Influence of secondary electro-conductive phases on the electrical discharge machinability and tribological behavior of ZrO_2-based ceramic composites

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Summary: ZrO_2-based composites with 40 vol. % WC, TiCN or TiN were hot pressed and reached an attractive combination of properties in terms of hardness, toughness and strength. Their electrical resistivity is low enough for shaping by wire electrical discharge machining (EDM) in demineralized water. Correlations between material removal rate (MRR), surface finish (Ra) and wire EDM parameters were derived. Noteworthy is that a surface finish (Ra) in the 0.6 to 0.7 µm range could be achieved for the three composites. Tribological data on these EDM'ed surfaces (flat against reciprocating WC-Co pin) show that within the regimes investigated: the friction wear volume and wear rate increase with increasing contact load; the ZrO_2-WC composite has the lowest wear rate followed by ZrO_2-TiCN and ZrO_2-TiN, as may be expected from their base properties; wear debris layers are formed on the ZrO_2-WC and ZrO_2-TiCN materials but not on the ZrO_2-TiCN for the load range investigated.

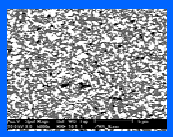
- A. Wear applications -

milling, drilling, reaming

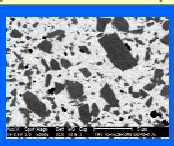
high-speed cutting

drawing dies, mandrels

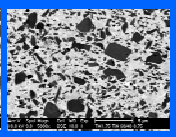
- B. High performance composites -



ZrO_2-WC



ZrO_2-TiCN

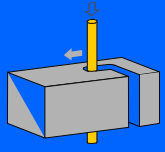


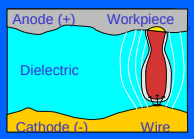
ZrO_2-TiN

40 vol%WC 0.8 vol% Al_2O_3	40 vol%$TiC_{0.5}N_{0.5}$ 0.75 vol% Al_2O_3	40 vol%TiN 0.75 vol% Al_2O_3	
1691 ± 8	1422 ± 10	1470 ± 7	HV_{10} [kg/mm²]
8.5 ± 0.4	7.0 ± 0.2	5.6 ± 0.1	K_{IC} [MPa√m]
328 ± 2	284	274	E [GPa]
1964 ± 88	1521 ± 61	1674 ± 314	Flex. strength [MPa]
9.80	5.76	5.81	Density [g/cm³]
4.3 10^{-6}	1.7 10^{-5}	4.6 10^{-6}	Electr. Resist. [Ω.m]
0.25	0.37	0.39	Av. grain size [µm]

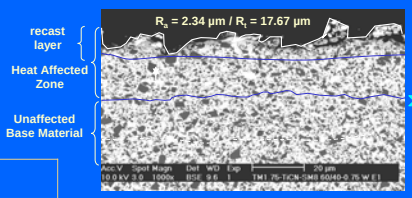
- C. Manufacturing & surface finishing -

Wire-EDM:
energy discharge between work piece & wire electrode



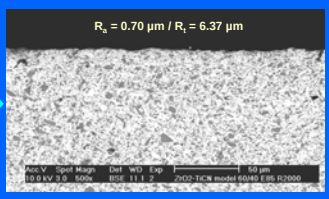


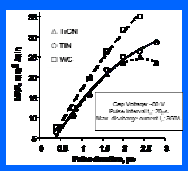
rough cut + several consecutive **finer** cuts

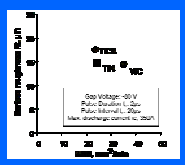


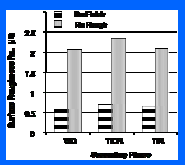
Grinding / Polishing:
diamond abrasive wheel

