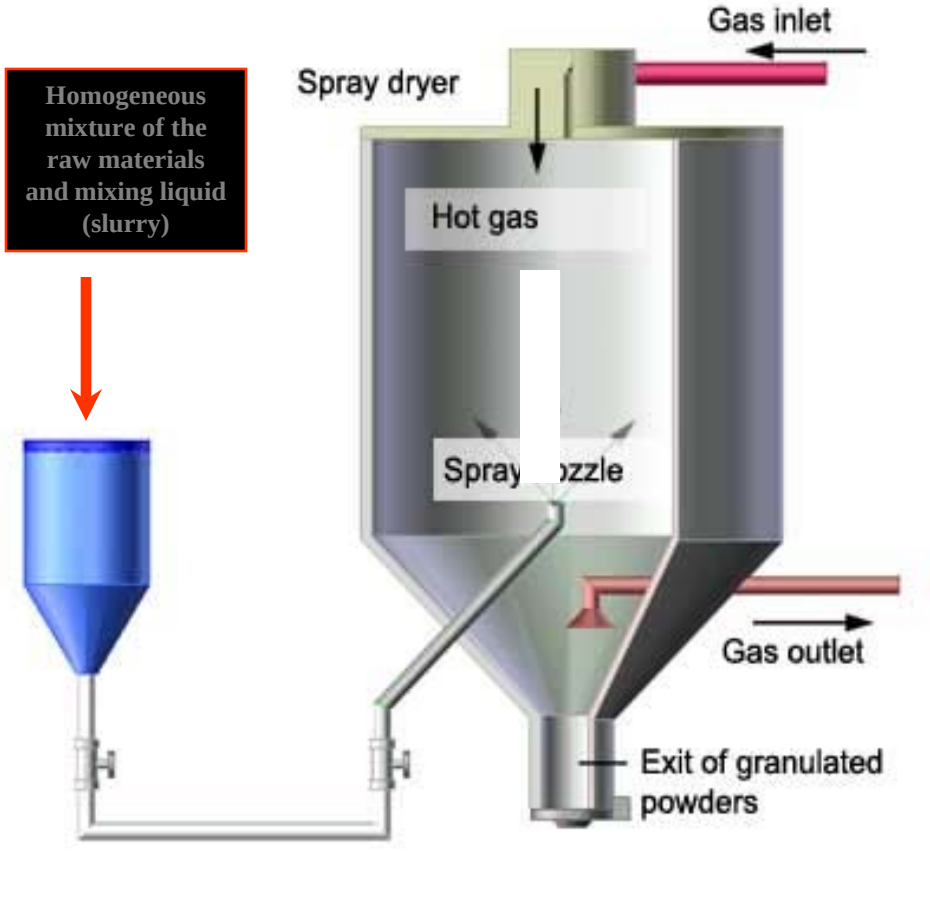
Spray Drying for Carbide Grade Formulations

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.

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.

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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.

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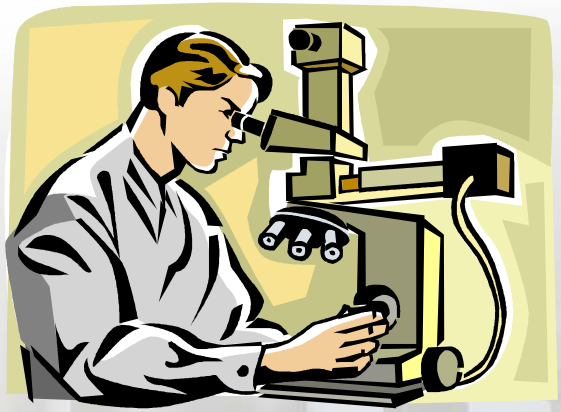
Cemented Carbide Grades - Design & Development



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New Materials Lab:

For Mechanical Strength

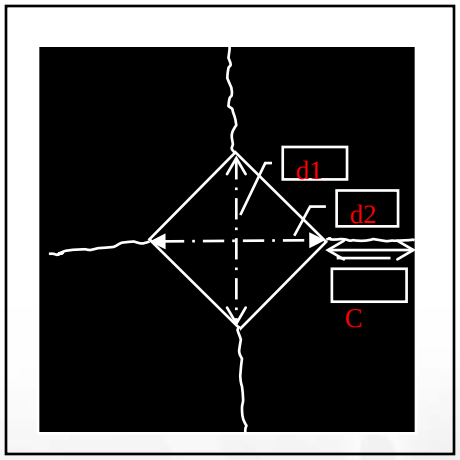
.....

