Surface toughening of ceramics

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This brief note deals with the increase in apparent surface toughness that results in ceramics from surface working operations. The ceramics tested included sialon, ZrO_2-toughened Al_2O_3 and a "mixed" $Al_2O_3 + TiN + TiC$ in the form of cutting tips and were of commercial origin. Surfaces were impacted by a stream of high velocity Al_2O_3 particles from a commercial compressed air operated grit blasting machine (particle speed $140 \pm 40\,m\,sec^{-1}$, particle size 200 to 500 μm) [1].

Indentations were performed using a Vickers diamond indenter on the ceramic surfaces in the as-impacted condition. Cracking could not be observed in these conditions owing to the extent of the surface damage, however, the geometry of the impressions could be used to provide a depth scale to determine the amount of material subsequently removed from the surface by careful diamond lapping using 1 μm diamond paste. Indentation cracking could be reliably determined by optical microscopy after removal of ~5 to 10 μm from the impacted surfaces, and apparent indentation toughness K_c^A was determined by direct application of the formula of Anstis *et al.* [2]. $K_c^A = 0.016(E/H)^{1/2} P/C^{3/2}$ where E is Young's modulus, H is hardness, C is crack length measured from the impression centre and P is the normal load which was here in the range 10 to 50 kgf (98 to 490 N). Initial values of apparent toughness K_c^A close to 19 MPa m$^{1/2}$ (sialon), 15 MPa m$^{1/2}$ (Al_2O_3) and 11 MPa m$^{1/2}$ ($Al_2O_3 + TiN + TiC$) were observed (see Table I). Apparent toughness fell rapidly with depth h beneath the surface from these extremely high initial values to a steady value close to 5 MPa m$^{1/2}$ (sialon) at $h \sim 44\,\mu m$, 4 MPa m$^{1/2}$ ($Al_2O_3 + ZrO_2$) at $h \sim 31\,\mu m$ and 4 MPa m$^{1/2}$ ($Al_2O_3 + TiN + TiC$) at $h \sim 34\,\mu m$, values which are representative of carefully prepared stress-free surfaces [3].

In conclusion, apparent toughness K_c^A in worked surfaces can greatly exceed K_c values obtained on carefully prepared surfaces (indentation toughness values K_c correlate well with toughness obtained by standard techniques) over a thin region ($\lesssim 50\,\mu m$).

The success of sialons and ZrO_2-toughened Al_2O_3 materials relative to other ceramics of nominally similar toughness, e.g. the "mixed" $Al_2O_3 + TiN + TiC$ ceramic, may in part be due to the higher values of apparent surface toughness that can be generated in these materials by surface working operations.

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References

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TABLE I Apparent toughening in ceramics resulting from impacting as determined from indentation testing

Material (manufacturer)	Load, P (kg)	a* (μm)	c (μm)	c/a	Depth, h (μm)	$P/C^{3/2}$ (MPa m$^{1/2}$)	H (MPa)	E/H	K_c (MPa m$^{1/2}$)
Sialon	30	102	111	1.09	6.3	252	13 050	23.0	19.3
(Sandvik CC680)	30	103	118	1.14	12.6	230			17.6
	10	58	81	1.40	23.2	134			10.3
	20	84	132	1.57		129			9.9
	30	103	187	1.82		115			8.8
	10	59	125	2.12	44.1	70			5.4
	20	84	199	2.36		70			5.4
	30	103	268	2.60		67			5.1
Al_2O_3 + 4 wt % ZrO_2	20	76	99	1.30	8.6	199	15 890	23.3	15.4
(Sandvik CC620)	30	93	125	1.34		210			16.2
	50	120	185	1.54		195			15.1
	10	54	87	1.63	18.4	120			9.3
	20	75	134	1.79		126			9.7
	30	93	173	1.85		129			10.0
	10	54	159	2.92	31.2	49			3.8
	20	75	249	3.28		50			3.9
	30	92	3.4	3.37		53			4.1
"Mixed" $Al_2O_3 + TiN + TiC$	30	84	151	1.79	7.5	158	19 210	19.3	11.1
(Sandvik CC650)	10	50	114	2.27	14.3	81			5.7
	20	69	182	2.62		80			5.6
	30	85	244	2.85		77			5.4
	10	50	142	2.83	33.6	58			4.1
	20	70	234	3.31		55			3.9
	30	85	306	3.56		55			3.9

*$2a$ = impression diagonal.

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