Kennametal overview
  – Materials portfolio
  – Processing capabilities

Basics of sintered carbide processing & properties

Thick coatings
  – Conformaclad
  – HIP-Clad

Case studies
Kennametal Overview

Kennametal delivers productivity to customers seeking peak performance in demanding environments by providing innovative custom and standard wear-resistant solutions, enabled through our advanced materials sciences, application knowledge, and commitment to a sustainable environment.

- Founded in 1938
- Nearly 12,000 employees worldwide
- Annual sales are approximately $2.4B
- Headquartered in Latrobe, PA
- Operations in over 60 countries
Materials Portfolio

Metal matrix composite
- Cemented carbide
- Cermets

Alloys
- Tungsten heavy alloys
- High temperature alloys (Co based)
- Infiltration alloys (Matrix bits)

Ceramics
- Silicon Nitride, Sialon
- h-BN
- TiB₂
- Alumina, Zirconia composites

Powder
- Thermal spray (WC-Co based)
- Shear cutter matrix
Processing Portfolio

Powder metallurgy

Hot pressing & HIP

Rapid omni-directional compaction (ROC)

Casting of alloys

Surface cladding
  - Conformaclad
  - HIP Clad

PVD/CVD coating
Carbide 101
Why Cemented Carbide?

• A continuous range of wear resistance + toughness can be obtained by simply changing % binder and WC grain size

• The wear resistance + toughness combination is better than what can be obtained from alloys and ceramics
Production of Cemented Carbide

- Tungsten Carbide
- Cobalt
- Alloy carbides

Mix and Mill

Grade Powder

Press

Pre-sinter & Preform

Sinter

Grind & Finish
Powder Preparation

Agglomerated WC

Milling
  - Deagglomeration
  - Particle size reduction
  - Mixing

Spray Drying
  - Drying
  - Flowable powder

Cobalt @ 4000X

Spray Dried Granules
Green Forming / Pressing

Uniaxial Pressing

Iso-static Pressing
Densification

- Patented technology
- Combined high pressure (110,000 psi) and high temperature
- Complete densification can be achieved without liquid phase formation
- Can make binderless carbide (100%WC)

Sinter-HIP Cycle

Shrinkage

- Powder height in die for spray dried process small particles requires more volume
- Powder height in die for conventional pelletizing requires less volume
- Pressed compact is 50-60% of powder height in die
- Sintered compact is approximately 50-60% of volume of pressed compact

ROC
Microstructure

Fine grain--higher hardness, higher wear, for industrial round tools, PCD anvils, circuit board drills

Medium grain-- wear parts, cutting tools, compacts

Coarse grain--lower hardness, for cutting compacts, in drilling, coal mining and construction tips
Properties

Rockwell ‘A’ Hardness of WC/Co compositions

Cobalt content, weight percent

HRA

Trendline for Transverse Rupture Strength of WC/Co Mixtures

TRS (MPa)

Cobalt content, weight percent

Trendline for WC/Co Compositions Fracture Toughness $K_{1c}$

Fracture Toughness

Flexural Strength

Hardness
Wear Resistance & Toughness
**ASTM B611** - Abrasive Wear

High stress wear tester

Uses steel wheel and large alumina particles (30 mesh, ≈600mm)

1000 revolutions

**ASTM G65** Abrasion Test

Low stress wear tester

Uses rubber lined wheel with softer, smaller quartz SiO$_2$ abrasive (50/70 mesh, ≈200-300mm)

6000 revolutions

**ASTM G76** Erosion Test

Dry or wet

Particle type size and flow rate can be adjusted
Increasing wear resistance

- Increasing hardness
- Increasing HC
- Decreasing grain size
- Decreasing cobalt

Coarse WC or higher % Co or both

Fine WC or smaller % Co or both

Increasing fracture toughness

Wear vs Toughness Compromise
Influence of Wear Environment

- All materials are ceramic + metal/alloy composite
- Different hard phase, binder phase and particle size in each

Relative wear resistance changes depending on wear environment

Vol. Loss (mm³)

Material 1 | Material 2 | Material 3 | Material 4 | Material 5 | Material 6

| ASTM G65 |

| ASTM B611 |

Vol. Loss (mm³)

Material 1 | Material 2 | Material 3 | Material 4 | Material 5 | Material 6
From repeated heating and cooling of carbide. Normally, surface areas will cool (or heat) more rapidly than bulk regions.

Frequent failure mode in roller cone bits: heat checking, snake skinning-perpendicular network of cracks.