Examples:

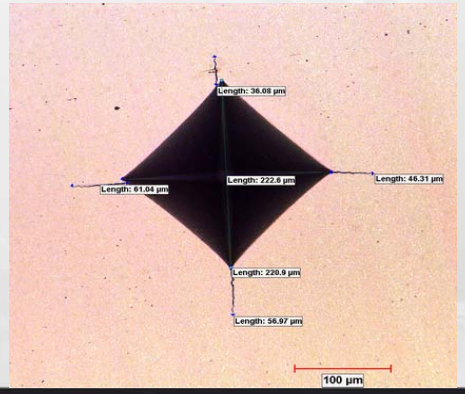
PM dies and punches, sizing dies…..

Palmqvist Fracture Toughness Test:

Schematic of Palmqvist Test with Vickers indentation.



Vickers Indent with Crack Origination.



- **Palmqvist Toughness (W_G)**

$$W_G = \frac{P}{T}$$,where

P = load in Newtons

T = total crack length in mm (Σc)

- **Palmqvist fracture toughness (W_K)**

$$W_K = A \times \sqrt{HV} \times \sqrt{W_G}$$

Where A-constant; HV-Vickers Harndess

Important Mechanical Properties for Selected Carbide Grades:

Grade ID	W_K MN * (m^(-3/2))	Standard Deviation
GC-313 *	18	3
GC-613CT	23	3
GC-411CT	17	1
GC-415CT	21	3

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

*** Denotes C-12 Grade**

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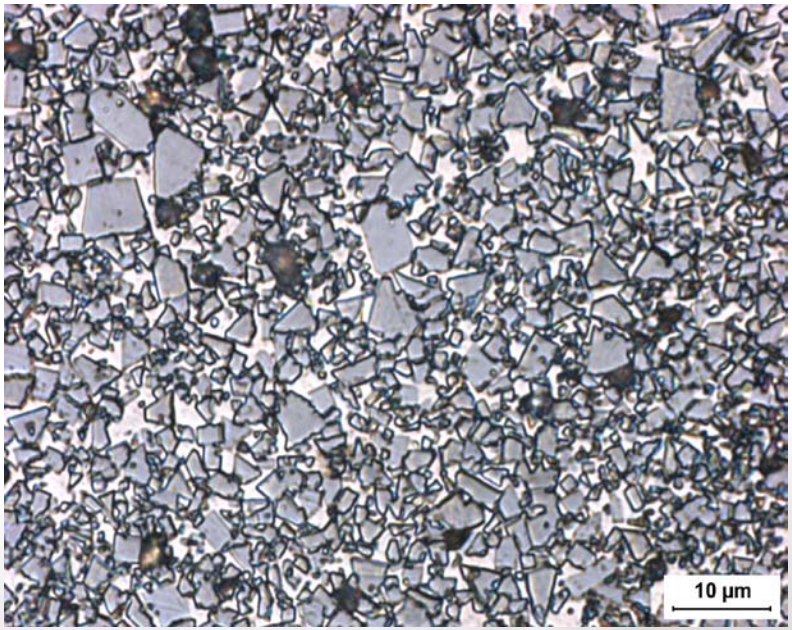
Material Design: Premium WC Crystals:



GC-411CT

GC-613CT

GC-415CT

GC-813CT

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

For Adhesive Wear …….

Examples:

PM dies and punches, sizing dies…..

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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

