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Abrasive Wear of Ceramic–Matrix Composites

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Abstract

The abrasive wear of various experimental and commercial ceramic–matrix composites was measured using a pin-on disc technique with SiC paper. The results are presented in a comparative way.

Der Abrasivverschleiß verschiedener experimenteller und kommerzieller Keramikmatrix-Verbundwerkstoffe wurde mit einem Stift-Scheibe-Test auf SiC-Papier gemessen und vergleichend dargestellt.

La résistance à l'abrasion de différents composites expérimentaux et commerciaux à matrice céramique a été mesurée par le méthode du stylet sur un disque de SiC. Les résultats sont présentés et comparés.

1 Introduction

Superior wear resistance of ceramic materials is still the main reason for their increased application in mechanical engineering. Within the past couple of years various ceramic–matrix composites were developed in the Advanced Ceramics Group at TUHH. The purpose of this study was to compare the abrasive wear of these composites with commercial wear-resistant ceramic materials and to try to correlate the results with mechanical properties.

2 Experimental Procedure

Four pin samples of dimensions $3 \times 4{\cdot}5 \times 4{\cdot}5\,\mathrm{mm}^3$ were machined from each material. The eight wear surfaces ($3 \times 4{\cdot}5\,\mathrm{mm}^2$) were ground on a 15 μm diamond grid. In the wear apparatus used,[1] the wear pin is driven at constant speed (300 mm/min) and constant pressure (2·2 MPa) across fresh SiC paper of either 600 (15 μm) or 180 (70 μm) grid. Before weighing, the surfaces were air-pressure cleaned. The wear w is represented according to

$$w = \Delta m / A l \rho \quad (\mu\mathrm{m/m})$$

where Δm is the weight loss, A the wear surface area, l ($=4$ m) the distance covered on the SiC paper and ρ density of the material tested. Eight data points were used to calculate w. The scatter was between 5% and 10%.

Details of the materials tested are given in the respective references. The commercial materials are designated by company codes; few further details were obtained.

3 Results

A compilation of all wear results is given in Table 1 together with other relevant property data. Some of the results are represented in Fig. 1(a) and (b).

3.1 Si_3N_4-base materials (Nos 1 to 11)

RBSN exhibits the lowest wear resistance of all ceramics tested which is mainly due to its high porosity ($\simeq$20% TD). The incorporation of large ($>100\,\mu$m) SiC platelets which are only loosely bonded to the RBSN matrix further increases the wear by acting as an additional abrasive. Pressure infiltration of metals, however, drastically enhances the wear resistance, e.g. Si-infiltrated RBSN (No. 7) shows a resistance one order of magnitude higher than the matrix (No. 4) and ranges between commercial hot-pressed tool tip Si_3N_4 composites (Nos 10 and 11) and wear-resistant Al_2O_3 ceramics (Nos 16

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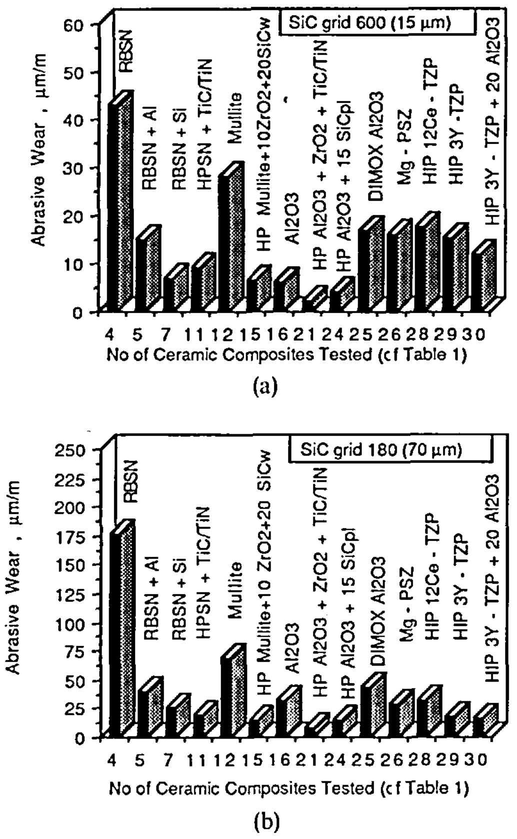
Table 1. Abrasive wear of various ceramic materials tested with pin-on disc technique on 600 and 180 grid SiC paper (relevant mechanical data are also given)

