Impact Fatigue of an Alumina Ceramic

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A new type of pendulum impact apparatus is described for determining single and repeated impact strength of ceramics. It has been demonstrated that specimens of a "Sintox" alumina ceramic exhibit fatigue behaviour, having a high stress plateau followed by progressively increasing endurance with decrease in applied impact energy. A fatigue limit, at least from the engineering view point, has been drawn at high endurances (10^5 impacts). The influence of environment (static fatigue) and/or plastic deformation to explain the fatigue behaviour is suggested.

1. Introduction

Evidence is accumulating that glasses [1] and ceramics [2] deform at room temperature. Failure of such materials under static [3–5] and dynamic [6–8] loading conditions is well known, which implies that these materials would behave similarly under impact loading conditions. In the present paper it is demonstrated that repetitive impact leads to "fatigue", i.e. failure at lower stresses than those needed to bring about single-blow impact failure.

Previous attempts to determine whether or not impact fatigue occurs seem to have been confined to "cermets" and "plastics". It was observed by Soxman and his colleagues [9] that, with drop-weight and pendulum tests, repeated impacting resulted in lowering of the impact strength of nickel bonded titanium carbide materials, particularly at elevated temperatures. The number of impacts involved was only of the order of ten or so. No relevant data have been found for ceramics; indeed, many impact strength determinations, based as they are on increment tests [10, 11] utilise the assumption that repeated blows do not influence such materials. This assumption was questioned many years ago by Navias [12].

2. Material and Test Equipment

2.1. Material

All tests were performed on the as-fired high-alumina ceramics, commercially designated as white "Sintox" [13]. Specimens were nominally 5.08 cm long, 0.476 cm diameter cylinders. Any having flaws, as revealed by a "Zyglox" penetrant technique, were rejected.

2.2. Repeated Impact Equipment

The swinging pendulum apparatus depicted diagrammatically in fig. 1, was devised and constructed. It consisted essentially of a steel shaft, mounted on bronze bearings, driven

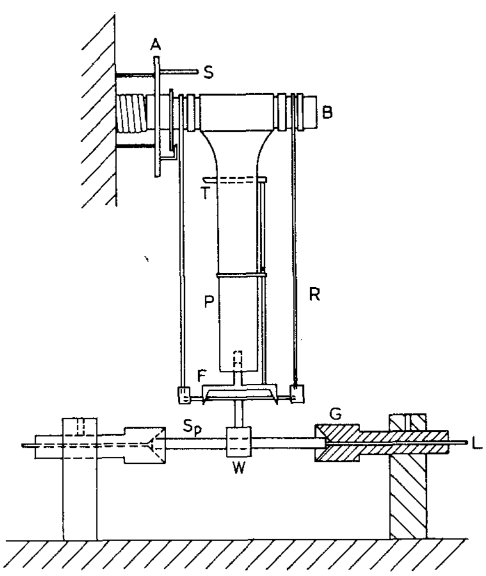

Figure 1 Schematic diagram of the impact apparatus and the specimen holder. A – graduated scale, B – motor driven shaft, S – striking pin, T – trigger, F – fork, P – pick-up arm, W – hammer weight, L – brass lead, G – tapered grip, Sp – specimen, R – steel rod.

through a chain and sprocket system (B), by a variable speed motor. Looped around the free end of the shaft were 0.317 cm diameter steel rods (R), spaced 7.68 cm apart, to the ends of which could be attached a cylindrical hammer (W). Between the looped rods was a pick-up arm (P), locked to the shaft. A spring-loaded pick-up in the shape of a two-pronged fork (F) was attached to the free end of this arm, which in turn was connected to a pivoted trigger (T) further up the arm. The test cylinder was held horizontally between two mild steel grips (G), shaped in the form of tapered cups which were spring loaded to hold the specimen tightly by the end faces. The cups had a hollow stem through which brass rods carrying connecting leads to an electrical circuit were placed in contact with the specimen.

2.2.1. Action of the Pick-up Arm

The pick-up arm revolved with the shaft, carrying the hammer on the fork until the trigger made contact with a striking pin (S), set at a pre-determined angle, the fork retracting to allow the hammer to fall. After impact the freely hanging hammer was picked up again, and again released. A damping device prevented multiple impact during a given revolution, but could be deactivated for single-blow impact studies.

2.2.2. Electrical Circuit

This enabled repetitive blows to be discontinued upon specimen fracture. Power was fed to the specimen through a microswitch via a step-down transformer, rectifier and amplifier, the microswitch being itself connected to the variable speed drive motor. Specimen ends were coated with colloidal graphite, a streak of this running lengthwise along the specimen. When the specimen fractured the circuit was broken, thus stopping the machine. A revolution counter registered the number of impacts.

3. Single-Blow Impact Tests

3.1. Energy Losses

The energy losses due to windage, friction and "toss" were determined. Briefly, using a 32.865 cm pendulum and for a total hammer weight of 0.189 kg, the hammer was released from various initial angles in the range of 90 to 30°. The final anguiar swing was noted, the difference, converted to energy (kg cm), being the losses incurred due to windage and friction. Total losses associated with windage, friction and "toss" were evaluated similarly with a broken specimen placed within the grips. Results are shown in table I.

3.2. Impact Strength of "Sintox" Alumina

The approximate value of the impact strength was first obtained by an increment method. A very low initial angle of swing was employed, this angle being increased by intervals of 10° until the specimen fractured. The procedure was repeated with a fresh specimen, using an angle of swing 10° below the previous value for failure. Eventually single stroke impacting was conducted at various angles in the region of the approximate critical value. The results are shown in table II.