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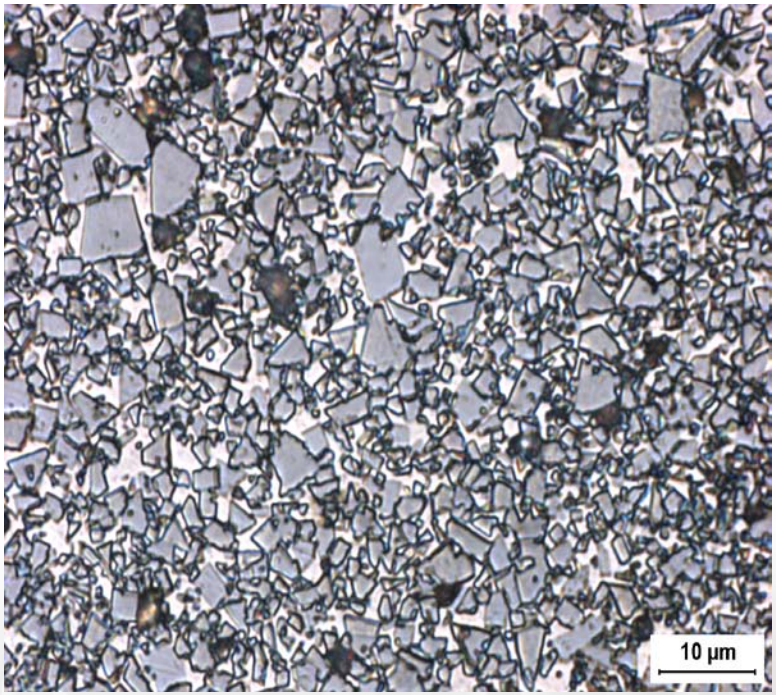
Grade GC-613CT



Composition:

Tungsten Carbide: (6.0 micron)	86.25%
Cobalt:	13.00%
Tantalum Carbide	3.00%
Other:	0.75%

Physical properties:

Hardness, HRA (ASTM B294)	87.4-88.4
Density, g/cc (ASTM B311)	14.01 -14.13
Aver. Transv. Rupture Strength, psi (ASTM B406)	500,000
Typical Porosity (ASTM B276)	A02-B00-C00

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…..

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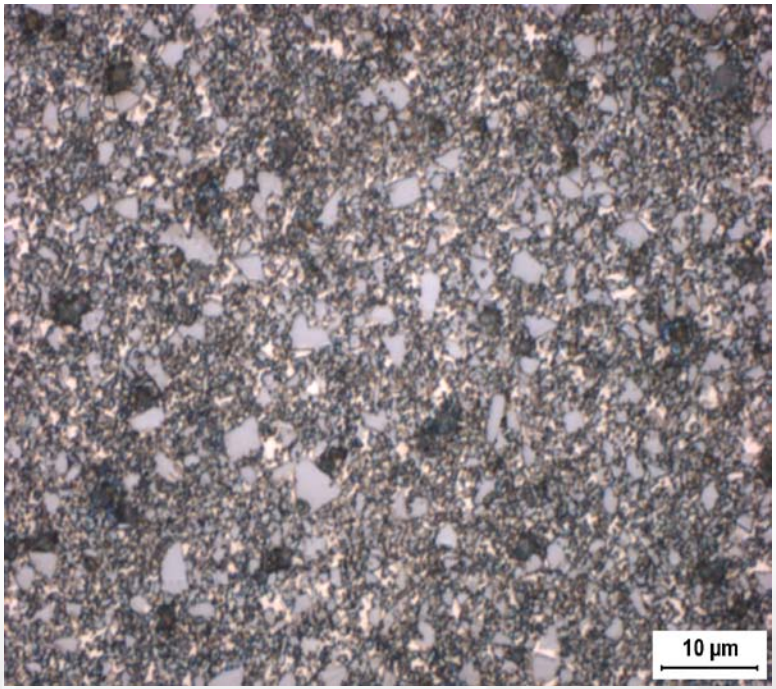
Grade GC-813CT



Composition:

Tungsten Carbide: (mixed: 1.0 and 4.5 microns)	86.5%
Cobalt:	10.5%
Tantalum Carbide	2.0%
Other:	1.0%

Physical properties:

Hardness, HRA (ASTM B294)	90.5-91.5
Density, g/cc (ASTM B311)	14.24 -14.36
Aver. Transv. Rupture Strength, psi (ASTM B406)	460,000
Typical Porosity (ASTM B276)	A02-B00-C00

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 powderscold 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.***

For Efficient Corrosion Resistance ….

