FRACTURE BEHAVIOUR OF ENGINEERING CERAMICS UNDER STATIC AND DYNAMIC LOADING

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The quasi-static and dynamic fracture toughness of engineering ceramics is investigated. Early dynamic studies on ceramics used variations of impact tests merely to investigate ceramic energy absorption characteristics. Several ceramic materials such as debased alumina, high purity alumina and partially stabilised zirconia are tested statically and dynamically using a servo-hydraulic testing machine and a modified Split Hopkinson Pressure Bar (SHPB) respectively. The results showed that advanced ceramics tested increased strength and fracture toughness with increased loading rate.

INTRODUCTION

The use of advanced ceramic materials in engineering applications is becoming more and more widespread, due to their superior stability at high temperatures. A major barrier to the wide use of ceramics as engineering components is its brittleness. In the last two decades, extensive research has been carried out to understand the mechanisms of fracture of ceramics and to improve its quasi static fracture toughness (1).

The behaviour of ceramics under high loading rate is still not fully understood, and the data available are very limited and far from satisfying the need of engineering applications. This is specially more important since ceramics are used in impact or under dynamic loading conditions in manufacturing , as amour plates, as components of automotive and gas turbine engines and as tiles of space crafts. Partially stabilized zirconia (PSZ) is one of the most attractive ceramics materials. Porter (2) suggested that the toughness of partially stabilized zirconia (PSZ) is mainly attributed to particles-cracks interactions, which results in a transformation

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zone around the crack tip. Firstly, particles within a critical distance of the crack tip interact with the stress field of the crack in such a way that the coherent particles lose their coherence and transform martensitically to monoclinic structure.

Rice (3) reviewed the micro structural dependence of fracture energy and substantial disagreement between the different techniques, the work of fracture (WOF) ,single edge notch beam or simply notch beam (NB), double torsion (DT) , and double cantilever beam (DCB)) as a function of grain size, porosity, and second phase contents. Extensive micro cracks formed in conjunction with crack propagation and increased with grain size.

The absence of the dynamic crack arrest, normally present in dynamic fracture of metals, is thought to be the cause of shattering in ceramics. Duffy and his co-workers (4 - 5) determined the dynamic fracture initiation properties of ceramics subjected to pure tension and pure torsion using circumferentially notched cylindrical specimen on a modified version of the Kolsky bars (Split Hopkinson Pressure Bar). The tensile pulse was produced by explosive detonation and a stored torque from a hydraulic system was used to produce the torsional pulse. The difficulties of the pre cracking were successfully overcome applying cyclic compressive stresses. Their experiments for a fine grained Alumina showed that the apparent dynamic K_{IC} and K_{IIIC} values were 50% higher than the corresponding quasi-static toughness.

Kobayashi and his colleagues (6) studied dynamic crack arrest in ceramic and ceramic composites and suggested a new bar impact tester for their dynamic impact testing. In this method, a rectangular bar specimen is impacted in such a way that the superposition of the incoming compressive wave and the reflected tension wave generates a clean tensile pulse for the loading. Crack opening displacement was measured with a laser interferometric displacement gauge and the results indicated an increase in the dynamic stress intensity factor K_1^{dyn} with increasing impact velocity while the dynamic initiation fracture toughness K_{1d} did not vary much with that increase.

Nojima et.al (7) reported their study of impact strength of three kinds of engineering ceramics using three types of Hopkinson pressure bar impact tests; three point bend, Brazilian and tensile test. They noted that the strain rate effect on the strength was different in those ceramics; in the Al_2O_3 and TTZ,the impact strength increased with the strain rate, while in the SiC, the strength decreased under impact.Kishi et.al (8) investigated the dynamic fracture toughness of ceramics by strain gauge method over a wide range of loading rates. Similar investigations were reported by Aoki et al (9).

