Advancements in Cemented Carbide Products & Processing for the Wire Die Industry

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Presented at Wire Expo 2009
April 28, 2009 Cleveland, Ohio

GENERALCARBIDE

Agenda

- What is a cemented carbide?
- Why do we use it?
- What advancements have been made in thermal processing?
- What advancements have been made in grade development?
- What progress has been made in failure analysis and troubleshooting?

CARBIDES?...

...What do we know about them?

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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.

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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 °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 (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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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….

Desirable Material Properties for Wire Draw Dies

1. high hardness - to resist wear
2. high toughness - to resist fracture
3. high thermal conductivity - to dissipate heat

Drawing Dies from WC

To Replace Diamond-Based Drawing Dies

1914 – Voigtlander & Lohmann (Essen)

Cast Carbide – (3.1 – 5.0 %C) 2750^{o}C

Sintered WC – Crushed Cast W_xC – Sinter just below MP (2500^{o}C) – Some Production – Brittle

1922 – Bramhauer – Osram Factory Berlin

<u>Significant Improvements:</u>

Fe infiltrated partially sintered WC

WC from Methane Carburized W powder.

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Karl Schröter Patents

Karl Schröter (Osram Studiengesellschaft)

[Established foundation for WC-Co Cemented Carbide technology that is utilized even today.]

- **1923-1929**

German Patent #420,689 (1925) – US Patent 1,549,615 (1925)

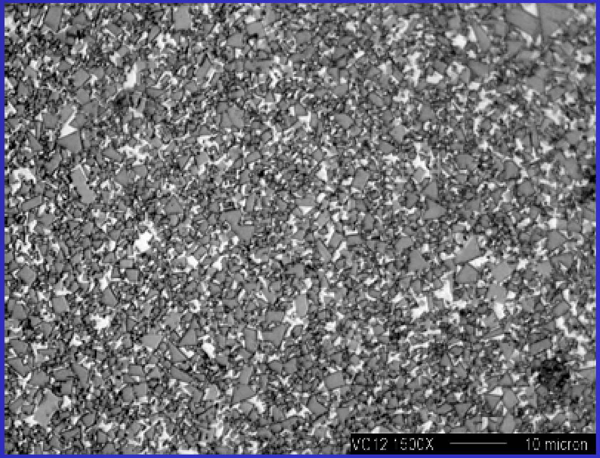
German Patent # 434,527 (1926) – US Patent #1,721,416 (1929)US Patent #1,757,846 (1930)

- **1925**

  Composition, w%. – {WC + (3 -10 Co)}, {WC + (4 -10 %C)}
  Sinter at 1500 – 1600^{o}C
  Sintering Atmosphere – H_2, N_2, A, CH_4, CO or their Mixture
  Cemented Carbide Binder are claimed to be based on Co, Ni, and Fe.

- **1929**

  Composition with 10 - 20% Binder (Co, Ni, Fe).
  CH_4 applied in order to get Carburized Tungsten Powder (Carbon content within WC get closer to 6.13%C)
  Sintering claimed at temperatures around 1400^{o}C



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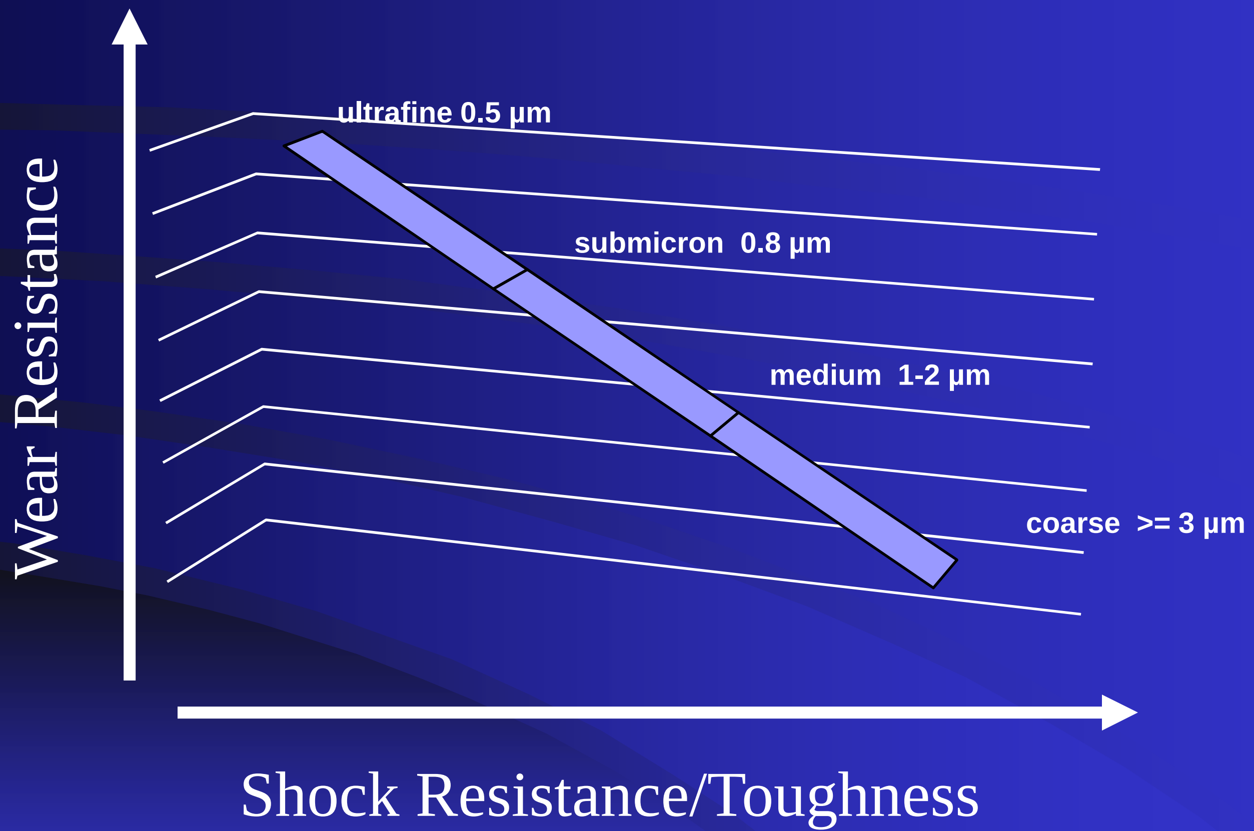
Properties of Some Selected Cemented Carbide Grades Recommended for Wire Dies

Material	Density, g/cm^3	Vickers hardness, kg/mm^2	Transverse-rupture strength, psi	Compressive strength, psi	Modulus of elasticity, 10^6 psi	Thermal conductivity, cal/cm sec °C	Coefficient of thermal expansion, 10^{-6}°C
Fused tungsten carbide	≈16	1800–2000	42,600–56,800	284,000	—	0.07	4
WC-Co 97-3, hot-pressed	15.5	1900	170,400	852,000	95	0.21	5
WC-Co 94-6, sintered	14.8	1600	241,400	710,000	85	0.19	5
WC-Co 94-6, hot-pressed	15.1	1650	213,000	781,000	88	0.19	5
WC-Co 91-9	14.7	1500	269,800	681,600	84	0.18	—
WC-Co 89-11	14.2	1400	284,000	653,200	82	0.16	5.5
WC-Co 87-13	14.1	1350	298,200	639,000	79	0.14	—
WC-TiC-Co 86-5-9	13.3	1600	227,200	653,200	84	0.15	5.5

Advancements in Cemented Carbide Grade Development.....