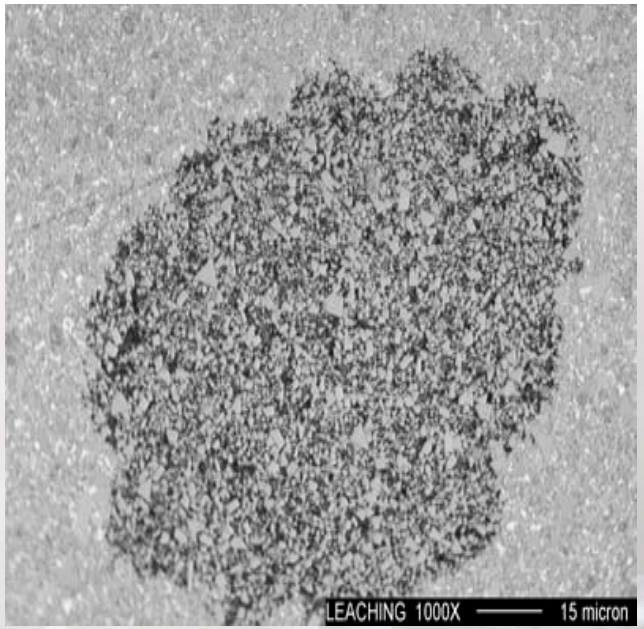
Examples:

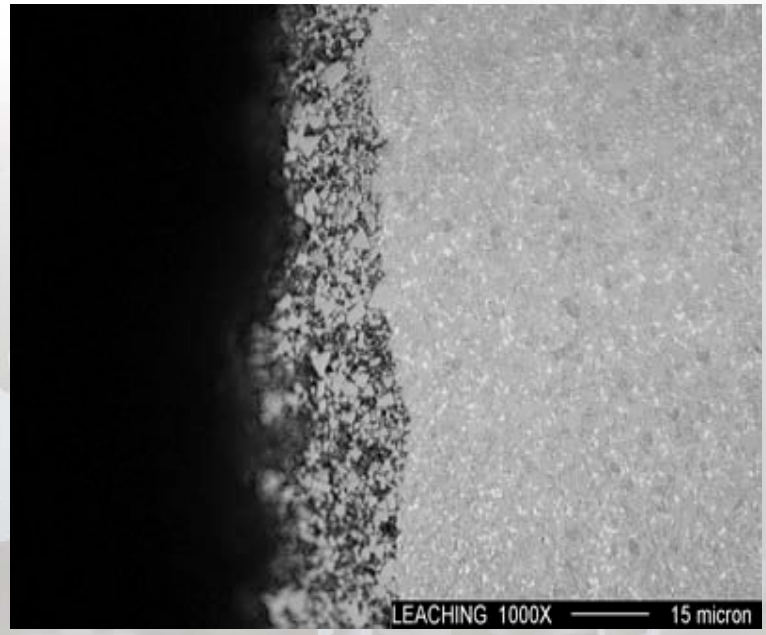
Negative influence of residual lubricants that may remain on the working surfaces of tools being stored in tooling premises for future usage.

…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.

