Fracture behaviour of WC-Co hardmetals with WC partially substituted by titanium carbide

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China is currently the largest tungsten producer, accounting for about 84% of world production in 2012. It is followed by Russia, Canada, Austria, Bolivia, Portugal and a number of smaller producers. China has also the largest reserves according to the USGS accounting for 59% of world reserves.
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Properties of tool materials

End users of machine tools

Estimation of the main tool materials use on the global basis
So the main goal of the research work is:

-modification of WC-Co hardmetals towards the partial substitution of tungsten carbide (WC) by addition of TiC ceramics
EXPERIMENTAL PROCEDURE

**WC-9.5 wt% Co with addition of TiC**

- Commercial powder YK.15,6
  - Chongyi Zhangyuan Tungsten Co. Ltd
  - 3.42 μm grade

- TiC powder obtained by SHS
  - 4.46 μm grade

**Properties**

- **Density [g/cm³]**: 4.92 → 15.72
- **Hardness HV [GPa]**: 28-35 → 17-24
- **Young’s Modulus [GPa]**: 410-510 → 620-720
- **Melting temperature [°C]**: 3340 → 3050
TiC powders at 5, 10, 20 wt% were mixed into WC-Co powder

specimens 5.0x6.5x20 mm

sintering at the temperature 1573 K, pressure 1500 atm

HIP (Hot Isostatic Pressing) GONAR Firm
**EXPERIMENTAL PROCEDURES**

Table 1. Physical and mechanical properties of tested composites

<table>
<thead>
<tr>
<th>Samples</th>
<th>Sample symbol</th>
<th>Vickers hardness HV30 [GPa]</th>
<th>Young’s modulus E [GPa]</th>
<th>Apparent density ρ [g/cm³]</th>
<th>Poisson ratio ν</th>
</tr>
</thead>
<tbody>
<tr>
<td>WC-Co +5wt%TiC</td>
<td>H5</td>
<td>12.7±0.2</td>
<td>549±20</td>
<td>13.09±0.03</td>
<td>0.22±0.01</td>
</tr>
<tr>
<td>WC-Co +10wt%TiC</td>
<td>H10</td>
<td>13.1±0.2</td>
<td>519±20</td>
<td>11.81±0.02</td>
<td>0.23±0.01</td>
</tr>
<tr>
<td>WC-Co +20wt%TiC</td>
<td>H20</td>
<td>13.9±0.2</td>
<td>458±20</td>
<td>9.60±0.03</td>
<td>0.22±0.01</td>
</tr>
<tr>
<td>WC-Co</td>
<td>H0</td>
<td>9.6±0.15</td>
<td>542±20</td>
<td>13.52±0.02</td>
<td>0.22±0.01</td>
</tr>
</tbody>
</table>
FRACTURE TOUGHNESS SPECIMENS

SEN'B

1.5×4.0×20.0±0.1 mm specimens
mechanically notched:

double notch

- 0.9 mm deep, 0.2 mm width
- 0.2 mm deep, 0.025 mm width

3PB with rate 1 μm min⁻¹
Stress intensity factor $K_{IC}$ was calculated from the equation (1)

$$K_{IC} = 1.5 \frac{PL}{W^2 B} Y_c^{1/2}$$

where: $P$ – critical load, $L$ – roller distance, $W$–specimen width, $B$-specimen thickness, $Y$ – geometric function calculated according to equation (2) $c$ – crack length

$$Y = \frac{\sqrt{\Pi}}{(1 - \beta)^3} \left[ 0.3738 \beta + (1 - \beta) \sum_{i, j=0}^{4} A_{ij} \beta^i \left( \frac{W}{S} \right)^j \right]$$

where: $c$ is the crack length, $\beta$ is the $c/W$ $A_{ij}$ are the coefficients given by Fett
EXPERIMENTAL PROCEDURES

Fracture toughness

<table>
<thead>
<tr>
<th>Specimen</th>
<th>WC-Co+5wt% TiC</th>
<th>WC-Co+10wt% TiC</th>
<th>WC-Co+20wt% TiC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>H5</td>
<td>H10</td>
<td>H20</td>
</tr>
<tr>
<td>$K_{IC}$ [MPa·m$^{1/2}$]</td>
<td>16.8</td>
<td>14.0</td>
<td>11.1</td>
</tr>
<tr>
<td>$K_{IC(HV)}$ [MPa·m$^{1/2}$]</td>
<td>12.0</td>
<td>10.9</td>
<td>9.0</td>
</tr>
</tbody>
</table>