Effect of grain size versus binder content

Effect of Grain Size



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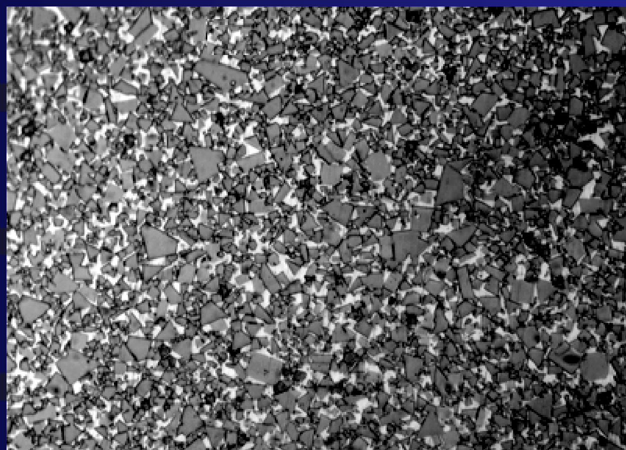
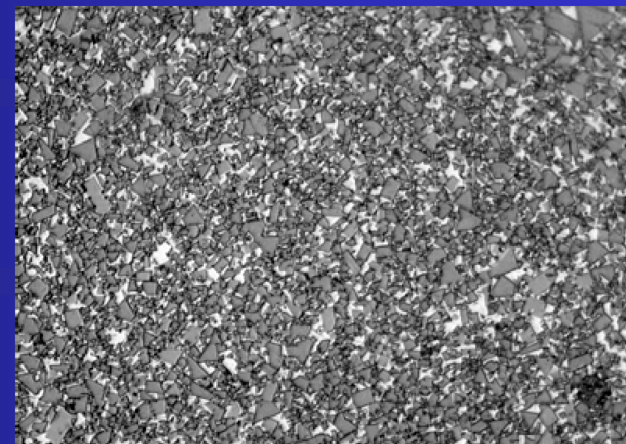
Constant binder content - varying grain size

4 µm

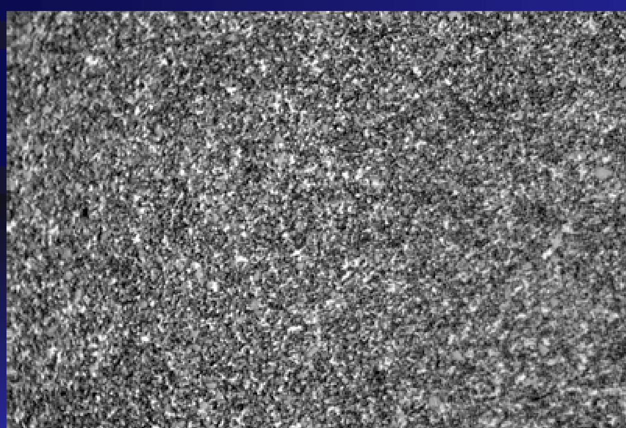


2 µm

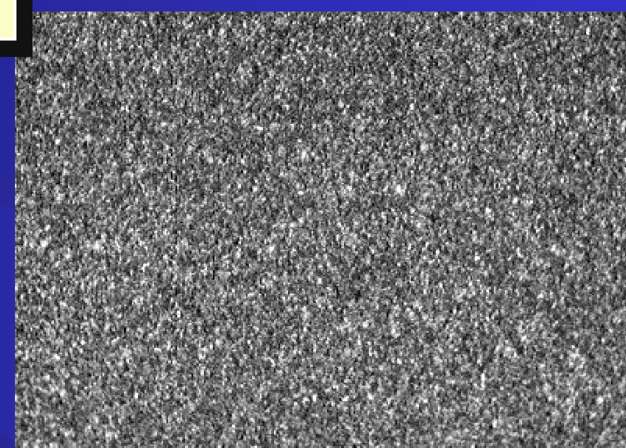


1500x

0.8 µm



0.5 µm



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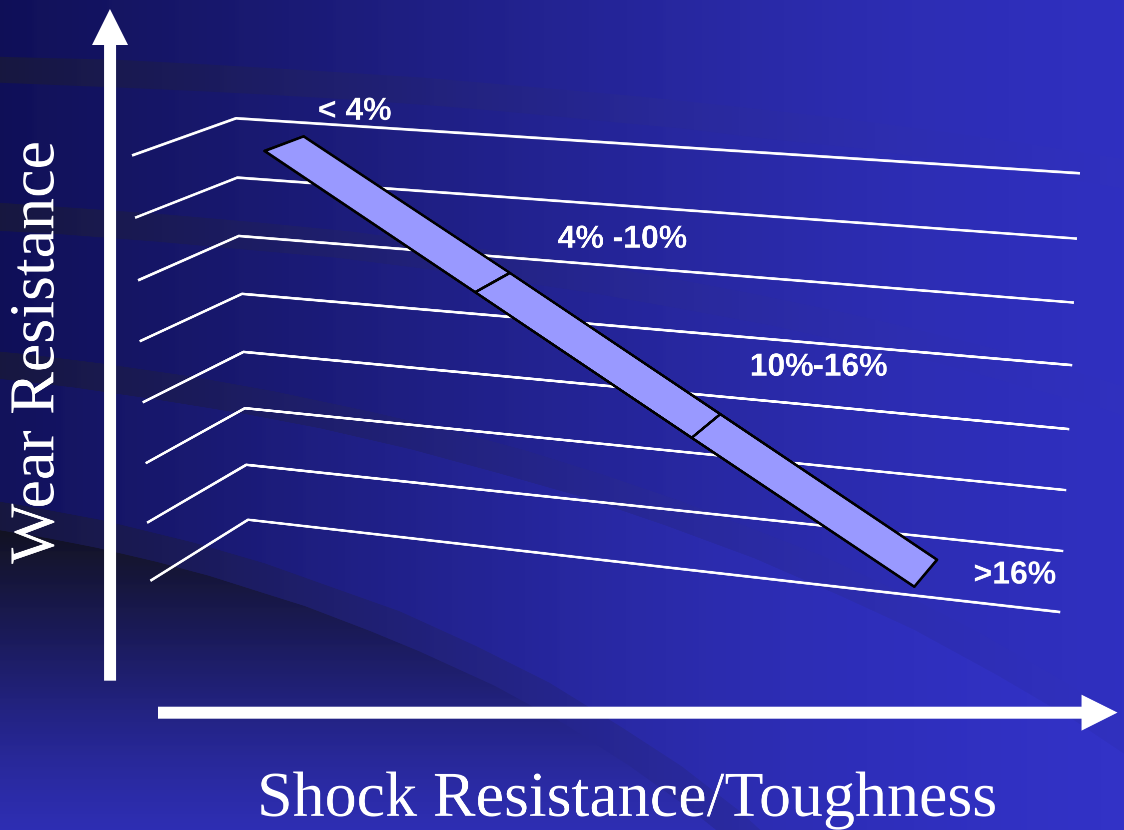
Effect of Binder Content



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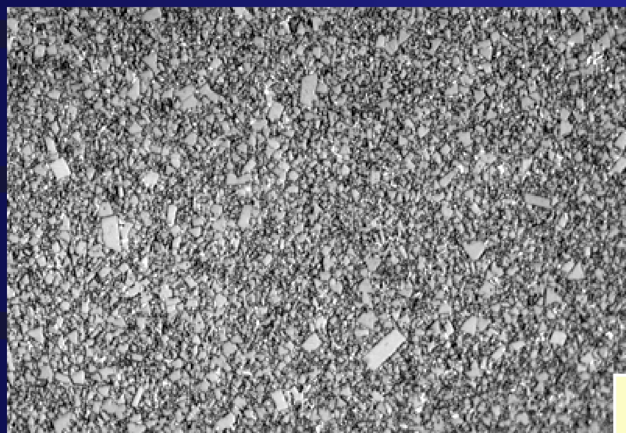
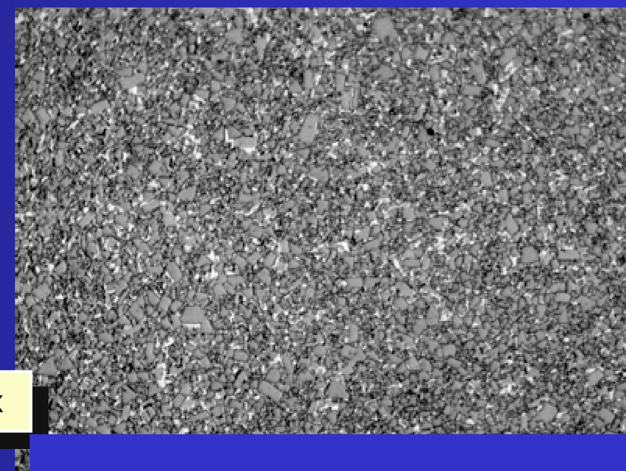
Constant grain size/varying binder content