Thermal Stress $\sigma_{th} = E \alpha \Delta T$

Hasselman thermal fatigue parameter

$$R \propto \frac{kK_{le}}{\alpha E}$$
Heat Checking Parameters

**Elastic Modulus**

Trendline for Modulus of Elasticity $E$ of WC/Co Mixtures

**Thermal Conductivity**

Trendline for Thermal Conductivity of WC/Co Mixtures

**Thermal Expansion**

Thermal Coefficient of Expansion (RT to 800°C)
Corrosion of Carbide

- Binder material (Co) is the reactive constituent

- WC is comparatively inert

- To improve corrosion resistance
  - Reduce cobalt content
  - Change binder from cobalt to nickel, or alloy with Cr

In artificial sea water

<table>
<thead>
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<th>Sample ID</th>
<th>Corrosion Rate (mils per year)</th>
<th>Total Volume Loss (cc)</th>
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<tr>
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<tr>
<td>KR855-1</td>
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<tr>
<td>CNC68-1</td>
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<th>Grade ID</th>
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<tr>
<td>CNC68-1</td>
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<tr>
<td>CNC68-2</td>
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Flow Control with Sintered Carbide

- Shapes with complex internal channels
- Materials combining high corrosion, wear resistance with toughness
- Lightweight cermets with high corrosion resistance
## Unique Carbide Based Materials

<table>
<thead>
<tr>
<th>Name</th>
<th>Hardness</th>
<th>Density</th>
<th>Chemistry</th>
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<tbody>
<tr>
<td>RT500</td>
<td>2750 HV</td>
<td>15.5</td>
<td>100% WC</td>
</tr>
<tr>
<td>RT100</td>
<td>2500 HV</td>
<td>14.95</td>
<td>WC + Mo&lt;sub&gt;2&lt;/sub&gt;C</td>
</tr>
<tr>
<td>CNC68</td>
<td>1830 HV</td>
<td>14.00</td>
<td>WC-TaC-TiC-Co-Ni-Cr-Mo</td>
</tr>
<tr>
<td>LW15</td>
<td>1375 HV</td>
<td>9.00</td>
<td>WC-TaC-TiC-Co-Ni</td>
</tr>
</tbody>
</table>
THICK COATINGS
Cladding Properties

- 70,000+ psi (483 MPa) Metallurgical Bond
- High Tungsten Carbide Loading (70%+ wt.)
- Hardness > 70 HRC (converted micro hardness)
- Uniform Carbide Distribution & Structure
- High Inter-Particle Bond Strength
- Controlled Cladding Thickness
- Minimal Dilution
- No Interconnected Porosity
### Conformalclad vs Other Coatings

<table>
<thead>
<tr>
<th>Coating Type</th>
<th>Coating thickness, &quot;&quot;</th>
<th>Typical coating thickness, &quot;&quot;</th>
<th>Surface hardness (Indentation from the top of coating)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boron diffusion layer</td>
<td>0.003-0.004</td>
<td>&lt;0.005</td>
<td>HRC: NA (affected by substrate since the coating is thin), (HRA: 35.3)</td>
</tr>
<tr>
<td>HVOF WC-12Co coating</td>
<td>0.004-0.0045</td>
<td>&lt;0.02</td>
<td>HRC: 24.1 (affected by substrate since the coating is thin), (HRA: 64.0)</td>
</tr>
<tr>
<td>Brazed WC cladding</td>
<td>0.05</td>
<td>0.01-0.12</td>
<td>HRC: 61.8 (HRA 83.2)</td>
</tr>
</tbody>
</table>

- Brazed WC cladding provides the abrasion layer over 10 times thicker than HVOF coating, and 30-50 times thicker than boron diffusion
- The bonding in brazed WC cladding and between WC cladding and the underneath substrate is metallurgical
Conformaclad vs Other Coatings

- Boronized Surface
- Porosity
- HVOF WC-12Co coating
- Steel substrate
- Brazed WC cladding
- WC
ASTM G76 Dry Sand Erosion Test

- 90° testing angle: erosion resistance of CCI brazed WC cladding is over 2 times better than HVOF coating and over 6 times better than boron diffusion
- 30° testing angle: erosion resistance of CCI brazed WC cladding is over 5 times better than HVOF WC-Co coating or boron diffusion

Test condition: -60 micron angular Al₂O₃ sand; Feeding rate: 2 g/min; Air velocity: 70 m/sec
**Comparative Erosion Data**

