TRIBOLOGICAL BEHAVIOR OF WIRE-EDM'ED ZrO_2-COMPOSITES AND CEMENTED CARBIDES

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Abstract

Five ZrO_2-based composites (ZrO_2-WC, ZrO_2-TiCN and ZrO_2-TiN grades) and five WC-Co cemented carbide grades were machined by wire-EDM and tested on a linearly reciprocating sliding pin-on-flat tribometer PLINT TE77 in dry conditions against WC-6wt%Co pins. Measurement of friction coefficient and penetration depth due to wear was performed continuously. The results revealed a strong influence of the secondary phase, surface finish, chemical and mechanical properties on the tribological characteristics of the ZrO_2-based composites and cemented carbides. WC10Co(Cr/V) displayed superior wear resistance compared to the other grades. The lowest coefficient of friction was encountered with ZrO_2-WC.

Keywords Friction, Wear, Electrical Discharge Machining, ZrO_2-composite, WC-Co

1 INTRODUCTION

Nowadays, there is an industrial need for materials to be applied under heavy tribological conditions and preferably without lubrication and high temperatures as for example for tools (chisels, cutting tools, dies, punches, etc.) and various machine parts (brakes, bearings, gears, sealings, etc.). To date hardened steels or hardmetals are often used for these applications. Some technical ceramic materials are used as well, in bulk or as a surface coating. The main purpose of these materials is to extend the lifetime of existing devices and components by decreasing their wear rate. A significant disadvantage of these materials is their relatively high coefficient of friction in dry contact conditions (heat development and energy loss). Moreover, their high hardness makes them intrinsically difficult to shape and to finish using conventional manufacturing methods. Usually the only suitable cutting technique is grinding by diamond or boron nitride tools, which restricts however seriously the possibilities in geometries that can be accomplished. Electro-discharge machining (EDM) allows a production of complex shapes in materials, irrespective of their mechanical properties, provided they are sufficiently electrically conductive.

Some research has already been performed on the effects of wire-EDM on friction and wear behavior of WC-Co cemented carbides [1, 2] and ZrO_2-based composites [3]. This paper compares tribological characteristics of these materials in dry reciprocating sliding wear tests with the goal to improve the fundamental insight into the tribology of these materials and to further extend the scientific perception of the influence of wire-EDM on tribological performance. Correlations between surface finishing conditions, testing parameters, material properties and friction coefficient and wear resistance are elucidated.

2 METHODOLOGY

2.1 Materials

The manufacturing process for ceramics is similar to powder metallurgy, where the end characteristics of components are largely dictated by powder characteristics (purity), “green densification” in forming, and finally the sintering process [4]. The present zirconia based composites were obtained by hot pressing Yttri-stabilised ZrO_2 powder mixtures with 40% vol.% WC, $TiC_{0.5}N_{0.5}$ or TiN. Starting powders were used in nanometric and micrometric sizes, the two corresponding grain sizes in the secondary phases are referred to as “fine” and “coarse” throughout the text. More information on processing and characterisation has been published in [5-7]. Physical and mechanical properties are listed in Table 1 as a function of secondary phases, microstructural properties for ZrO_2-WC, ZrO_2-TiCN and ZrO_2-TiN grades and five WC-Co cemented carbides grades.

Table1. Physical and mechanical properties for ZrO_2–based composites and WC-Co cemented carbides

Grade	Composition	Crystal size[i] [nm]	E [Gpa]	HV_{10} [kg/mm2]	$K_{IC,\ 10Kg}$ [Mpa.m$^{1/2}$]	Density [g/cm^3]	Average grain size, d_{av} (μm)	Grain size, d_{50} (μm)	Grain size, d_{90} (μm)
A	ZrO_2-WC	20-40	382±2	1691±8	8.5±0.4	9.8	0.25	0.11	0.54
B	ZrO_2-WC	800-1000	340±6	1502±9	8.5±0.2	9.79	0.3	0.17	0.17
C	ZrO_2-TiCN	<100	307±2	1629±8	3.9±0.1	5.59	0.15	0.12	0.33
D	ZrO_2-TiCN	1600	284±2	1422±10	7.0±0.2	5.76	0.37	0.22	0.84
E	ZrO_2-TiN	800-1200	274±1	1370±7	5.6±0.1	5.81	0.39	0.25	0.86
F	WC10Co	-	578±6	1149±10	>14.9±0.1	14.33	2.2	1.8	4.2
G	WC12Co(*V*)	-	563±2	1286±8	>14.9±0.1	14.08	0.9	0.7	1.5
H	WC12Co(*Cr*)	-	546±2	1306±5	>14.9±0.1	14.01	0.9	0.8	1.7
I	WC10Co(*Cr/V*)	-	541±4	1685±38	11.0±0.6	14.23	0.3	0.3	0.6
J	WC6Co(*Cr/V*)	-	609±4	1913±13	8.4±.02	14.62	0.6	0.5	1

[i] crystal size of the secondary phase starting powders;

2.2 Surface finish

The finest wire-EDM regime F4 and E23 was selected for sliding tests in dry conditions in order to compare the frictional response of fine and coarse ZrO_2-based composites and WC-Co cemented carbides respectively. Additional information of machining for the composites mentioned above is given in [2, 8]. The corresponding wire-EDM settings are listed in Table 2.