6%

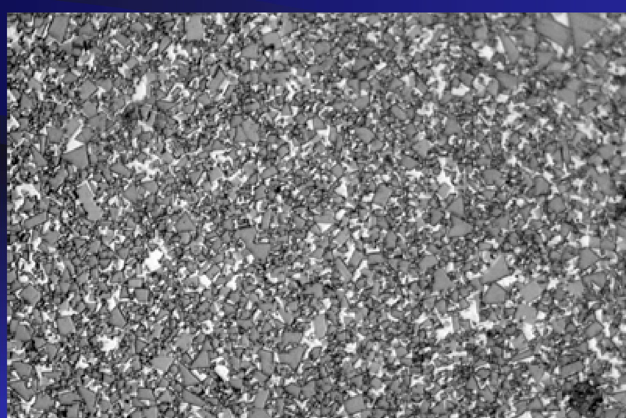


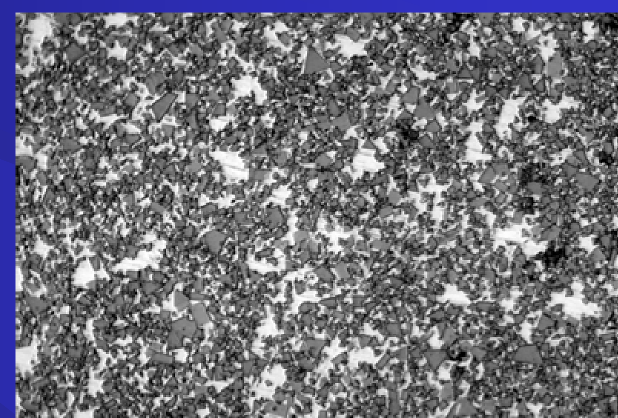


10%

1500x

16%





24%

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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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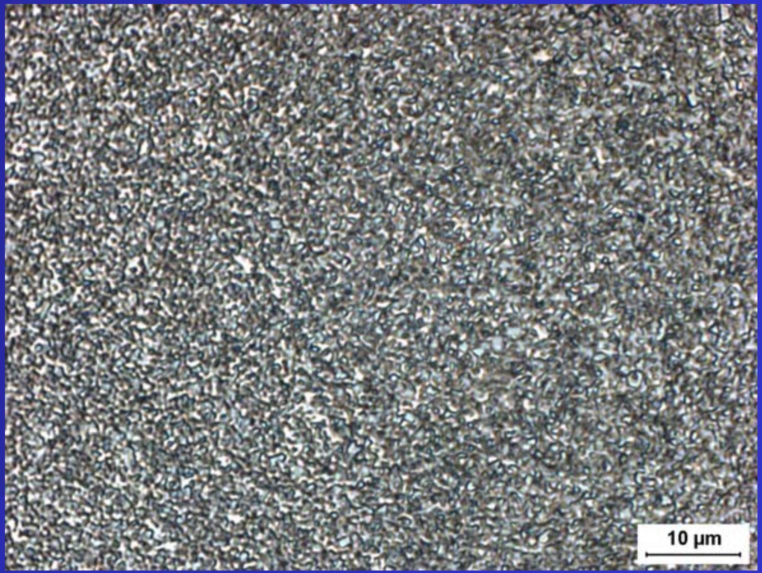
Fine grain formulations:

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



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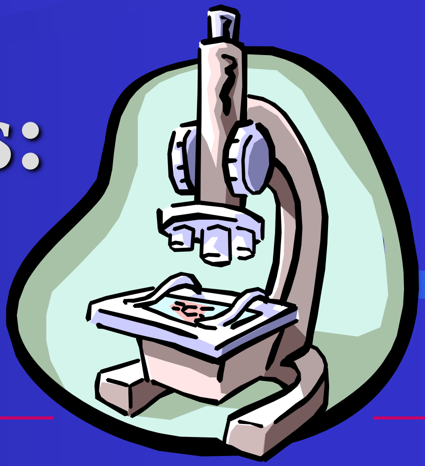
Cemented carbide formulations:



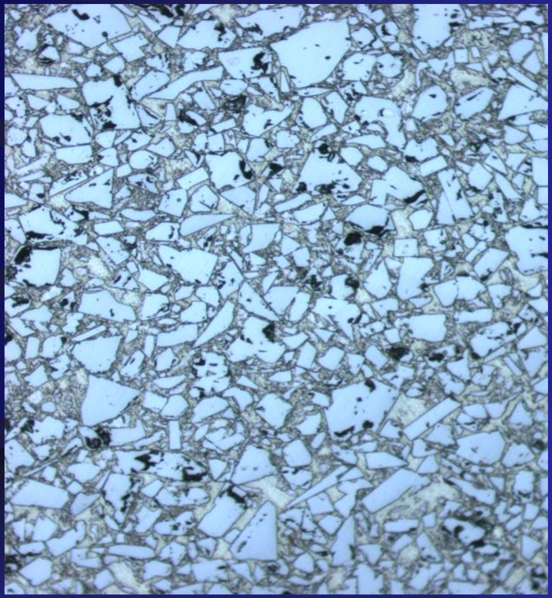
Wide variety of available grades:

- WC range: 0.6 to 11+ micron
- TaC additive
- Grades with Ni binder
- Cobalt range: 3.5% to 30%

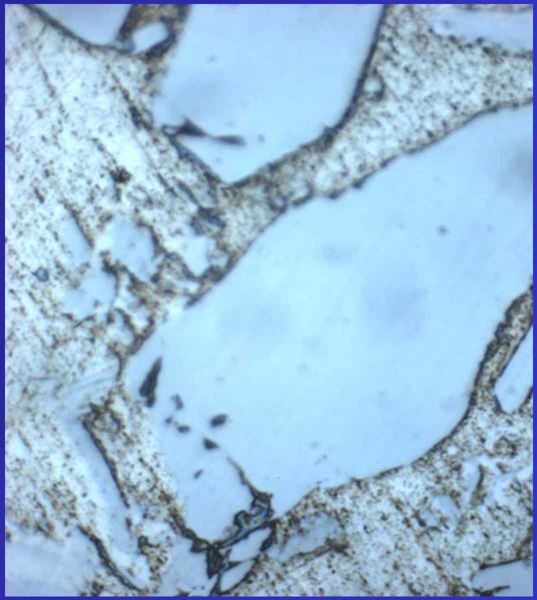
Advancements in New Material Development…..

A Cemented Carbide with high Thermal Shock Resistance ….

Microstructure



100X



1500X

GenTuff™ Products

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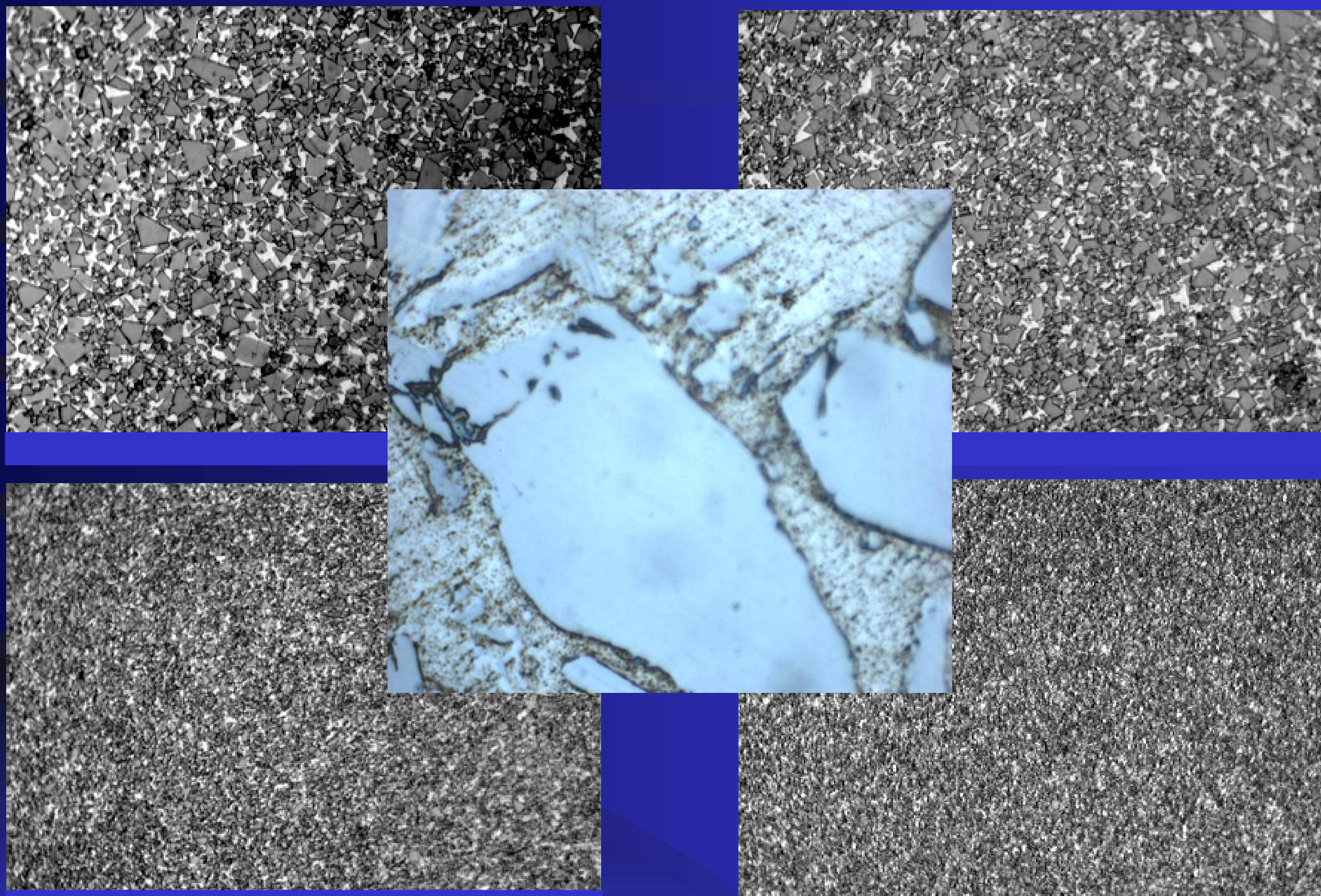
Grain Size Comparison - Cemented Carbide vs. GenTuff™