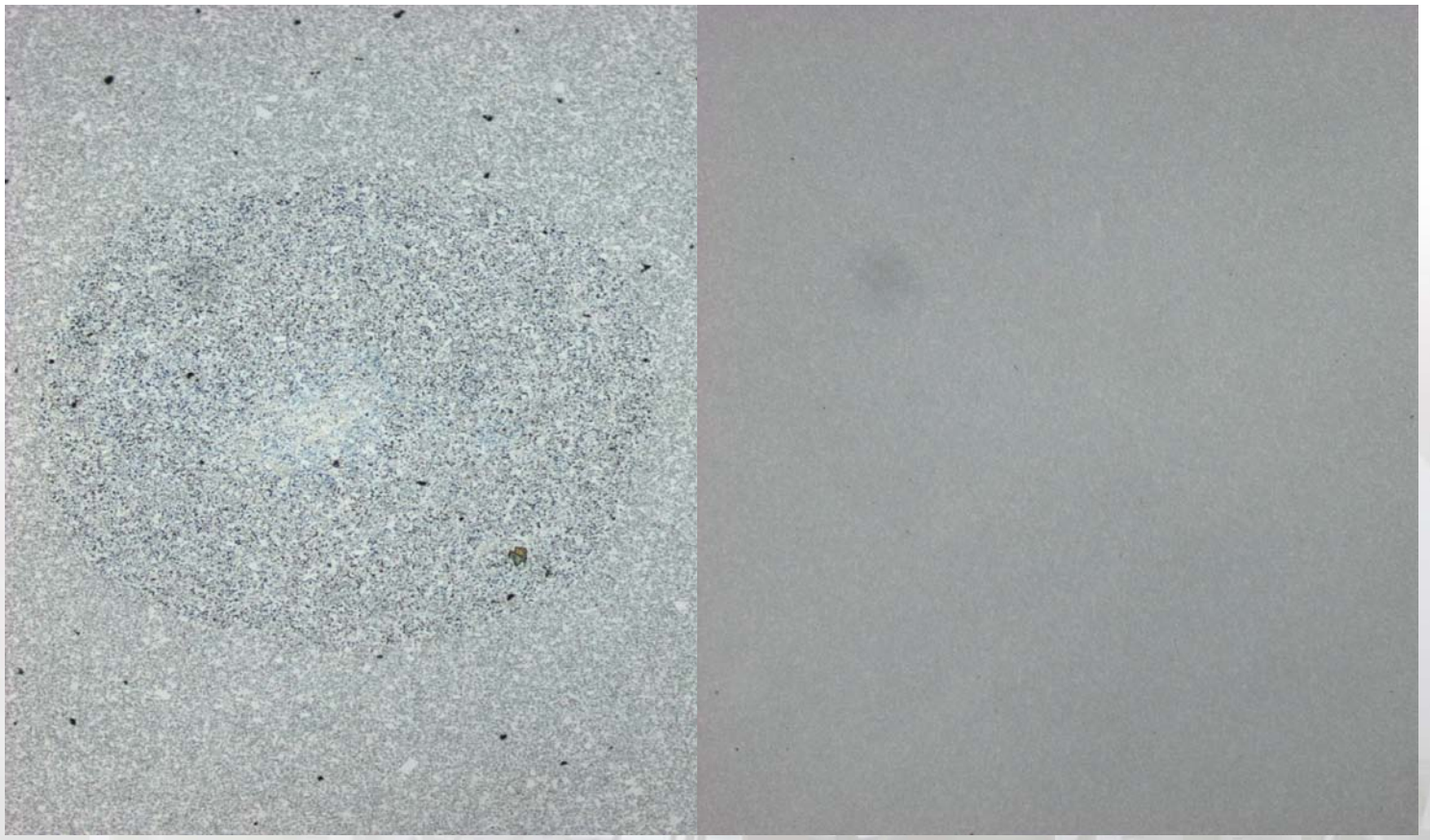




Corrosion resistance of GC-411CT

GC-313*

GC-411CT*



*Test conducted in tap water over 48 hours.

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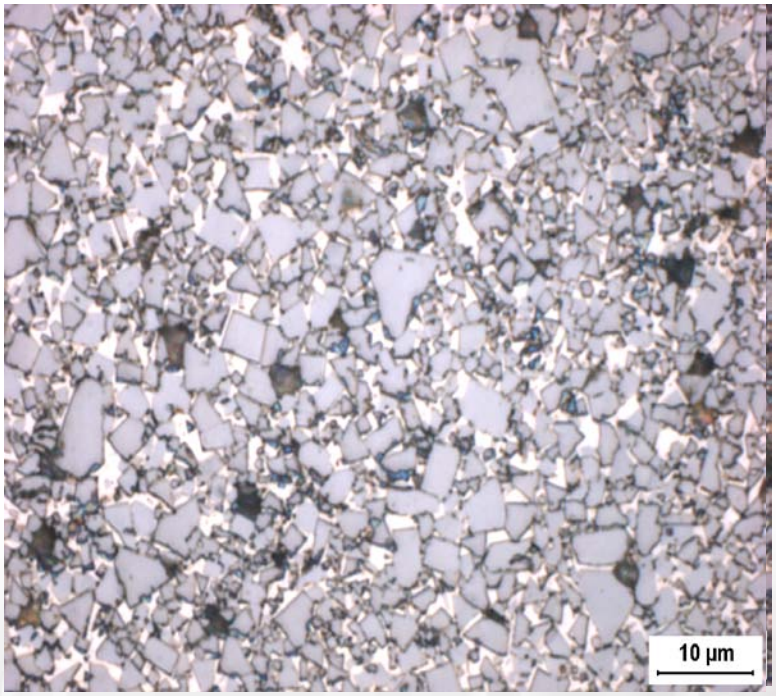
Grade GC-411CT



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

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.