**ASTM G65**

Higher number better

![Bar chart](chart1.png)

**ASTM G76**

![Bar chart](chart2.png)
Corrosion Resistance

ASTM G31 1% Sulfuric Acid @ 100C

Corrosion Rate

Conforma Clad WC210
316 SS
17-4 PH

0
10000
20000
Corrosion Rate
Conformaclad Ultraflex

Cloth Limitations

- Area to be Clad must be reachable by hand
- Complex Parts require multiple seams

Ultraflex Solution

- New Delivery Method
- Similar Cladding Composition
- Ultraflex is thinner: 0.005” - 0.030” vs 0.020” - 0.065” Cloth
- Ultraflex has no seams
- Same Vacuum Brazing Operation
- Able to Provide Wear Protection in Previously Inaccessible Areas
  - Small ID’s
  - Long ID’s
  - Complex Shapes
  - Screens
Microstructure Comparison

Increasing Abrasion Resistance

- WC219 (48 %)
- WC210 (55 %)
- WC200 (62 %)
- WC200U (45 %)
- WC100U (52 %)

Cloth

Ultraflex
HIP – Clad

[Image of HIP (Hot Isostatic Pressing) - Clad components and materials, including a close-up image of a cross-section with a scale of 200 µm.]
**HIP-Cladding Process**

Pressurization and temperature increase are shown in the graph. The process involves the following steps:

1. Prepare capsule
2. Pour powder
3. Seal
4. HIP
5. Dense Component

Graph showing pressure and temperature over time.
HIP-Clad Types

Bi-Metallic

St 37

Inconel 625

Powder Metallurgy

forged duplex steel

HIP duplex steel
Specially for the valve and off shore industry

Different steel grades

Duplex: 1.4462, ASTM-UNS S 31803 / S 39209

Super Duplex: 1.4501, ASTM-UNS S 32760

Low carbon steel to customer instructions

Nickel based alloys as layer or solid part

Benefits

- Total diffusion bonding without defects
- High grade material keeps its purity because there is no mixing zone with the low grade material
- Better mechanical properties of the HIP products
- **Bimetallic valve bodies by HIP are promising alternatives to weld on valve bodies**

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### Technical Data of HIP Units

<table>
<thead>
<tr>
<th>Units</th>
<th>Diameter (mm)</th>
<th>Length (mm)</th>
<th>Maximum Temp. (°C)</th>
<th>Maximum Pressure (bar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HIP 1</td>
<td>200</td>
<td>500</td>
<td>2000</td>
<td>1000</td>
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<tr>
<td></td>
<td>247</td>
<td>700</td>
<td>1450</td>
<td>1000</td>
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<tr>
<td>HIP 2</td>
<td>450</td>
<td>1300</td>
<td>2000</td>
<td>1300</td>
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<td>HIP 4</td>
<td>600</td>
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<tr>
<td>HIP 3</td>
<td>900</td>
<td>2700</td>
<td>1400</td>
<td>1400</td>
</tr>
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</table>

### Kennametal HTM Qualifications

- ISO 9001:2008
- Norsok M650 for MDS D44 (up to 206mm wall-thickness)
- Norsok M650 for MDS N01 (up to 186mm wall-thickness)
- Redensification qualified from Safran Group, Rolls Royce, and PCC
- FDA-approved
Examples & Case Study
Oil Sands – Application of Cloth Cladding

Equivalent Erosion Resistance

(Approximately to scale)

50X Better Wear at 1/80th Weight

15X Better Wear at 1/10th Weight

1/16"

1.0"

Conformaclad

Chrome Carbide Weld Overlay

Carbon Steel

3"+
**Product:** Pumps in Oil Sands, currently made of CWI

**Problem:** Wear of the impeller face

**Solution:** Carbide tiles bonded to the face. 10X predicted life increase
Petrochemical Refining

- P-8 case wear ring after 10 months
  - May 2005

- P-8 case gouge after 8 months
  - Oct 2008

- 1 unit shutdown, lost both pumps
Petrochemical Refining

Damage to Previous Pump

- Boron Diffusion worn through (wear plate close up)
- 25 Chrome iron impeller tip wear
Applying Conformaclad cloth coating –

• Projected life extended to 3-4 years, from ~12 month max run with WC HVOF.

• Separate Houston area Olefins plant applied IBTCC inside a tar pump. Internal inspection showed no wear after 5 months. The pump required repair every 4-6 months with previous coatings.