Title of Paper Internal Friction in Ceramics

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ABSTRACT

A brief review is made of measurements of internal friction carried out on a wide range of ceramic materials. The problems and techniques are briefly discussed and examples of various applications are given.

INTRODUCTION

Ceramics can be broadly divided into four groups.

(1) Pottery - bone china, earthenware, electrical porcelain and glazes.
(2) Refractories - steelmaking, glass tank, kilns and high-temperature processing.
(3) Special Ceramics - refractory oxides, nitrides, borides, carbides.
(4) Heavy Clay - building bricks, tiles, drainpipes.

The bulk of the work on internal friction, which is being briefly reviewed, is concerned with groups 1 and 2. Specimen sizes range from bars a few centimetres long to three-storey-high walls.

PROBLEMS Ceramics are difficult to process. For precision work the specimens must be diamond ground - often a long and tedious operation particularly with oxides or carbides. It is sometimes possible to mould or extrude test pieces in groups 1 and 2, but these still need grinding. In groups 2 and 4 the availability of much larger samples makes it possible to cut specimens and the accuracy of finish required is not so great. In these groups square or rectangular specimens are more normally used as compared to cylindrical specimens in the other two groups.

TECHNIQUES The basic method is to vibrate the specimen at its resonant frequency and to either measure the sharpness of resonance or the rate of decay when the excitation is removed.

The excitation methods can be divided into direct and indirect drive. The former is mainly used for the larger specimens (>150 mm long) where the vibration generator and/or detector is directly coupled to the specimen. The indirect technique is more suited to small specimens and is usually electrostatic.

This latter poses a further problem in that the specimen must be conducting. Most ceramics are excellent insulators. At room temperature a typical alumina will have an insulation resistance of about 10^{14} ohms. The specimen must be rendered conducting with either silver paint or a vacuum deposited coating. The latter has not been found suitable due to the relatively high resistance giving a poor signal/noise ratio.

With this method the specimen is clamped at its mid-point being earthed through the clamp. An electrode, at about 300 volts D.C. to earth is brought up close to each end of the specimen. The gap is usually of the order of 0.1 mm, which requires that the end faces of the test piece are ground flat and parallel. The drive voltage, which may be in the region 1 kHz to 200 kHz, is applied to one electrode, the other electrode being coupled to a high impedance amplifier. Display is usually on an oscilloscope, a valve voltmeter may be used for bandwidth measurements. The drive voltage may be up to 100v p-p, 5 to 15v p-p being normally used.

In a single ended variant of this method the drive is applied in the normal manner. The capacitance across the gap is used as the tuning capacitance of an R.F. oscillator. When the specimen vibrates the oscillator carrier is frequency modulated. The signal is picked up by a commercial F.M.-tuner, the output of which is at the specimen resonant frequency. This technique is useful for high-temperature measurements because the gap can be kept constant, despite thermal expansion, by using the tuning indicator on the tuner.

High temperature work poses another problem. The silver paint method cannot be used since the measurements have to be made in vacuo and volatilisation occurs at relatively low temperatures. A fired-on platinum coat has been used up to about 800°C above which temperature volatilisation again causes trouble.

The Forster two-wire method has been tried with indifferent results. It is difficult to avoid spurious resonances in the support wires and the placing of the wires is critical. If they are at the nodes the drive and detection efficiencies are low. If displaced from the nodes then extra damping results and the measurements are in error.

The actual measurements can be made in several ways. The bandwidth method is normally used with the direct-drive technique. The oscillator is tuned through resonance and the sharpness of response measured. This method is usually limited to values of Q^{-1} greater than 2×10^{-4} because of oscillator stability. If however decay times are measured then the accuracy improves as the damping decreases. The technique involves the measurement of the time taken for the amplitude of vibration to decay between two fixed levels when the excitation is removed. This can be done by either setting up the decay curve on the oscilloscope or by using electronic techniques to count the number of cycles between two amplitude levels.

Some typical values are given in the table below:-

Material		Q^{-1}		
Alumina	99.9%		10^{-5}	In vacuo
	95 - 99%	1 to 3	$\times 10^{-5}$	" "
Silicon nitride		2.5	"	" "
Fused silica		5	"	" "
Bone china		25	"	" "
Electrical porcelain		30 to 100	"	" "
Glazes		30 to 200	"	" "
Vitreous earthenware		80 to 150	"	" "
Porous earthenware		100 to 250	"	" "
Magnesite refractories		125 to 330	"	In air
Silica refractories		250 to 1000	"	" "
Siliceous refractories		600 to 2500	"	" "
Glazed drainpipes		125 to 500	"	" "

APPLICATIONS At room temperature measurements can be used as a refined form of quality control either to select specimens or to detect damage. This latter may be brought about by thermal shock, frost damage, mechanical shock, heat treatment to name a few. Optimum firing temperatures can be checked since the method is more sensitive than the measurement of Young's modulus or the more usual bulk density determination. It can also be used to follow drying-out or moisture absorption at low water contents. It has been used to some extent to eliminate faulty pipes from strength determination trials of glazed drainpipes. Some difficulties were observed due to the shape and natural variation between pipes which may be as much as 20%. One interesting application is to materials where high impact strength is required. This involves two conflicting parameters - high Young's modulus and high damping capacity.