$k_{IC(HV)} = 0.035 \left( \sqrt{H} \right) \left( \frac{E \phi}{H} \right)^{2/5} \left( \frac{l}{a} \right)^{-1/2}/\phi$
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Surface distribution of elements (EDS technique)

SEM image of H0

Surface distribution of elements (EDS technique)
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SEM image of H10

Surface distribution of elements (EDS technique)
Quantitative analysis of elements distributed on the surface of $\text{H10} \xrightarrow{\text{EDS}}$

<table>
<thead>
<tr>
<th>Spectrum</th>
<th>C</th>
<th>Ti</th>
<th>Co</th>
<th>W</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spectrum 1</td>
<td>6.4</td>
<td>-</td>
<td>90.5</td>
<td>3.1</td>
<td>100.0</td>
</tr>
<tr>
<td>Spectrum 2</td>
<td>7.5</td>
<td>-</td>
<td>84.6</td>
<td>7.9</td>
<td>100.0</td>
</tr>
<tr>
<td>Spectrum 3</td>
<td>12.7</td>
<td>-</td>
<td>-</td>
<td>87.3</td>
<td>100.0</td>
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<tr>
<td>Spectrum 4</td>
<td>10.2</td>
<td>-</td>
<td>-</td>
<td>89.8</td>
<td>100.0</td>
</tr>
<tr>
<td>Spectrum 5</td>
<td>13.7</td>
<td>24.0</td>
<td>-</td>
<td>62.3</td>
<td>100.0</td>
</tr>
<tr>
<td>Spectrum 6</td>
<td>13.1</td>
<td>24.7</td>
<td>-</td>
<td>62.2</td>
<td>100.0</td>
</tr>
</tbody>
</table>
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SEM image of H20

Surface distribution of elements (EDS technique)
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Quantitative analysis of elements distributed on the surface of H2O EDS

<table>
<thead>
<tr>
<th>Spectrum</th>
<th>C</th>
<th>Ti</th>
<th>Co</th>
<th>W</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spectrum 1</td>
<td>12.0</td>
<td>-</td>
<td>-</td>
<td>88.0</td>
<td>100.0</td>
</tr>
<tr>
<td>Spectrum 2</td>
<td>11.6</td>
<td>-</td>
<td>-</td>
<td>88.4</td>
<td>100.0</td>
</tr>
<tr>
<td>Spectrum 3</td>
<td>8.8</td>
<td>2.9</td>
<td>80.0</td>
<td>8.3</td>
<td>100.0</td>
</tr>
<tr>
<td>Spectrum 4</td>
<td>7.7</td>
<td>1.5</td>
<td>84.9</td>
<td>5.9</td>
<td>100.0</td>
</tr>
<tr>
<td>Spectrum 5</td>
<td>14.7</td>
<td>24.9</td>
<td>-</td>
<td>60.3</td>
<td>100.0</td>
</tr>
<tr>
<td>Spectrum 6</td>
<td>14.0</td>
<td>25.3</td>
<td>-</td>
<td>60.7</td>
<td>100.0</td>
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<tr>
<td>Spectrum 7</td>
<td>24.0</td>
<td>68.4</td>
<td>-</td>
<td>7.6</td>
<td>100.0</td>
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<tr>
<td>Spectrum 8</td>
<td>24.2</td>
<td>56.9</td>
<td>-</td>
<td>18.8</td>
<td>100.0</td>
</tr>
</tbody>
</table>
Friction coefficient of WC-Co with 10wt% TiC
XRD DIFFRACTION PATTERNS of WC-Co with 10wt% TiC
CONCLUSION

Values of mechanical properties recorded for WC-Co with 5wt%-10wt% TiC:

- Fracture toughness 14.0-17.0 MPa·m$^{1/2}$
- Young's modulus 520-550 MPa
- Vickers hardness about 13 GPa

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Thank you for attention