Table 2. Parameters and device settings for finer cutting EDM regimes

EDM regime	F4	E23
Open voltage (V)	120	140
Pulse duration, t_e (μs)	0.4	1
Pulse interval, t_o (μs)	4	4
Reference servo voltage Aj (v)	0	0
Pulse ignition height IAL (A)	5	2.5
Flushing pressure (bar)	0	0
Wire tension (N)	12	10
Wire winding speed (m/min)	8	4.8

2.3 Wear Testing

The dry sliding friction and wear behaviour of ZrO_2 and cemented carbide composites are investigated using a Plint TE77 tribometer according to ASTM G133 in ambient air, for instance, 23 ± 1 °C and 60 ±1 % relative humidity, WC-6wt%Co cemented carbide pins (length l = 22mm and diameter d ≈ 8mm) was rubbed in oscillating movement against flat specimens (width w = 38 mm x length l = 58 mm x thickness t = 4 mm) with a constant frequency of 10Hz, a stroke length of 15 mm and an average sliding velocity of 0.3 m/s. Three normal contact forces were imposed, i.e., 15, 25 and 35 N. Schematic illustration of linearly reciprocating pin-on-flat sliding wear system geometry is outlined in Figure 1.

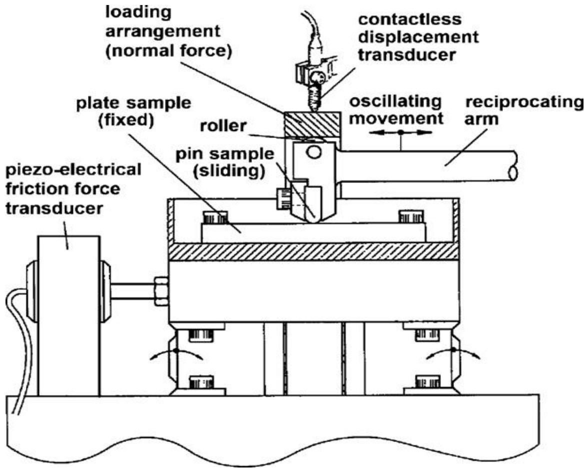

Figure 1. Schematic view of Plint TE 77 reciprocating pin-on-plate tribometer [9].

3 RESULTS AND DISCUSSION

3.1 COEFFICIENT OF FRICTION (μ)

A continuous registration of the imposed normal contact force (F_N) and the tangential friction force (F_T) of pin-on-flat sliding pairs was carried out using a load cell, parallel with the lever of the loading frame, and a piezo-electric transducer respectively. The coefficient of friction (μ) is calculated from the F_T / F_N ratio. In addition, the measured friction force can be differentiated in a static and a dynamic component:

$$F_{T,stat} = \frac{\left|F_{T,\min}\right| + \left|F_{T,\max}\right|}{2} \tag{1}$$

$$F_{T,dyn} = \sqrt{\frac{1}{T}\int_0^T (F_T(t))^2\,dt} \tag{2}$$

The data obtained from online monitoring are provided in table 4, in which friction coefficient and penetration depth at different sliding distance (running in and steady state) are compared for cemented carbides and ZrO_2 composites. The static and dynamic friction coefficients of the tested tribopairs are in the range of 0.55 – 0.86 and 0.39 – 0.68, respectively. Within whole data range it can be clearly seen that cemented carbides showed lower friction coefficient, however, the lowest friction level was recorded for the ZrO_2-WC Course, whereas the ZrO_2-TiN achieved the highest coefficient of friction. On the one hand, the effect of secondary phases and grain size is very important in ZrO_2-composites, the friction coefficient for course composites is lower than fine composites and even the penetration depth for coarse are shallow. On the other hand, the secondary phases were not much relevant for cemented carbides because those composites showed similar friction coefficients. As can be seen in Table 3 in the full sliding distance range with contact load of 35N the lowest wear depth was recorded for WC10Co(Cr/V), whereas wear testing of ZrO_2-TiN (Grade E) yields the highest penetration depth.

Table 3. Friction coefficient (static and dynamic) and penetration depth as function of sliding distance (s) for wire-EDM'ed ZrO_2-based composites and WC-Co cemented carbides against WC-6wt%Co (F_N=35N).