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Attributes of GenTuff™:

- High metal-to-metal wear resistance
- Resistant to thermal shock
- Can be easily machined
- Operates with or without coolant
- High impact strength….resists chipping
- No known equivalent material

Successful applications in the rod/wire industry:

- Rod mill persuader rolls
- Guide rolls
- Looper rolls
- Side loopers

GenTuff™ Products

Advancements in Thermal Consolidation of Cemented Carbides…

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Methods of Thermal Consolidation used in manufacturing Cemented Carbide:

- Vacuum Sintering (less often Atmospheric sintering)
- Hot Isostatic Pressing (HIP)
- Sinter-HIP Processing
- Hot Pressing (anisotropic) under vacuum

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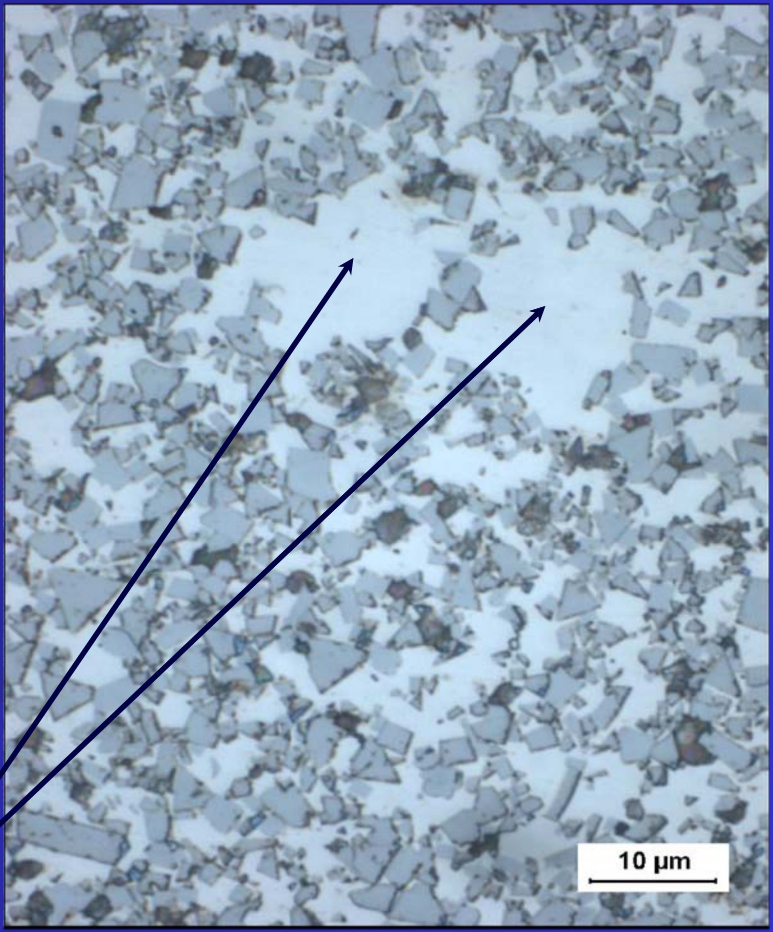
Sinter-HIP versus Post-HIP:

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 cobalt is squeezed into a macro-void that might occur within the material at the liquid stage of the sintering operation.



Cobalt lake defects

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.

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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:

Progress in Failure Analysis & Troubleshooting…..

Process defects versus Operational defects:

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

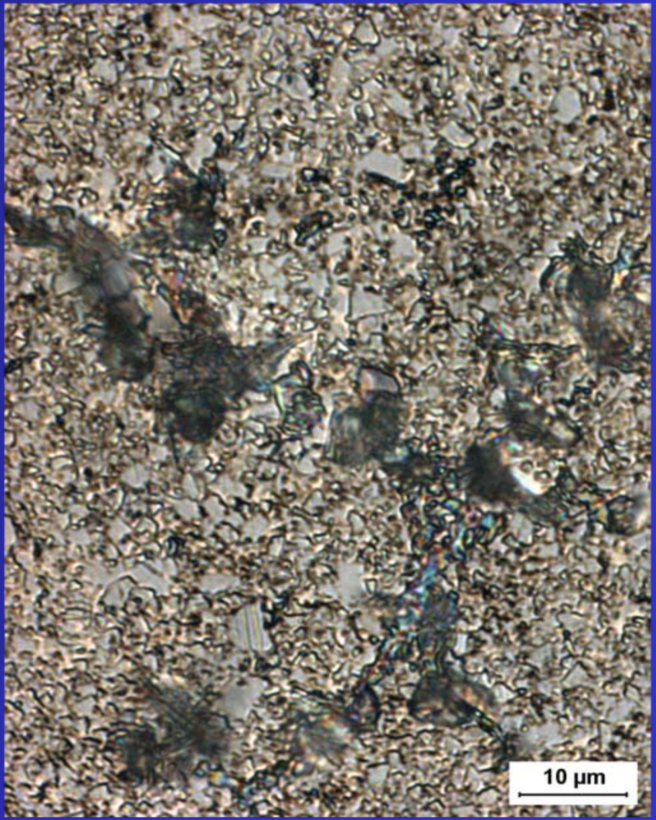
1. Processing defects (eta-phase occurrence, large grain cluster formations, powder shaping cracks)

