Material Research
Tungsten Carbide

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Armor Piercing
SMALL ARMS AMMUNITION
Topics

- Nammo Armor Piercing - Background
- Next generation Armor Piercing
- Material Research
  - Kennametal
- Armor Piercing Designing
- Summary
M993 & M995 Armor Piercing

- World leading military specified Armor Piercing in caliber 5.56 and 7.62 mm
- Designed by Nammo Vanäsverken 20 years ago
- Kennametal has been sole supplier of the Tungsten Carbide core

- 150 million Armor Piercing cartridges produced
- Qualified as M993 respectively M995 by US Army 1996
Next Generation Armor Piercing

- Improved penetration
  - Different impact angels
  - Armor Steel
  - Ultra hard targets (Ceramics)
- Improved ballistic match to ball reference
- Tungsten Carbide core without Cobalt
  - Nammo Green Ammunition Concept

Adapting projectile and projectile core geometry

Tungsten Carbide material research
Who is Kennametal?

World Headquarters
Latrobe, PA

About Us
Kennametal Delivers Productivity To Customers Seeking Peak Performance In Demanding Environments By Providing Innovative Custom And Standard Wear-resistant Solutions

Our Products
• Energy Exploration Cutting Systems
• Road Rehabilitation, Mining Drums and Cutting Systems
• Machine Tooling: Turning, Milling, Holesmaking, Systems
• Specialty and Defense products

Our Customers
• Aero-Structure, Aero-Engine Manufacturing
• Surface and Underground Mining
• Transportation Manufacturers
• Oil and Gas Drilling
• Manufacturing Machining Centers

Our Differentiators
• Proprietary Powder Metal Material Formulas
• Specific Customer Application Expertise, Engineered Solutions
• Patented Pressing, Sintering and HIPing Methods
• Specific Tungsten Processing Methods

Our Processes
Using Advanced Materials Expertise Including Tungsten Carbide, Ceramics, And Super-hard Materials, And Superior Product Development Methods To Deliver High Performance Wear Solutions

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Defense Products

Small Caliber Cores
- Tungsten Carbide
- Tungsten Heavy Alloy

Medium & Large Caliber Penetrators
- Tungsten Heavy Alloy

Trend
- Increasing demands for Co-free Tungsten Carbide and Tungsten Heavy Alloys in the defense industry

Challenge
- Replacement of Co by alternative binder metals maintaining the performance of the established Co-containing alloys
Manufacturing Process Tungsten Carbide Core

From Raw materials...

Wet milling

Spray drying

Pressing

Sintering

Grinding & Quality Control

... to Tungsten Carbide Core

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Nammo
Microstructure / Material Properties

Tungsten carbide (WC)

Different WC grain size affects the following properties:

- Hardness
- Fracture Toughness

Variation of WC grain size, amount of binder phase, type of binder metal determines the material properties of the tungsten carbide core
Binder phase

- Properties affected by the binder phase:
  - Hardness
  - Fracture Toughness
  - Corrosion Resistance

- Binder metals for hardmetal: Cobalt, Iron, Nickel and combinations

  ![Periodic table and element cards for Co, Fe, Ni]

  - Lattice structure: hexagonal
    Density: 8.9 g/cm³
    Melting point: 1493 °C

  - Lattice structure: body-centered cubic
    Density: 7.9 g/cm³
    Melting point: 1536 °C

  - Lattice structure: face-centered cubic
    Density: 8.9 g/cm³
    Melting point: 1455 °C
Cobalt free Binder

- Cobalt is the most popular binder metal in the hardmetal industry
- Co free means: Iron and/or Nickel
2-Phase Area and Properties for WC - 10% Co-free binder hardmetal

Width of Carbon Window:

<table>
<thead>
<tr>
<th>Material</th>
<th>Carbon Window</th>
</tr>
</thead>
<tbody>
<tr>
<td>WC - 10% Co</td>
<td>~ 0.20%</td>
</tr>
<tr>
<td>WC - 10% Co free binder</td>
<td>~ 0.30%</td>
</tr>
</tbody>
</table>

Properties 2-Phase Area:

<table>
<thead>
<tr>
<th>Property</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density [g/cm²]</td>
<td>14.42 - 14.48</td>
</tr>
<tr>
<td>Hardness HV30</td>
<td>1420 - 1450</td>
</tr>
<tr>
<td>Palmqvist [K₁c]</td>
<td>10.2 - 10.5</td>
</tr>
</tbody>
</table>

Wide carbon window insures consistent mechanical properties
Co-free Tungsten Carbide Cores 7.62 mm

Mechanical properties can be tailored for specific applications.
Live Firing Penetration Test

- 7.62 mm M993 vs. Cobalt free equivalent
- Cobalt free cores with same dimensions as M993 core
- Same projectile mass on tested cores/projectiles
- Same muzzle velocity
- Penetration test program with standard M993 as reference
- Recording of $v_{50}$ velocity (50% penetration / 50% stop)
Live fire penetration test

- Tested at threat targets found in battle space
- Armor Steel and ultra hard Armor Steel (HB300 – HB500)
- Light vehicle add-on Armor (Ceramics + Armor Steel)
- Impact angles between 0 and 45° NATO
Live fire penetration test

- 18 mm Armor Steel 300 HB
- Target distance 100 m
- Impact angle 0° Nato
Conclusion

Cobalt free Tungsten Carbide Cores gives;

- Same high penetration performance in all kind of targets and impact angles
- No compromising of the Nammo AP all round top performance including inclined targets
- Same ballistic performance
- Same cartridge requirements
Continued AP Development

- Enhanced penetration capabilities by adapting geometry

1. Geometry theoretically optimized by FEM simulations
2. Theory tested in reality
3. Cartridge adapted for ballistic match to ball reference
Summary

• Challenges in producing Cobalt Free Tungsten Carbide solved by Kennametal

• Cobalt free Armor Piercing gives the same high penetration performance

• Enables Nammo to expand the Green ammunition concept to the Armor Piercing small arms products

• Enhanced Armor Piercing, Cobalt free, in 5.56 and 7.62 mm available soon
Questions
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