Kobayashi et al (10) studied the dynamic fracture toughness of partially stabilized zirconia(PSZ) and Si_3N_4 by impact response curve method using a strain gauge attached to the specimen in an instrumented Charpy impact test.He noted that dynamic fracture toughness in PSZ increased with loading rate, whereas dynamic fracture toughness in Si_3N_4 decreased once and then increased with increased K. When specimen without precrack were tested, the fracture toughness increased with the increase of notch root radius.

EXPERIMENTAL TECHNIQUE

Some of the most commonly used fracture toughness methods are
(1) chevron-notched bend bar (CNB)
(2) single edge notched bend bar (SENB)
(3) single edge pre cracked beam (SEPB)
(4) two kinds of hardness indentation methods, a direct crack size measurement and K evaluation from strength measurement (ISB).

In this work, the dynamic measuring system is based on the one-dimensional wave propagation theory and various versions of the Kolsky bars can be used for high rate loading tests in compression, tension, torsion and for fracture toughness testing. In this system, the specimen is positioned between two cylindrical pressure bars of the same material and cross section. The compressive stress wave is produced by the impact of the free end of the input bar by a striker to produce an input pulse of rectangular shape and a very small initial rise time. Arriving at the interface with the specimen, the incident pulse is partially reflected and partially transmitted through the specimen into the second pressure bar, as shown in the diagrams of Figure 1. The system has been previously used by Al-Mousawi (11) for high rate loading of metallic materials and to determine dynamic stress strain curves and more details can be found in a previous publication by the author (12).

A modified version of the Kolsky bar was used for metal testing by Klepaczko (13), to determine the fracture toughness over a wide range of loading rates. The system is shown schematically in Figure 2. The incident bar is subjected to impact loading by a striker of exactly the same diameter as the pressure bars (d=20 mm), fired from a gas gun at a predetermined velocity, v_o, for the desired loading rate. Upon recording the incident, reflected and transmitted waves at strain gauge positions T_1 and T_3 as illustrated in Figure 2, sufficient information about specimen loading and fracturing is provided. The onset of a crack propagation can be detected by a strain gauge, T_2, positioned directly on the specimen very close to the front of the fatigue crack. The proper choice of the distances enable a time separation of the incident and reflected pulses.

RESULTS AND DISCUSSION

The production processes of engineering ceramics are constantly being improved to produce finer ceramics with a wide range of tensile strength and fracture toughness.

The ceramic materials investigated are debased Alumina, high purity Alumina, and so called toughened Zirconia ceramics. Yttria (Y_2O_3) is generally regarded as the preferred stabilizer which produces fine grained tetragonal Zirconia characterised by high strength and toughness value, but at a high production cost. As an alternative, one can use Ceria (CeO_2) to partially stabilized Zirconia.

An extensive testing programme was undertaken to measure quasi-static fracture toughness using several testing methods and test results are the average of 10 samples for each test method and each material. The specimens were all produced at the ceramic laboratory of Staffordshire University where they were sintered at 1450 ^oC - 1650 ^oC. It was found that double torsion(DT) tests give the highest toughness value among the test methods used and single edge pre cracked bar(SEPB) tests give the lowest toughness value whereas single edge notched bar (SENB) tests produce the toughness value higher than that of SEPB method. The chevron notch bar(CNB) method results in fracture toughness values very close to that of SENB method. For the materials tested, debase alumina is tougher than fine alumina . Debase alumina had toughness values ranging from (3.5 - 6.3)while Ce-PSZ with a flexural strength of 750 MPa shows an increased fracture toughness of 12 MPam$^{1/2}$, and its grain size is larger than that of fine alumina with fracture toughness values (3.2 - 4.9) MPam$^{1/2}$. It indicates that for alumina, there is a grain size effect on fracture toughness . Most of these new results were close and comparable to earlier published test results.