2. Fabrication defects (braze cracks, thermal cracks)

3. Environmental failures from corrosion, erosion, etc.

4. Mechanical failures caused by brittle fracturing, wear, fatigue…..etc.

Carbide Processing Defects



Eta-Phase in Cemented Carbide Materials

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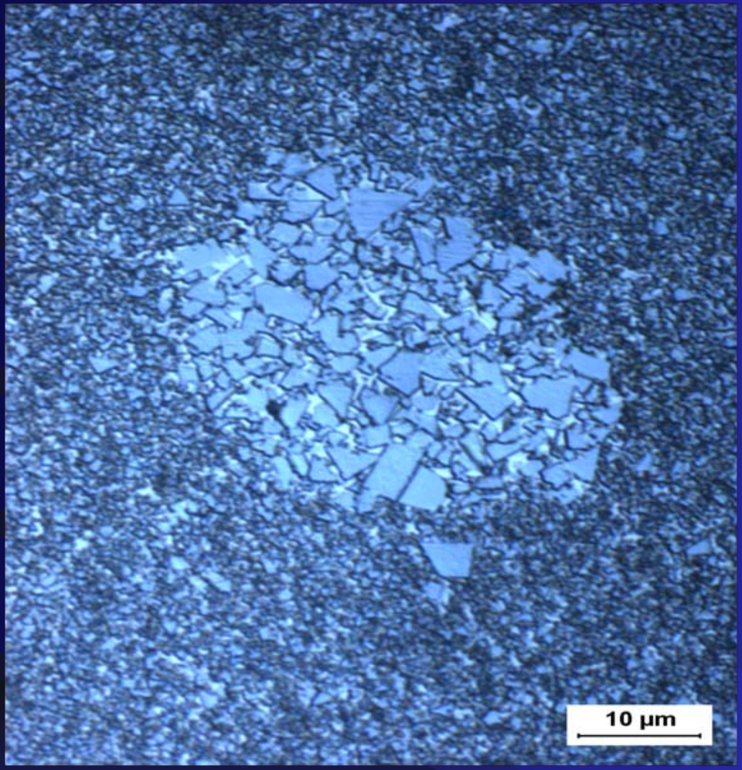
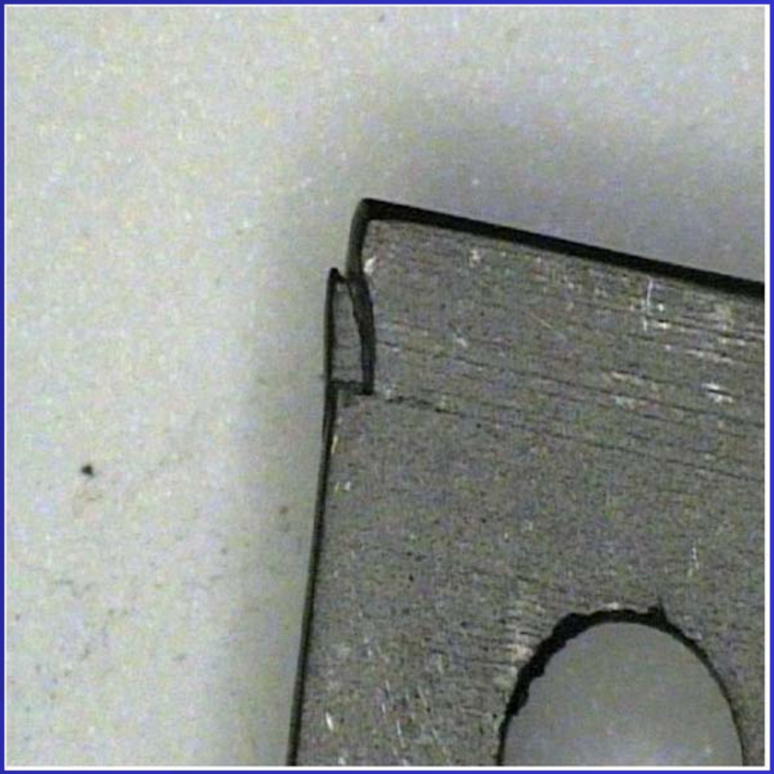
Carbide Processing Defects



Large Carbide grains cluster formation



Chipping crack resulting from green carbide shaping operation

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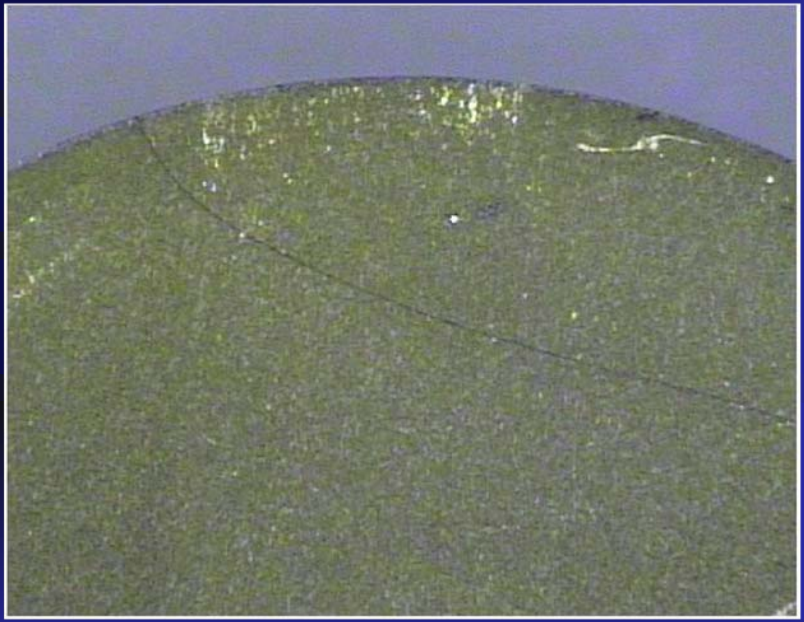
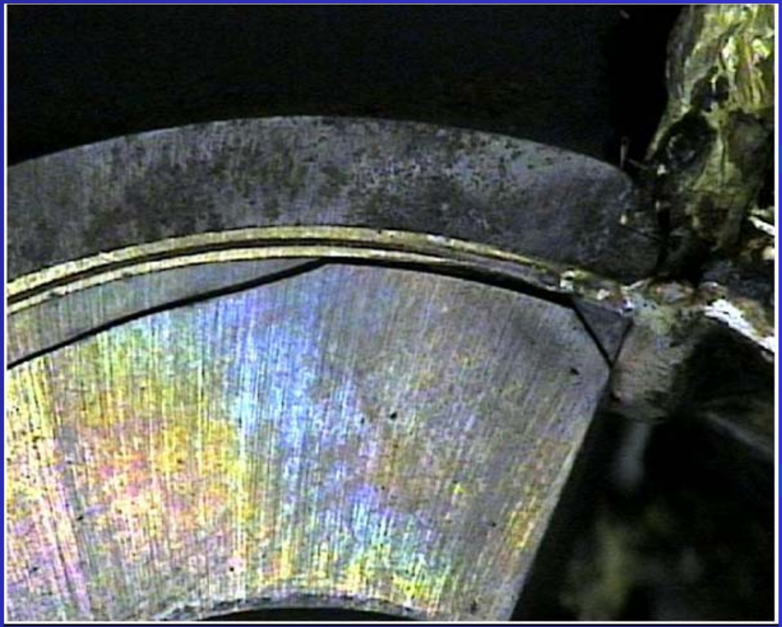
Fabrication Defects

EDM Crack

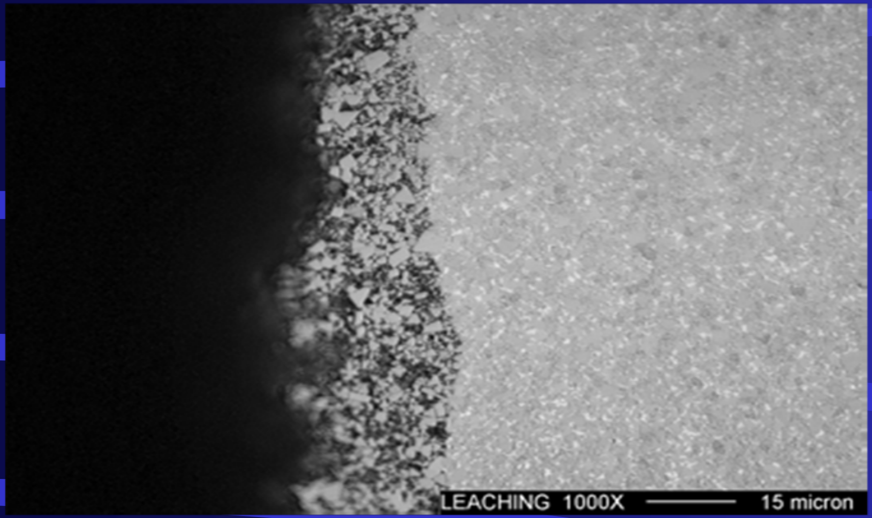


Brazing Crack

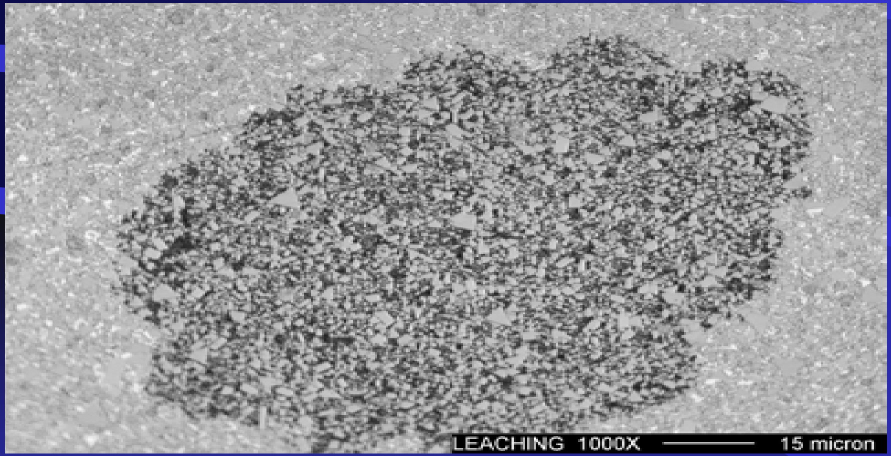


Environmental Failures

a)