The main application at the B.C.R.A. has been in work concerned with the mechanical properties of materials at high temperatures, either from the purely scientific or commercial application viewpoint. The last twenty years has seen an ever-increasing use of ceramics in electronics and the aerospace industry. They may be used as structural or active elements. As valve electrode supports the requirements are high resistivity and strength with low deformation at temperature. Similar requirements apply to valve envelopes. Alumina is a typical choice in the latter case. Fig. 1 shows damping coefficient/temperature curves for four aluminas. The 88%

Al_2O_3 material has appreciable amounts of clay present to act as a bonding agent. This results in a relatively high glass content. The peak at about 280°C is probably due to alkali ion movement in the glass lattice. This peak is also observed in electrical porcelains and its position depends to some extent on the Na_2O/K_2O ratio in porcelains of similar composition. It will be noted that the higher purity aluminas have flatter, less complex curves. Unfortunately it has proved impossible to extend these measurements above 1000°C because of experimental difficulties connected with the coating of the specimen.

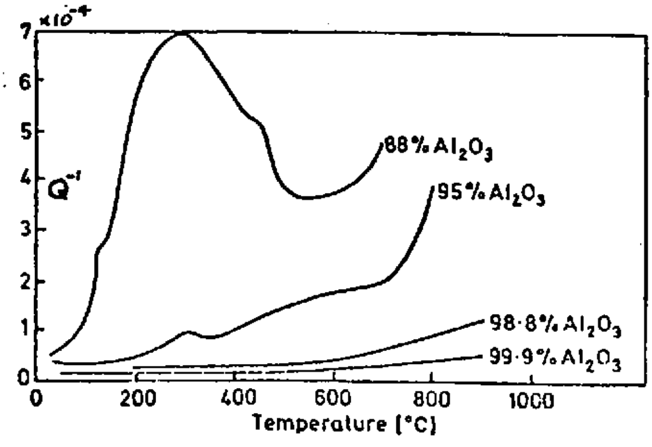

Fig 1 Internal friction/temperature curves for aluminas

Refractories are usually multiphase materials and as such may exhibit complex damping coefficient/temperature curves. An example is shown in Fig. 2. The material is a silica refractory containing 70% tridymite, 15% cristobalite, 5% quartz and 10% glass. The complexity of the curve is due to the tridymite inversions between 100° and 200°C and the cristobalite inversion in the 200° to 250°C region. Where free quartz is present in appreciable amounts the curves are again complex in the 550° to 590°C region.

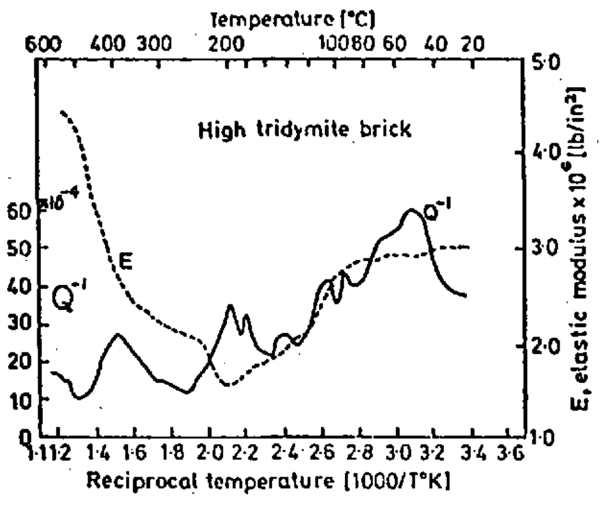

Fig 2 Modulus and internal friction/temperature curves for a silica refractory

These changes in the damping coefficient can affect the behaviour of the material when subjected to thermal shock. They have been used as a means of detecting damage under such conditions and of following the development of the resulting cracks. They also provide a means of determining the minimum thermal stress needed to cause damage.

With less complex refractories such as sillimanite, mullite and high-aluminas the curves are much simpler showing in general a slight rise with temperature. There may be small rises at about 200° to 300°C and again in the 575°C region dependent on the amounts of cristobalite and free quartz present. A more pronounced rise starts in the 800° to 900°C region the rate of rise increasing up to about 1100°C with the onset of plastic deformation in the bond. The method is very sensitive as mechanical deformation tests do not show comparable effects until much higher temperatures are reached.

The final example to be discussed is very large scale. It concerns building walls. The tests were made to obtain the natural resonant frequency and damping coefficient to determine their behaviour when subjected to gas explosions. Single 8' high cavity walls, restrained only at top and bottom had resonant frequencies in the 20 to 30 Hz range, Q^{-1} values being of the order of 0.06. Where the wall was part of a complete three-storey building the resonant frequencies averaged 45 Hz ranging between 42 and 50 Hz. The damping coefficients were higher, Q^{-1} averaging 0.15, ranging between 0.13 and 0.20.

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