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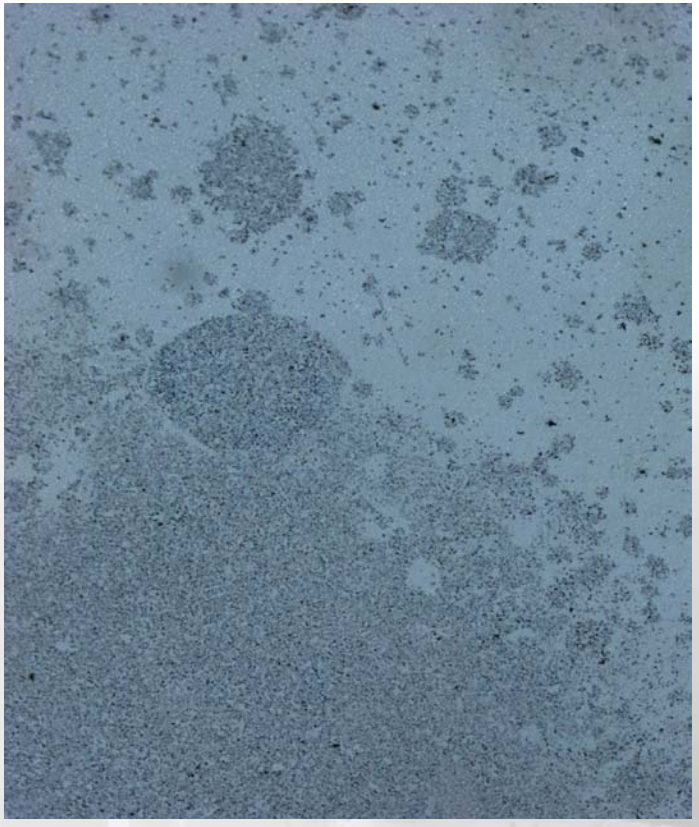
Electrolytic Attack

GC-313*



GC-411CT*

*Test conducted in wire tank for 100 hours.

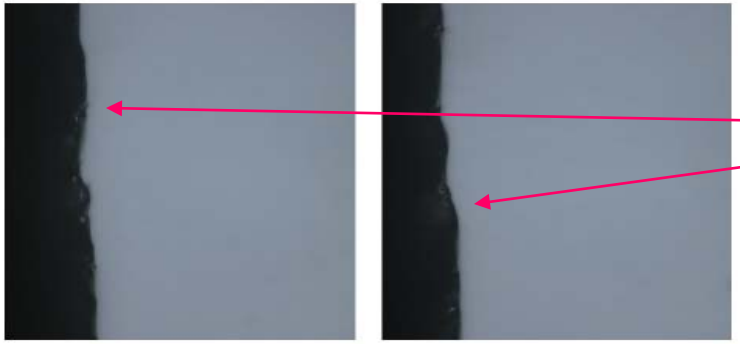
General Recommendations to Resist Corrosion:

- 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.

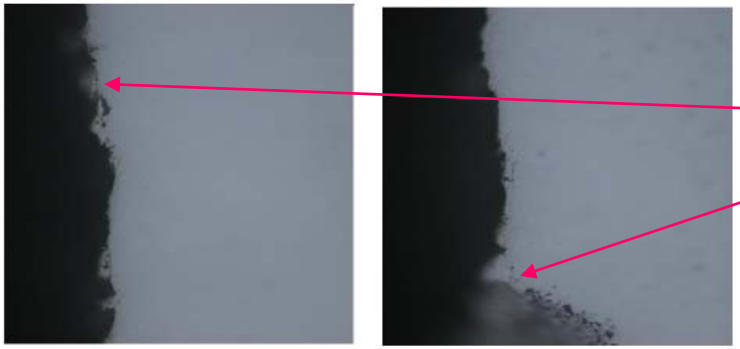
EDM Serviceability: Effect of Alloying Concept

GENERALCARBIDE.