R_a < 0.1 µm

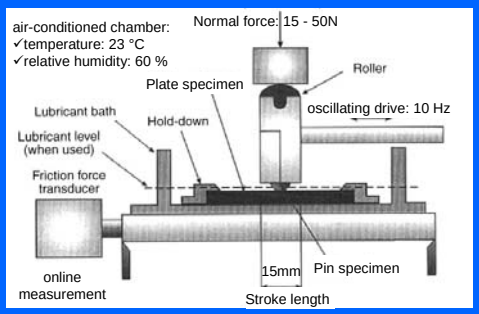




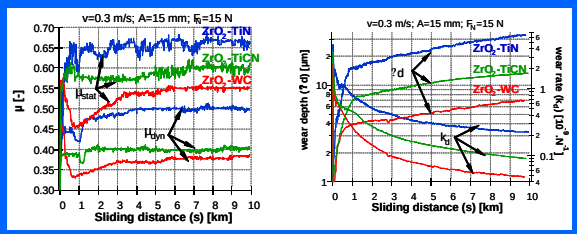




- D. Reciprocative sliding wear (ASTM G133) -

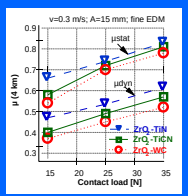


- each curve is an average of at least 2 experiments performed under equal conditions
- standard deviation between samples of equal material is < 10%
- error bars indicating the extent of the variations are excluded to make the figure better readable



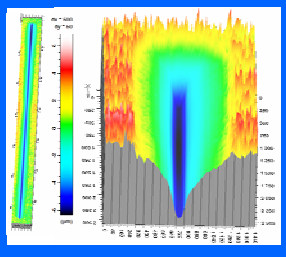
Static and dynamic friction coefficient exhibit a similar trend, but different level. The dependence of friction and wear on the secondary phase in the ZrO_2 composites is quite pronounced. The highest friction and wear is recorded for the ZrO_2-TiN composites

- Friction -



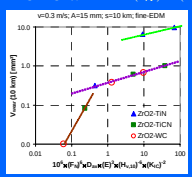
Friction increases with increasing contact load

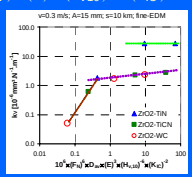
- 3D wear surface topography -



- Wear vs. material & test parameters -

Define $\chi = 10^6 \cdot (F_N)^6 \cdot (D_{av})^1 \cdot (E)^3 \cdot (H_{v10})^{-6} \cdot (K_{IC})^{-2}$





$V_{wear}(10km) = 0.3813 \cdot \chi^{0.2632}$ $R^2 = 0.9877$

$k_v(10km) = 1.485 \cdot \chi^{0.1849}$ $R^2 = 0.957$

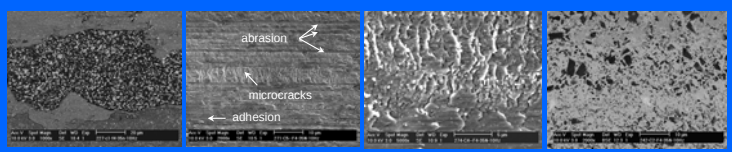
Wear volume & wear rate increase with contact load

- Wear surface observation -

Load	surface	ZrO_2-WC	ZrO_2-TiCN	ZrO_2-TiN
15 N	EDM	Clean	Clean	Clean
	Polished	Clean	Clean	Clean
25 N	EDM	Clean	Clean	D (start)
	Polished	Clean	Clean	D (start)
35 N	EDM	D (start)	Clean	$D_{debris\ layer}$
	Polished	D (start)	Clean	$D_{debris\ layer}$

-ZrO_2-TiCN is least prone to load-dependent wear **debris layer** formation (see micrographs)
- Wear debris is strongly agglomerated and mainly present as chunks
- For ZrO_2-WC/WC-Co tribopairs, EDX reveals remaining bright WC particles in a darker atomic number contrast (BSE) W-Zr-O-Al matrix. The WC debris particles are substantially smaller than in the original composite material.

Wear mechanisms at higher contact load occur more pronounced:
- microcracking
- spalling
- delamination
- adhesion
- abrasion
- wear debris formation



ZrO_2-WC, EDM, 35 N, 0.3 m/s

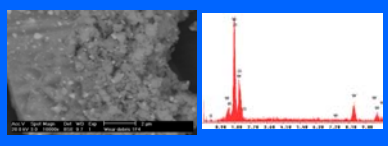
- localised spalling of top layer
- delamination

ZrO_2-TiN, EDM, 35 N, 0.3 m/s

Wear formdebris layer ation, containing microcracks

ZrO_2-TiCN, EDM 35 N, 0.3 m/s

No wear debris layer visible, absence of microcracks



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