4. Repeated Impact Tests

A pendulum length of 32.385 cm and a hammer weight of 0.189 kg was selected on the basis of prior tests. The initial angle of pendulum swing was set at a 10° interval below the single-blow fracture value. Impacting, at a frequency of 6 impacts/min was continued to fracture in each instance. Striking energy ranged from that required for single-blow fracture to about a quarter of this value, at which value failure did not occur after a quarter of a million blows.

It should be remarked that during these tests

TABLE I Evaluation of windage, friction and "toss" losses, hammer weight 0.189 kg, Pendulum arm length 32.865 cm.

Angle of release, degrees	Initial energy, kg cm	Final angle of swing, degrees	Final energy, kg cm	Toss angle, degrees	Toss energy, kg cm	Total energy loss, kg cm	Energy loss/ degree
90	6.1443	87	5.8226	76	4.6581	1.4862	0.0077
80	5.0778	77	4.7681	67	3.7437	1.3341	0.0078
70	4.0435	68	3.4290	58	2.8882	1.1453	0.0078
60	3.0727	59	2.9793	47	1.9543	1.1184	0.0090
50	2.1953	49	2.1134	37	1.2371	0.9582	0.0095
40	1.4412	38	1.3005	27	0.6769	0.7643	0.0114
30	0.8320	29	0.7655	19	0.3348	0.4977	0.0100

TABLE II Single-blow impact strength.

Angle of release, degrees	Initial energy, kg cm	Final angle of swing, degrees	Final energy, kg cm	Energy loss/ degree	True rupture energy, kg cm
90	6.1454	32	0.9339	0.0078	4.1699
85	5.6035	22	0.4473	0.0078	4.3216
80	5.0732	35	1.1068	0.0078	3.0694
80	5.0732	22	0.4473	0.0078	3.8303
77	4.1768	30	0.8232	0.0078	2.5190
80	5.0732	19	0.3343	0.0078	3.9667
82	5.2922	15	0.2075	0.0078	4.3281
80	5.0732	20	0.3678	0.0078	3.9254
82	5.2922	35	1.1068	0.0078	3.2828

the damper device was so synchronised with shaft rotation as to eliminate rebound of the hammer after each blow. This prevented broken pieces of the specimen being thrown out of the clamps after fracture, thus no "toss" losses were registered. However, the total energy losses due to windage, friction and "toss", registered previously, were subtracted from the initial energy in order to determine the actual impact energy.

The results are tabulated in table III, whilst the energy required to cause fracture is plotted with the scatter band against endurance in impacts (fig. 2). It should be noted that endurances of around 10^5 impacts were regarded as an experimental limit, for at and above such values the specimen edges tended to chip so that good electrical contact could not be maintained.

5. Discussion

The data, plotted in fig. 2 as applied impact load against number of impacts to cause fracture, indicate an apparent fatigue effect for the alumina ceramic considered in this investigation. It is interesting to note that at high impact energy levels, though below the single-blow fracture value, the material endured a minimum of 10 impacts before failure, followed by increasing

TABLE III Repeated-blow impact strength.

Angle of release, degrees	Initial energy, kg cm	Total energy loss, kg cm	Impact energy, kg cm	Endurance impacts
70	4.0435	1.1453	2.8980	15
				20
				143
				28
				33
60	3.0727	1.1184	1.9543	98
				154
				27
				38
				59
50	2.1953	0.9582	1.1371	184
				854
				646
				382
				259
40	1.4412	0.7643	0.6769	5612
				2576
				967
				22 440 UB
				11 213
35	1.1114	0.4977	0.6137	256 000 UB
				128 572 UB

UB = Unbroken specimen

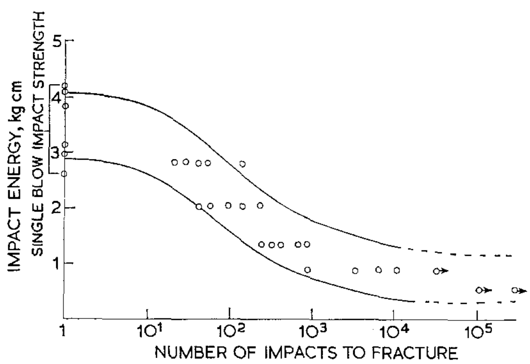

Figure 2 Impact fatigue of "Sintox" alumina.

endurance with decreasing applied impact energy. The present results, where the specimens at approximately 0.27 of the critical energy of impact failed after several thousands of blows (967 impacts at lower limit to 11 213 impacts upper limit), demonstrate that the impact fatigue is real in these materials. The number of tests performed at 0.6137 kg cm energy levels was not sufficient to conclude a well defined fatigue limit, but the slope of the fatigue curve is such that the suggested limit would not be totally inappropriate. It is considered that the range of impact energy levels employed is sufficiently wide to exclude the possibility of failure at any particular energy level being due to accidental over-stressing up to the single-blow value.

It may be argued that the single-blow impact strength as reported is not necessarily an absolute value. However, it has been assumed that the unknown contribution of machine rigidity is the same for single-blow and repetitive impact. No doubt, in stressing by repetitive impact the unfractured specimen will vibrate, but the time period of 10 sec between each blow ought to be sufficient to enable the specimen to come to rest. The feature of importance is the significance of environment, this possibly influencing the contribution of "static fatigue" to the overall "dynamic fatigue" effect demonstrated here.

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