The quasi-static flexural strength of Ce-PSZ is about 800 MPa and its fracture toughness value was in the range of (5.3 - 7.7)MPam$^{1/2}$. while Ce-PSZ with a flexural strength of 750 MPa shows an increased dynamic fracture toughness of 12 MPam$^{1/2}$. The toughness values could even be improved depending on the adopted firing regime, but at the cost of lower strength. The behaviour of the PSZ was compared with the response of debased and high purity Alumina subjected to high rate loading. The dynamic testing is continuing and early results indicate an increased dynamic initiation fracture toughness with increased K rate, which are in general agreement with published results for other ceramics. However, a lot more testing is required together with numerical analysis to validate the results on the dynamic fracture behaviour of partially stabilized Zirconia

CONCLUSIONS

The experimental results obtained for fine grained partially stabilized Zirconia suggest that the dynamic fracture initiation toughness increases significantly in comparison to the corresponding quasi-static K_{IC} values. With increased use of advanced ceramics under impact,there is an urgent need for considerable additional research in the field of dynamic fracture mechanics of ceramics and ceramic composites at room and elevated temperatures.

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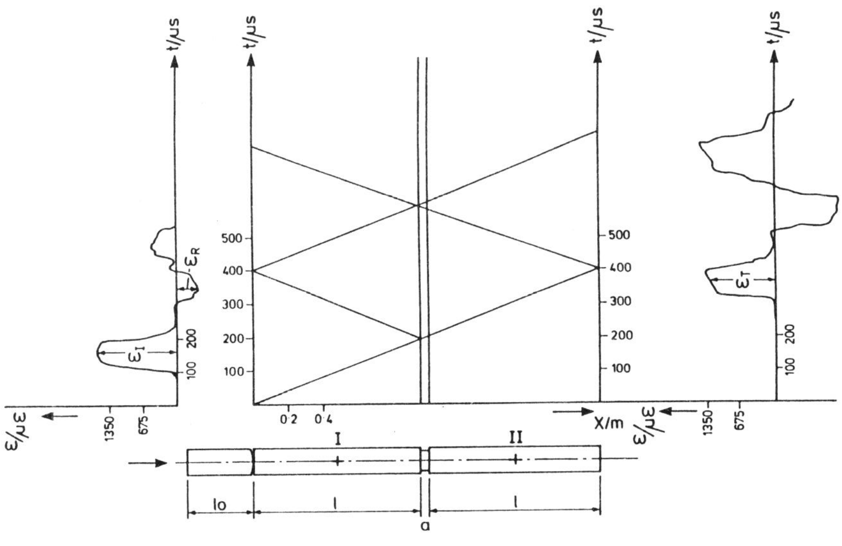

Fig. 1 Stress wave propagation in the split Hopkinson bars.

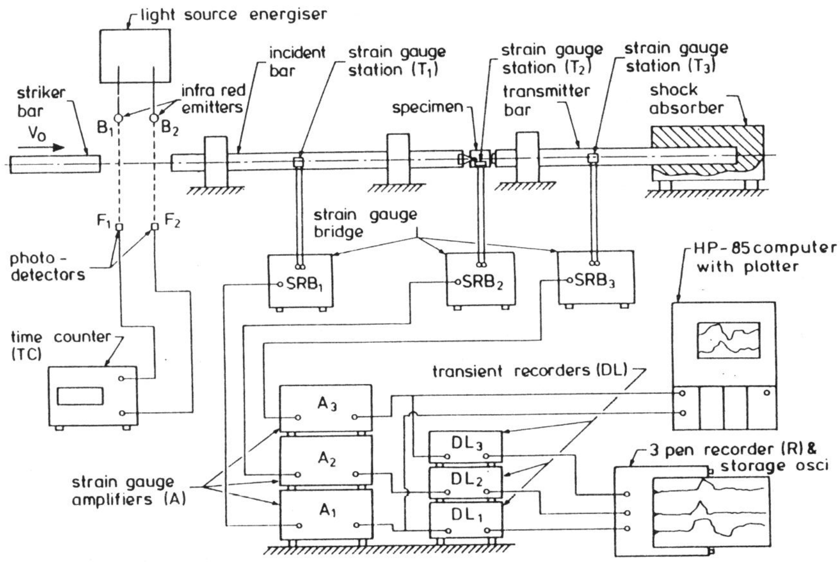

Fig. 2. Fracture toughness testing using SHPB.