GC-411CT / WEDM / ROUGHCUT / 500x



GC-313 / WEDM / ROUGHCUT / 500x



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

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GRADE SPECIFICATIONS

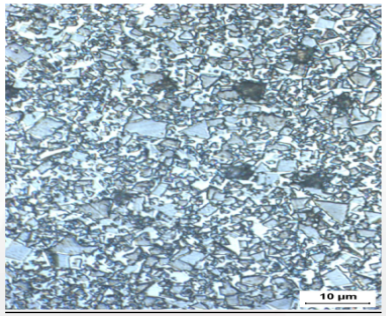
Grade: **GC-415CT**

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.

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GRADE SPECIFICATIONS

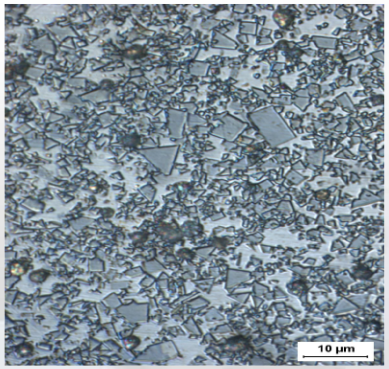
Grade: **GC-425CT**

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
Density, g/cc (ASTM B311)	12.88 - 13.12
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.....Modest

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

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Grade Recommendations for PM Tooling

PM TOOLING GRADES:

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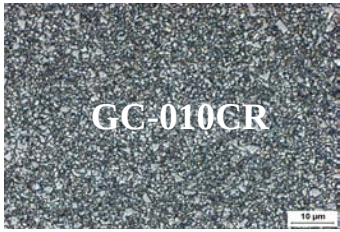
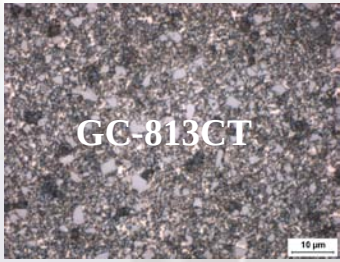
INDUSTRY CODE	STANDARD	PREMIUM	COMMENTS
C2/C9	GC-106	GC-0004 GC-010*	HighWear Dies Small WEDM Dies & Pins-Excellent for pressing ceramics & large non-EDM liners
C10	GC-209	GC-813CT*	High wear / Fine Teeth/ WEDM Dies & Cores/ Intricate Forms / Excellent for Stainless PM
C11	GC-211*	GC-313T* GC-411CT*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





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

PM TOOLING GRADES:

GENERALCARBIDE.
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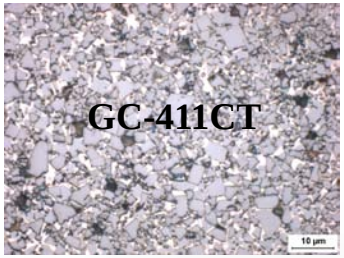
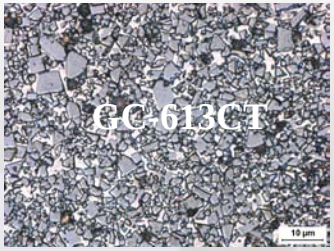
INDUSTRY CODE	STANDARD	PREMIUM	COMMENTS
C12	GC-313* GC-712C	GC-411CT*	Med/ Lg WEDM Dies High Toughness Form, Gear Dies & Cores Excellent Wear
C13	GC-315*	GC-613CT* GC-415CT *	Med/XL WEDM Dies Extreme Toughness Good Wear Complex Internal Shapes
C14	GC-320*	GC-618T* GC-425CT*	High Impact Sizing Dies Complex Internal Shapes Excellent Shock & Impact Strength





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

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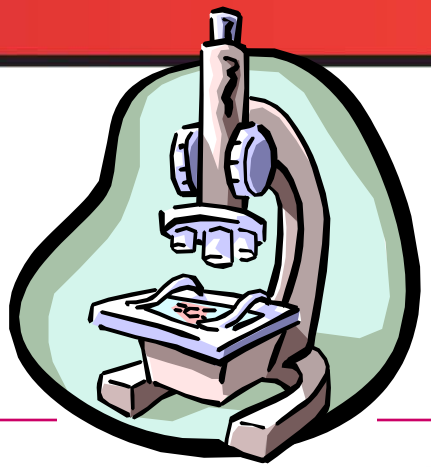
In Summary: General Carbide offers Distinct Grade Development Capability specifically for the PM Industry….