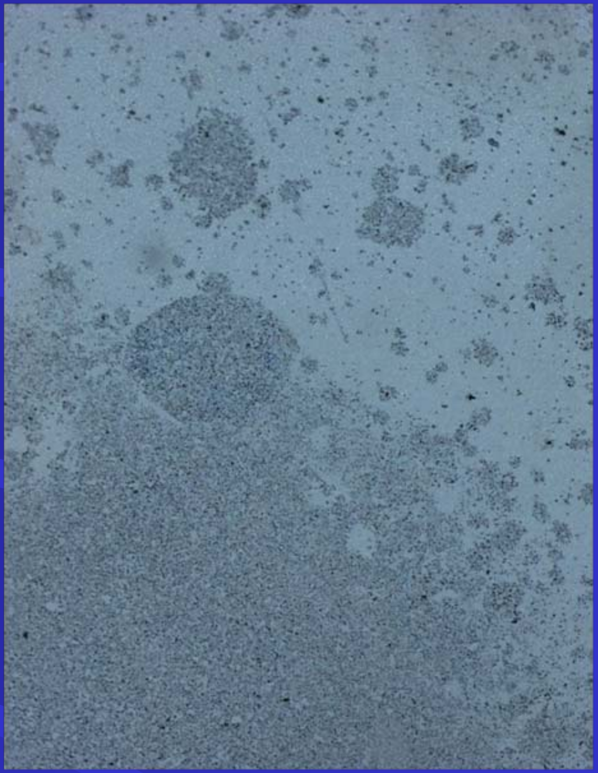


b)



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

Electrolytic Attack*



*Test conducted in wire EDM tank for 100 hours.

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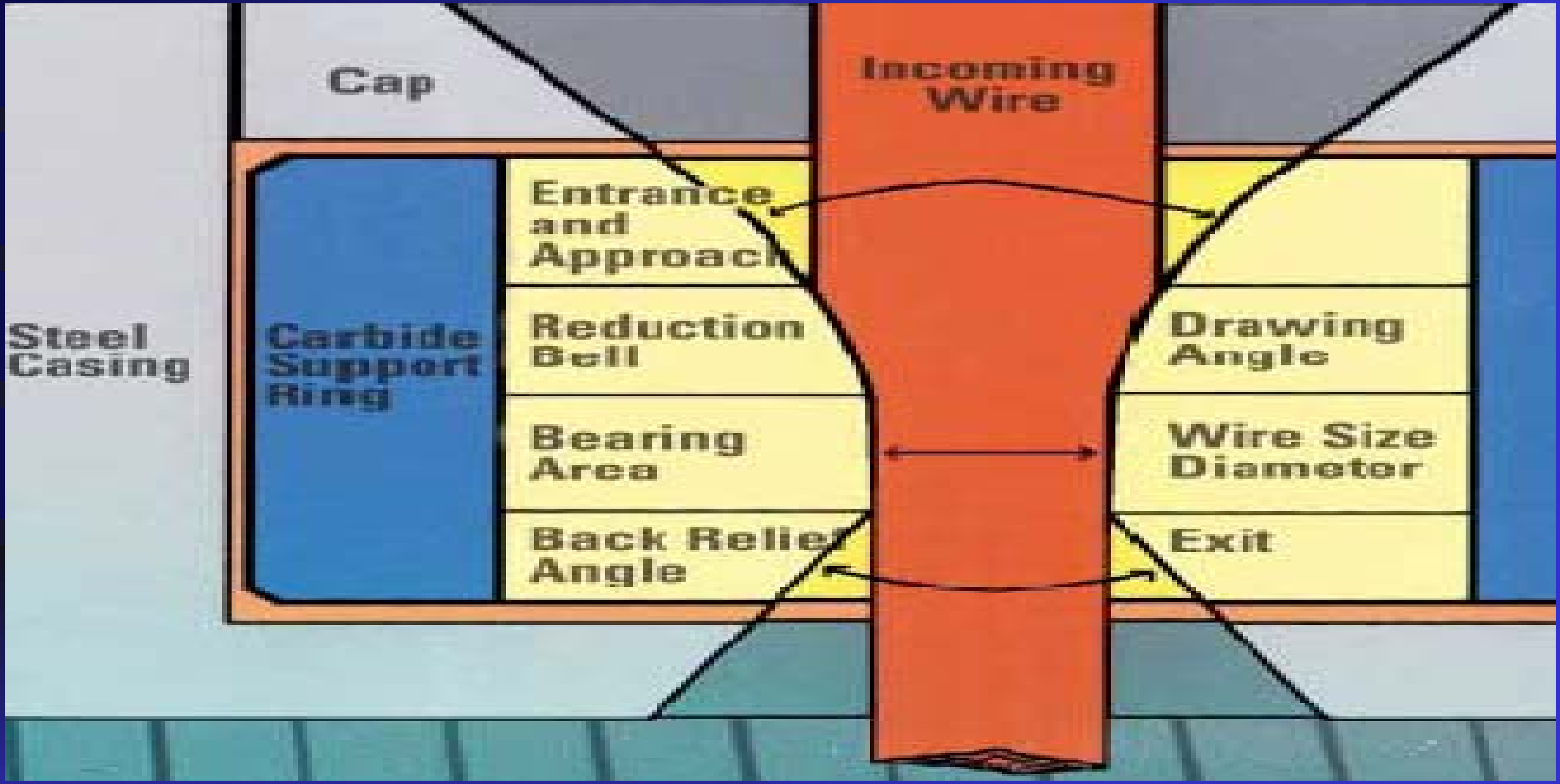
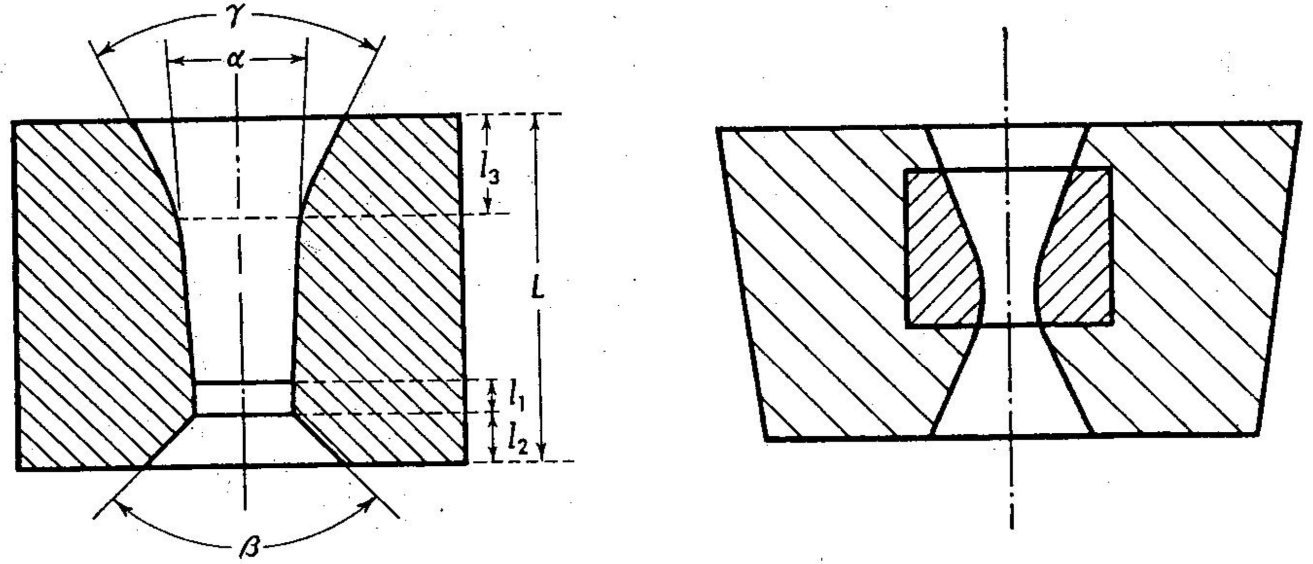
Failure Patterns Associated with Operational defects in Wire Drawing Applications….

Wire Drawing Process:



Typical Wire Draw Die Design



L: total length; l_1: bearing; l_2: back relief; l_3: bell;
α: approach angle, β: relief angle; γ: bell angle

Sections of Drawing Die Nib (left) and Cased Die (right).