Number	*Material*	*Wear, w (μm/m)*		*Hardness HV 30 (GPa)*	*Toughness, K_{Ic} ($MPa\sqrt{m}$)*	*Strength*[a] *(MPa)*	*Young's modulus (GPa)*	*Density (g/cm³)*	*Remarks*	*Reference*
		600	*180*							
1	RBSN	36	147	4·5	2·5[b]	200	175	2·58	ACG[c]	2
2	RBSN + 10 vol% SiC_{pl}	57	346	4·5	2·5[b]	130	—	2·45	ACG, SiC platelets, American Matrix	2
3	RBSN + 20 vol% SiC_{pl}	74	630	4·1	2·0[b]	65	—	2·41	ACG, SiC platelets, American Matrix	2
4	RBSN	43	177	5·1	2·7[d]	227	—	2·83	Annawerk	
5	RBSN + Al (99·9%)	15·0	40	11·0	5·0[b]	478	—	3·08	No. 4 gas-pressure infiltrated at ACG	3
6	RBSN + Al–Si–Mg alloy	16·7	42	11·5	4·5[b]	463	—	2·96		3
7	RBSN + Si (99·99%)	7·1	26	15·3	3·9[b]	427	—	2·85		3
8	α-Sialon	5·9	14·5	18·0	4·2[e]	430	325	3·29	MPI,[f] 76 Si_3N_4, 15 AlN, 9 Y_2O_3	
9	HP β-Sialon	3·8	2·5	15·3	4·1[e]	410	310	3·16	MPI,[f] $Si_{5\cdot3}Al_{0\cdot7}O_{0\cdot7}N_{7\cdot3}$	4
10	HP Si_3N_4 + TiC/TiN	13·6	23	16[g]	7·5[g]	900[g]	300[g]	3·16	Krupp Widia, Widianit, N 1000[h]	
11	HP Si_3N_4 + TiC/TiN	9·2	20	14[g]	7·0[g]	1 000[g]	280[g]	3·26	Krupp Widia, Widianit, N 2000[i]	
12	Mullite	28	69	8·3	2·3[d]	200	—	3·14	ACG, HP at 1600°C	5
13	Mullite + 20 vol% ZrO_2	20	39	10·4	3·5[d]	260	—	3·58	ACG, HP at 1610°C	5
14	Mullite + 22 vol% ZrO_2	20	40	10·8	5·0[j]	260	—		MPI, reaction sintered	6
15	HP Mullite + 10 vol% ZrO_2 + 20 vol% SiC_w	6·4	14·6	12·9	5·4[d]	580	240	3·42	MPI, HP, SiC Whiskers, Tateo	7
16	Al_2O_3	6·0	32	14·5	4[g]	330[g]	380[g]	3·76	Feldmühle, V 38, 96%	
17	Al_2O_3	9·8	40	15·1	4[g]	330[g]	380[g]	3·79	Hoechst CeramTec, 98%	
18	Al_2O_3	7·8	50	16·8	4[g]	325[g]	380[g]	3·94	Friedrichsfeld, 99·8%	
19	Al_2O_3 + ZrO_2	7·3	34	17·2	5·8[g]	500[g]	380[g]		Feldmühle, BN 70	
20	Al_2O_3 + ZrO_2	5·9	12·3	17[g]	5·1[g]	800[g]	410[g]	4·16	Krupp Widia, Widalox U	
21	HP Al_2O_3 + ZrO_2 + TiC/TiN	2·3	8·8	19·3[g]	4·5[g]	620[g]	400[g]	4·25	Krupp Widia, Widalox H	
22	Al_2O_3 + 10 vol% SiC_{pl}	8·2	51	12·2	4·1[d]	200	—	3·70	ACG SiC platelets, American Matrix	5
23	Al_2O_3 + 15 vol% SiC_{pl}	11·3	56	13·9	5·2[d]	215	—	3·67	ACG	5
24	HP Al_2O_3 + 15 vol% SiC_{pl}	4·4	15	18·2	5·7[d]	290	—	3·75	ACG	5
25	Al_2O_3 + Al	17	44	10·2	4·5[d]	250	—	3·47	Melt-oxidation derived	8
26	Mg-PSZ	16	29	11·4	8·1[g]	520[g]	210[g]	5·78	Feldmühle, ZN 40	
27	Mg-PSZ	8·2	32	10·7	8·9[g]	525[g]	210[g]	5·75	Friedrichsfeld	
28	HIP 12 Ce-TZP	17·5	32	9·2	9·5[b]	480	205	6·26	ACG	9
29	HIP 3 Y-TZP	15·5	18	14·0	5·4[b]	1 560	210	6·10	ACG	10
30	HIP 3 Y-TZP + 20 vol% Al_2O_3	10·2	16	14·4	4·2[b]	1 280	258	5·51	ACG	11
31	HIP 3 Y-TZP-Duplex	13·8	18	13·4	6·9[d]	558	247	5·38	ACG	11