	Surface finish	μ_{stat}				μ_{dyn}				Δd_p(mm)			
Grade	s(km)	0.015	1	4	10	0.015	1	4	10	0.015	1	4	10
A	F4	0.80	0.77	0.78	0.75	0.53	0.51	0.52	0.51	6.4	22.2	40.0	55.6
B	F4	0.56	0.55	0.56	0.56	0.39	0.40	0.41	0.40	2.1	8.7	20.6	30.8
C	F4	0.83	0.86	0.86	0.84	0.64	0.65	0.65	0.63	11.0	161.5	197.8	274.8
D	F4	0.75	0.79	0.80	0.81	0.59	0.60	0.61	0.60	3.0	36.8	45.4	63.1
E	F4	0.79	0.81	0.82	0.82	0.61	0.65	0.68	0.68	9.9	99.6	200.5	362.7
F	E23	0.66	0.64	0.64	0.64	0.43	0.42	0.42	0.42	2.6	6.8	7.6	11.1
G	E23	0.64	0.63	0.63	0.62	0.43	0.42	0.42	0.41	2.1	5.9	6.6	8.2
H	E23	0.68	0.64	0.63	0.61	0.44	0.42	0.42	0.41	1.9	5.5	7.1	8.1
I	E23	0.64	0.62	0.64	0.61	0.41	0.41	0.41	0.40	2.3	4.8	6.0	7.5
J	E23	0.64	0.63	0.62	0.60	0.41	0.41	0.41	0.40	4.1	5.8	6.7	8.0

After the full sliding distance of 10 km the wear track was quantified for ZrO_2-composites, evidencing how it can be affected by the secondary phase, surface finish and the applied normal contact force (Figure 2). ZrO_2-WC course (grade B) showed the highest wear resistance, whereas the lowest wear resistance is found for ZrO_2-TiN (Grade E). Analogously, the highest wear is found with EDM'ed surfaces compared to equivalent ground ZrO_2-based composites. Moreover, it can be seen that the largest volume wear was encountered when the heaviest normal force was imposed.

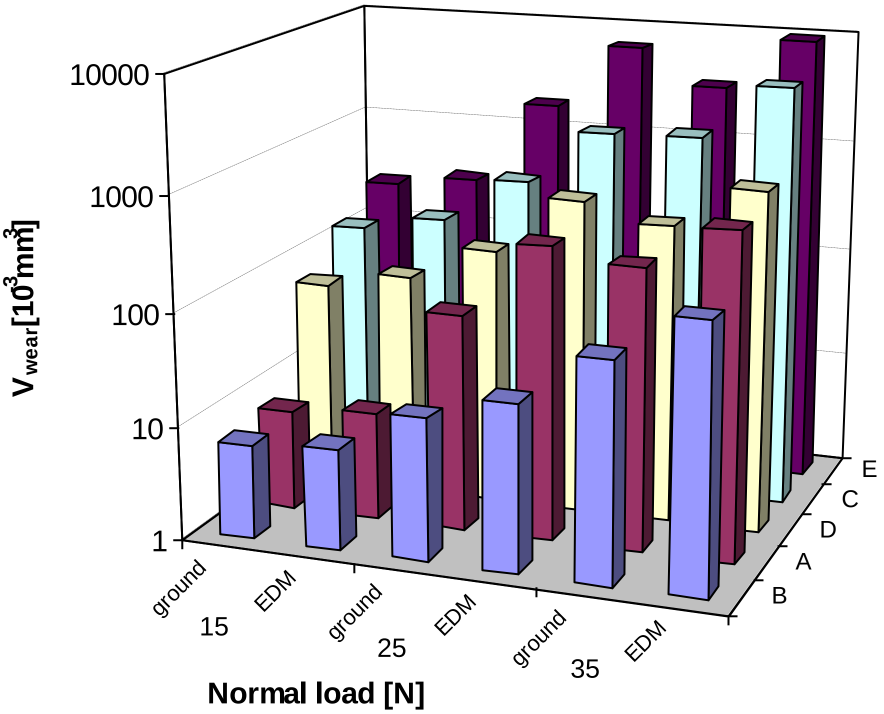

Figure 2. Volumetric wear of ZrO_2-based composite grades as function of surface finish at 15, 25 and 35N. (Sliding distance 10km, v = 0.3m/s)

4 CONCLUSIONS

Dry sliding pin-on-flat experiments on reciprocating movements of wire EDM'ed ZrO_2 composites and cemented carbides plates against WC-6%wtCo pins under normal contact loads of 15, 25 and 35 N revealed that the tribological properties are intimately affected by surface finishing, physical and chemical characteristics of the secondary phase and the imposed normal contact force. The lowest friction coefficient was encountered with ZrO_2-WC Coarse (grade B), whereas ZrO_2-TiCN Fine (grade C), displayed the highest friction at the normal force of 35N. Furthermore, the lowest wear was encountered with WC10Co(Cr/V) (grade I), while ZrO_2-TiN (grade E) showed the highest wear.

5 NOMENCLATURE

μ	Coefficient of friction	-
F_N	Normal contact force	N
F_T	Tangential friction force	N
μ_{stat}	Coefficient of friction static component	-
μ_{dyn}	Coefficient of friction dynamic component	-
V_{wear}	Wear volume	mm^3

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