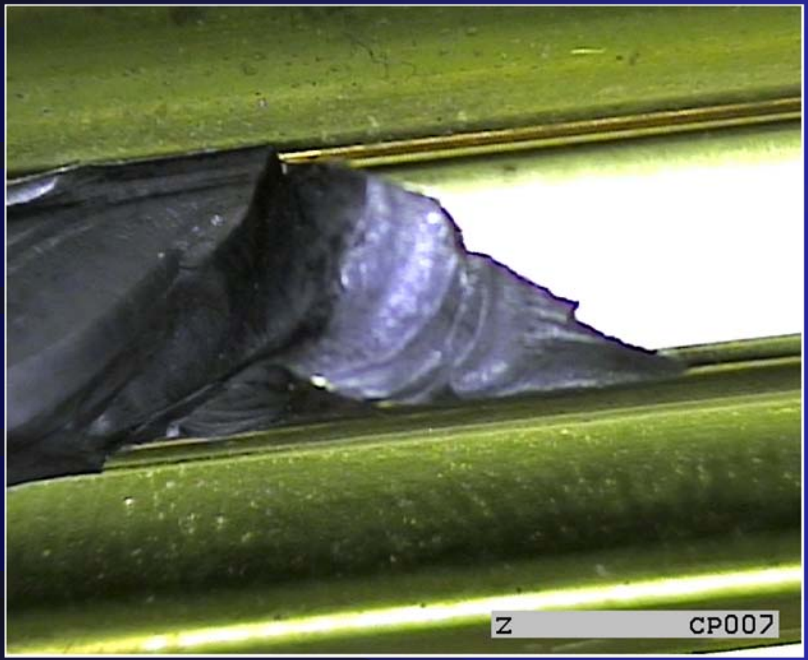
Typical Failure Modes & Defects Occurring in Wire Dies

- Brittle Cracks and/or Fractures
- Pitting & Environmental Corrosion
- Ring Wear and Roughing of the ID surfaces during drawing
- Thermal and Mechanical Stresses
- Abrasive Wear Patterns & Scuffing
- Spalling and Web Cracking

Cracks and Fracturing

- Cracks or fractures are almost always formed by a release of stresses within the part.
- Stresses are inherent within any material structure.
- Tensile and as well as bending and cyclic stresses facilitate crack origination and propagation.
- Compressive stress makes a carbide microstructure more resistant to crack propagation.

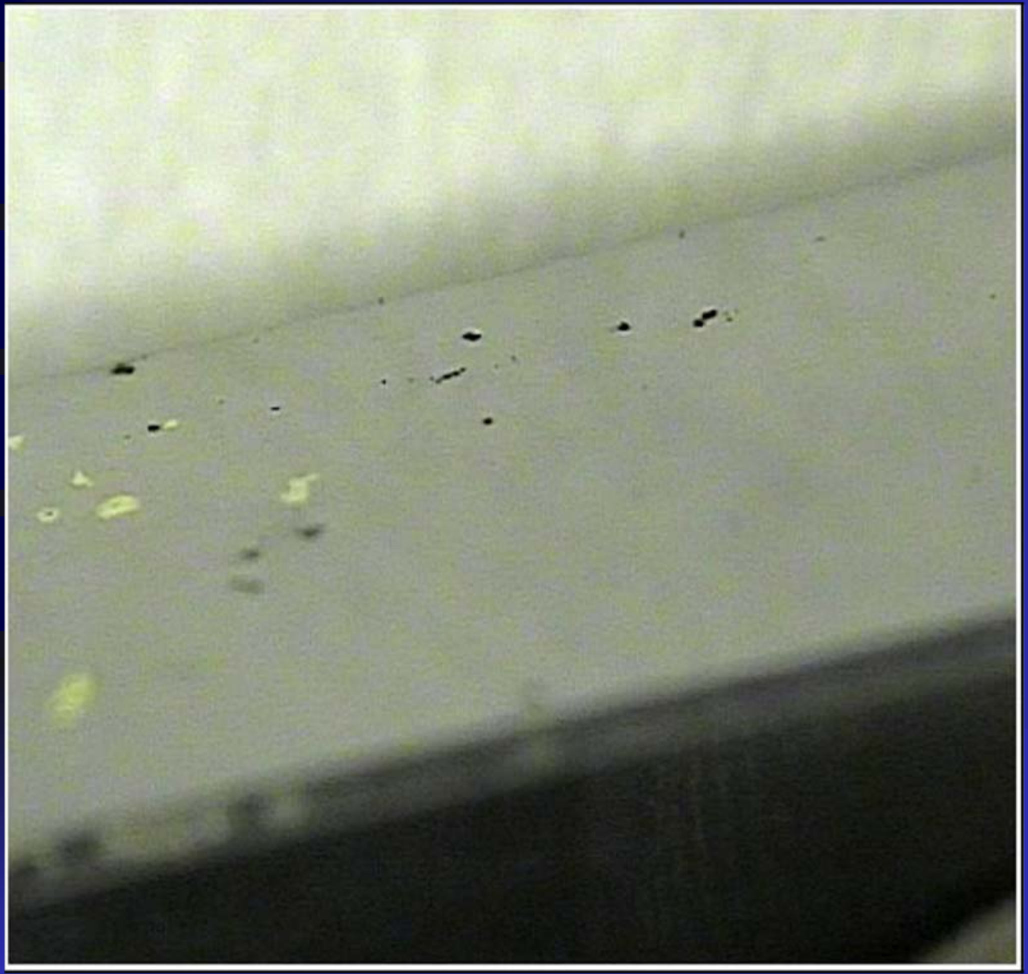
Carbide Failure Patterns



Brittle Fracture Defect

Cyclic Fatigue Failure

Pitting



Pitting is one of several structural pore-like defects within the cemented carbide body. These can be caused either by the pullout of large grain clusters or by cobalt pools or by the loss of metal binder.

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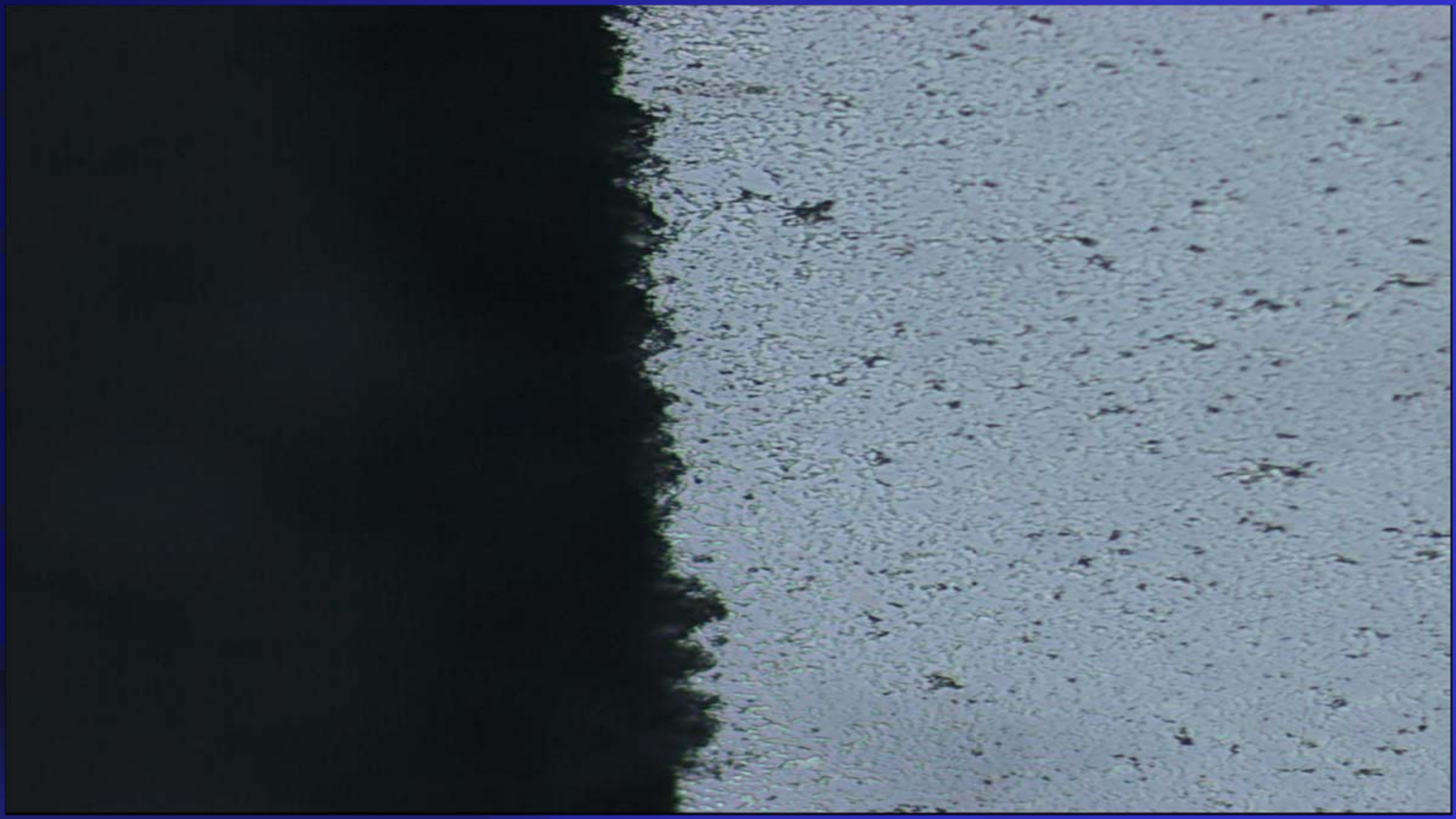
Environmental Corrosion Defects:



Corrosive attack on metal-based binder within Cemented Carbide material structure.