[a] 4-point bending.
[b] Chevron notch.
[c] Prepared at Advanced Ceramics Group, TUHH.
[d] Indentation-strength method.
[e] Indentation-crack length method.
[f] Max-Planck-Institute of Metals Research, Stuttgart, FRG.
[g] Data supplied by manufacturer.
[h] Contains about 2 wt% Al_2O_3 and 2 wt% MgO.
[i] Contains about 6 wt% Y_2O_3 and 3·5 wt% Al_2O_3.
[j] SENB method.



(a)

(b)

Fig. 1. Comparative representation of the abrasive wear of various ceramic materials tested with pin-on disc technique on (a) 600 and (b) 180 grid SiC paper.

to 18). The hot-pressed β-Sialon (No. 9) exhibits the best wear behaviour; it was the only material with less wear when the coarse 180 grid SiC paper was used.

3.2 Mullite-base materials

The data showed a slight improvement in the wear resistance of mullite when ZrO_2 was added (Nos 13 and 14). Dispersion of 20 vol% SiC whiskers (No. 15) further increased the resistance to values typical for Al_2O_3.

3.3 Al_2O_3-base materials

Addition of ZrO_2 (Nos 19 and 20) does not affect the abrasive wear resistance of Al_2O_3. Only when hard materials such as TiC and TiN are dispersed in Al_2O_3 (No. 21) is the wear reduced by a factor of ~3. Sintered SiC platelet-Al_2O_3 composites (Nos 22 and 23) show reasonable resistance in spite of some residual porosity (~3 to 5%). The hot-pressed composite (No. 24), however, exhibits nearly the same resistance as the best Al_2O_3-base cutting tool material (No. 21). The directed melt-oxidation derived Al_2O_3/Al material (No. 25) with about 25 vol% Al is comparable to the Al-infiltrated RBSN (Nos 5 and 6).

3.4 ZrO_2-base materials

The various transformation-toughened ZrO_2 ceramics (Nos 26 to 31) exhibit slightly inferior wear resistance on fine grid SiC when compared to Al_2O_3; however, on coarse grid SiC, ZrO_2 ceramics are more resistant than Al_2O_3, 3 Y-TZP composites (Nos 29 to 31) even by a factor of two.

4 Conclusions

Metal infiltration considerably improves the abrasive wear resistance of RBSN. On fine grid SiC paper, Si-infiltrated RBSN even excels the most wear-resistant hot-pressed TiC/TiN-containing Si_3N_4 composite of a commercial supplier (No. 11 in Table 1). The addition of SiC platelets to Si-infiltrated RBSN indicates further enhancement.[2] SiC whisker and platelet dispersions also increase the wear resistance of mullite (Nos 12 and 15) and Al_2O_3 (Nos 16 and 24). It is interesting to note that the wear resistance of 3 Y-TZP composites is superior to that of Al_2O_3 when coarse grid SiC is used, while the situation reverses when fine grid SiC is used (Fig. 1(a) and (b)). The best performance was found with a hot-pressed β-Sialon (No. 9) and with an alumina-based cutting tool material (No. 21).

Fitting the wear data to the general relation[12] $w \propto K_{Ic}^m H^n$, where K_{Ic} is the fracture toughness and H the hardness, did not lead to any reasonable results. Scaling with hardness is more dominant than with toughness. No attempt was made to interpret the results and associate them with specific wear mechanisms.

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