- **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 …

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Designer's Guide to Tungsten Carbide

See** 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?…

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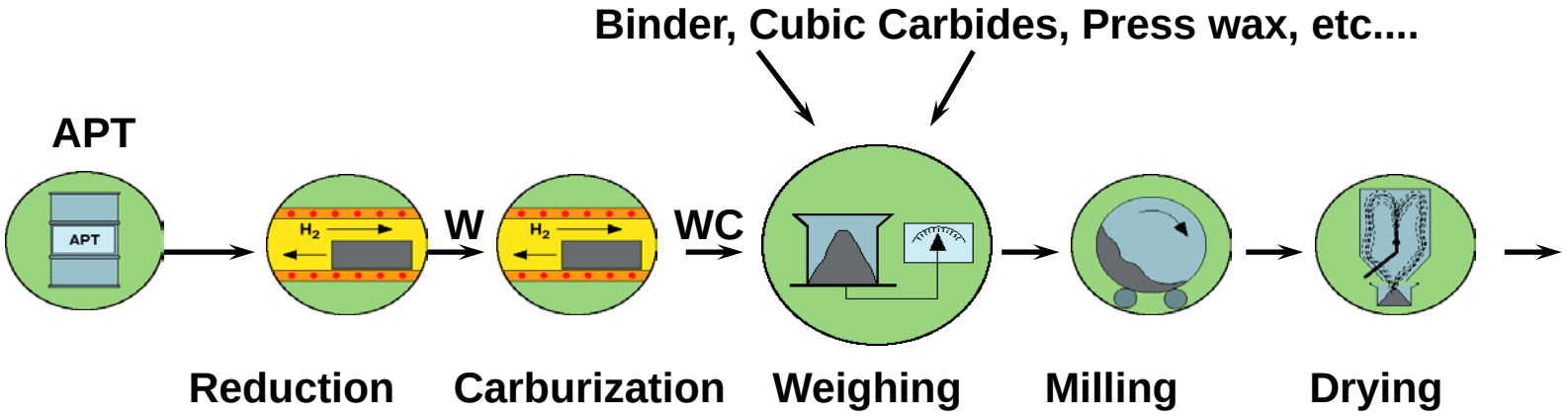
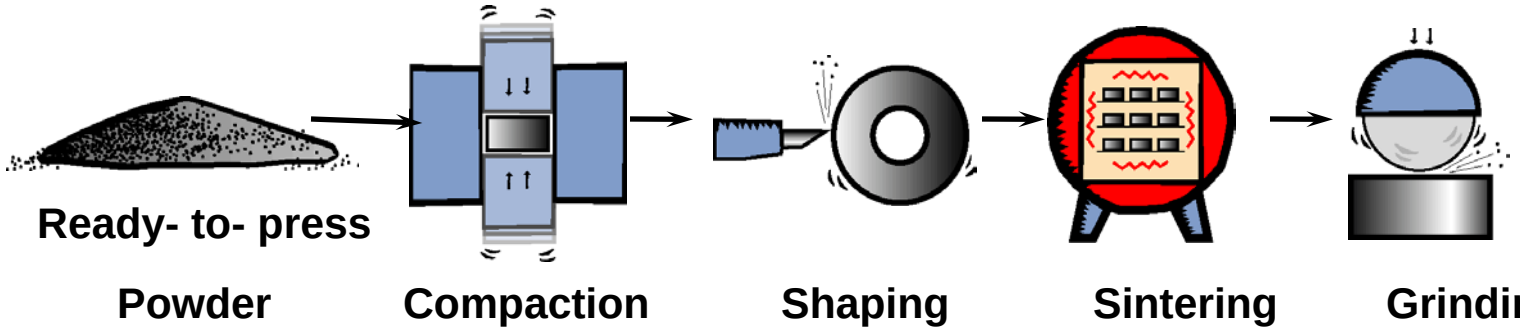
Manufacturing process for cemented carbide products:

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





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

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www.generalcarbide.com

GENERAL CARBIDE PRODUCTS ARE MADE IN THE USA

Grade Specifications

GENERALCARBIDE.

	Chemical Composition Weight Percent WC	Co	TaC	Other	Hardness HRA	Nominal Grain Size microns	Density g/cm³	Average Transverse Rupture Strength (psi)
Corrosion Resistant Specialty Grades								
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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