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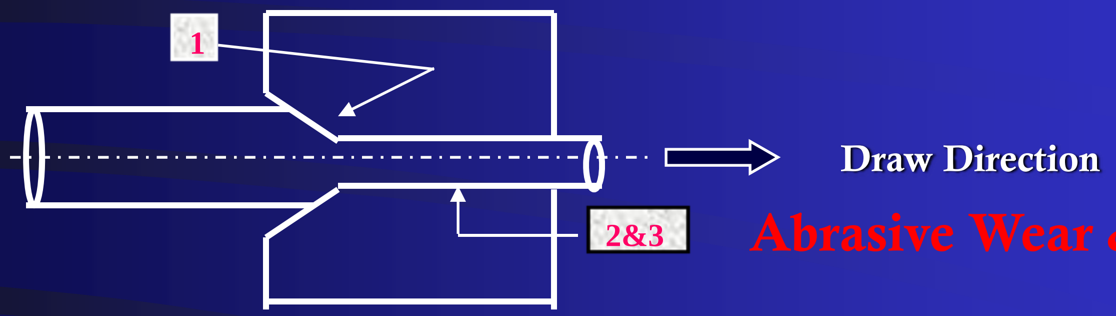
Causes of Mechanical Stresses

- Mechanical stress caused by poor pre-forming and machining practices.
- Die misaligned when mounted into the steel case.
- Insufficient wall thickness of carbide die nib due to oversized entrance or die bore.
- Insufficient compressive strength imparted to the die nib.
- Insufficient thermal stress relief in large dies.

Wear process of a Wire Draw Die

Ring Wear & Roughing of the Wire Die ID Surfaces



Abrasive Wear & Scuffing/Galling

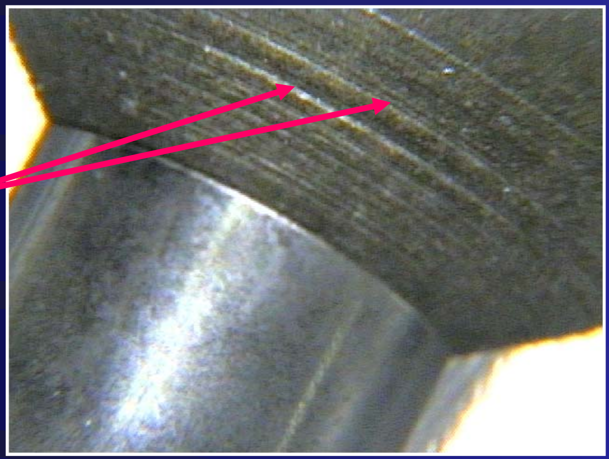
1 - Ring wear: surface cracking from mechanical, corrosive or thermal origin.

2 - Abrasive wear: carbide grain loss due to binder removal/abrasion under pressure and interaction with hard particles (e.g. iron oxides) during wire sliding.

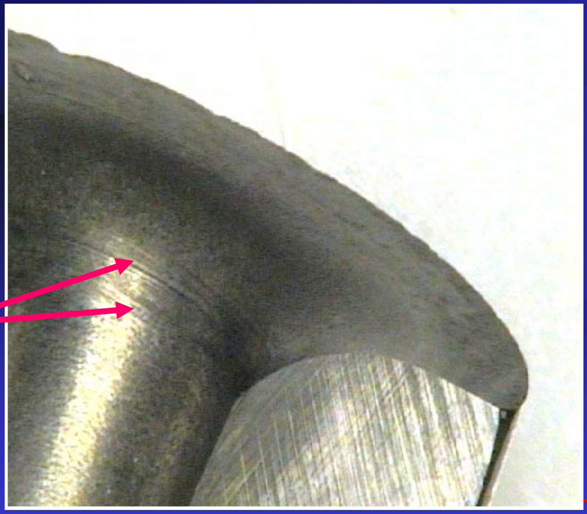
3 - Scuffing: caused by excessive frictional heat that results in surface damage including binder degradation and scoring

Ring Wear Failure & Roughing of the ID Surfaces During Drawing Operation

Wear Rings



Roughing of ID Surface



Ring Wear Pattern:

- Usually is exposed as one or more circular grooves or fractures in the bearing area or on the top of the reduction area of the nib.
- Cracks can develop if not caught in time.

Causes:

- Excessive use of die beyond the recommended re-cut time.
- Interrupted lubrication flow during drawing causing material to depart the carbide die surface.

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Wear Failure Patterns

Abrasive Wear

Galling /Scuffing Wear

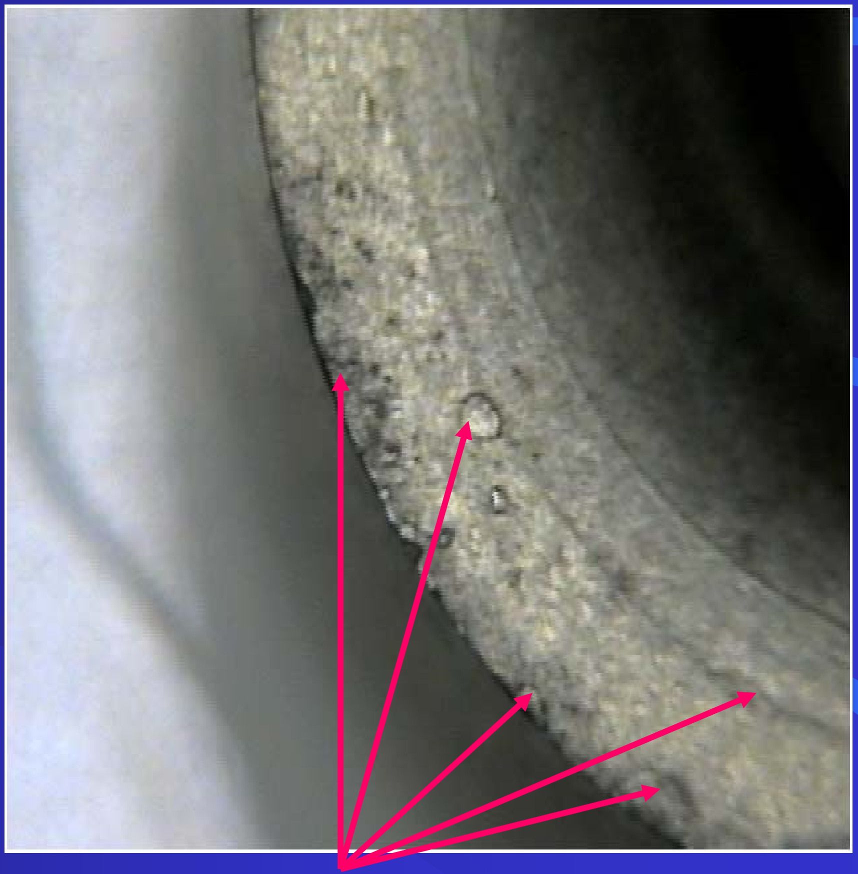
Multiple Crack Pattern

Multiple Crack Pattern is defined as an appearance of numerous cracks traveling in different and non-uniform directions.

Multiple Crack Pattern & Spalling.

Possible Causes:

- Wear rings generated during wire drawing process.
- Misaligned die during mounting process induces stress.
- Excessive thermal damage either from brazing or sintering as well as from wire drawing or re-cutting.
- Incorrect die design, e.g. die wall is too thin for existing working conditions
- Stresses caused by improper wire feed impacting the die nib



Multiple Cracks

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Spalling

- Spalling is a separation of the chunks of material (agglomerates of surface particles) as a result of sub-surface fatigue in more extensive form than pitting.
- Spalling manifests itself as a spontaneous chipping, or partial fragmentation of the part’s surface.

…ANY QUESTIONS ?

OR COMMENTS

PLEASE…