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The Materials and Mechanics of Rate Effects in Brittle Fracture

Progress Report

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Abstract

The critical stress intensity factors for propagating cracks, K_{ID}, was experimentally found to decrease with increasing crack velocity. K_{ID} was measured using rapidly wedged double cantilevered beam specimens. The crack length versus time was continuously recorded using electro-potential techniques. The specimens were fractured at temperatures well below the brittle to ductile transition temperature. The crack velocity in these specimens varies continuously but is typically in the range of 100 to 200 meters/sec. The analysis of fully dynamic crack propagation in double torsional beam specimens was solved in closed analytic form. The solutions for rotational rate loading and for constant applied torque, predict constant crack velocity. The crack velocity is given by the applied rate of rotation, the magnitude of the applied torque and specifics about the beam. The maximum crack velocity is the torsional wave speed. The use of the analysis is to deduce K_{ID} during crack propagation without measuring the crack velocity directly. The measurements of static, dynamic loading and propagating crack, stress intensity factors establishes that rate is an important variable in specifying the stress intensity factor for fracture.

Contract E(11-`` 2422 October 1975
Technical Prog s Report

Summary of Work in Progress

The period covered by this progress report saw completion of three phases of work: i) the experimental measurements of dynamic fracture toughness values, K_{ID}, for propagating cracks; ii) the analysis of dynamic crack propagation in double torsion beam specimens at constant rotational rate loading and constant applied torque; iii) the comparison of static, dynamic loading and propagating crack stress intensity factors.

The experimental measurements of crack length versus time using rapidly wedged double cantilevered beam specimens gives a continuous record of K_{ID} versus crack velocity. The data is reproducible from test to test although the experimental difficulties are non-trivial. However, this test does provide a reasonable method for measuring $K_{ID}(\dot{\ell})$ in reactor grade steels. A single test gives a range of crack velocities i.e. the crack velocity is not constant during the test but is dispersive continually decreasing with time. Measured $K_{ID}(\dot{\ell})$ decrease with increasing crack velocity in the brittle range of fracture

The analysis of crack propagation in double torsion beam specimens was extended from static to fully dynamic relations in the limit of torsional beam theory. The crack propagation problem in torsional beam theory is considerably easier analytically and the solution explicitly contains inertia terms not only in the solution of beam rotation but also in the dynamic fracture criteria. The analysis indicates that the dynamic fracture criteria for all propagating cracks must be given more careful scrutiny.

The completion of Z. J. Bilek's thesis with comparisons of measured K_{Ic}, K_{Id} and K_{ID} is timely and important. The experimental measurements of K versus strain rate and temperature were compared to theories that relate K_{Ic} to the stress/strain characteristics of the solid; no single theory explains the experimental measurements over the range of variables tested.

Outline of Work in Progress during Period October 74 - October 75

1. Modification of the electronics used to record the crack length versus time in rapidly wedged double cantilevered beam specimens. The crack recording system is now applicable to large specimens and fast crack velocities.

2. The analysis of arm breaking during fast fracture.

3. Measurements of K_{ID} for specimens with different crack widths to establish plane strain conditions for fast crack propagation. Dynamic plane strain conditions are less stringent than static relations.

4. The testing of fracture specimens from Battelle Columbus (George Hahn) and an exchange of experimental data.

5. Construction of a double torsion attachment for crack propagation in polymers.

Details of Current Research

i) The critical stress intensity factor during crack propagation, $K_{ID}(\dot{\ell})$ was measured in 1018-CR steel. The rapid wedge loading technique used in this laboratory for recording K_{ID} versus crack velocity is unique in that the crack velocity continuously changes during crack propagation. A substantial effort was expended in checking the reproducibility of the data recorded. This work has been completed. The time for the fracture to completely break the specimen is reproducible from test to test -- provided the specimen completely fractures. The measurement of crack length versus time has been improved by using radio frequency (RF) electro-potential techniques. RF technique specifies the skin depth during crack propagation eliminating an arbitrariness present in the D.C. current technique. The RF voltage signal is also easier to process to reduce spurious noise in the voltage (crack length) versus time records. In simple beam analysis of fracture it is assumed that the beam is built-in at the crack tip, thus the strain energy beyond the tip of the crack is neglected. In more complicated beam analysis the assumption that the beam is built-in at the crack tip is eliminated. A simple geometrical relation depending on the ratio of the crack length to the beam height is used to give the proper stress intensity factor when the crack length is comparable to the beam height. Thus, K_{ID} can be measured for early crack propagation where the crack velocity is the largest.

About 1/3 of our test specimens failed by breaking off one of the double cantilevered beam arms before the crack completely fractured the specimen. The source of this experimental difficulty is a compression wave generated at the load end of the specimen and reflected from the bottom of the specimen as a tensile wave. The interaction of the tensile wave with the crack causes one or both arms of the DCB specimen to break.

The measured K_{ID} for specimens fractured at temperatures well below the brittle to ductile transition temperature shows that K_{ID} is decreasing with increasing crack velocity.

(Staff: C. Chow and S. J. Burns)

ii) Crack propagation in double torsion beam specimens was analyzed for constant deflection rate loading. Slow crack propagation has been extensively studied in double torsion beam specimens. The mechanics analysis necessary to interpret the rapid crack propagation region was not available. The analysis of the double torsional beam specimen proves that constant deflection rate loasing is identical to constant torque loading. Experimentally it was known that constant rate loading gave constant slow crack velocifies and constant applied torque in double torsion beam specimens. The analysis predicts all of these features. Its main value, however, is that it establishes that by applying one boundary condition, i.e. the deflection rate, and measuring the other boundary condition, i.e. the applied torque, that K_{ID} can be calculated without measuring the length of the crack as a function of time. The beam analysis for double torsion specimens is analytically tractable, in a simple form, since the motion of a torsional beam is a second order differential equation. The fraction criteria in this paper will be controversial since the kinetic energy less the strain energy appears in the fracture criteria. The solutions for fast crack propagation reduce to the static relations for slow propagating cracks in the limit when the crack velocity is much less than the velocity of torsional waves.

(Staff: S. J. Burns)

iii) Strain-rate effects in fracture can be studied for crack initiation or crack propagation. The two effects are probably well correlated but differ since the plastic zone for initiating crack is dissimilar from the plastic zone for a propagating crack. A comparison of measured critical stress intensity factors for crack initiation and crack propagation permits the more complicated crack propagation data to be placed in better perspective Z. J. Bilek's thesis which is now being typed compares the propagation data to the initiation data over a wide range of brittle temperatures.

(Staff: S. J. Burns)

Oral Presentations:

S. J. Burns, "Rapidly Wedged Double Cantilevered Beam Specimens", ASTM, March, 1975.

S. J. Burns, "Metallurgical Aspects of Fracture", Session Chairman, Gordon Conference, June, 1975.

S. J. Burns, "Crack Propagation in Rapidly Wedged Double Cantilevered Beam Specimens", October, 1975, Society of Engineering Science.

Technical Reports and Articles:

COO-2422-02, "Crack Propagation in Rapidly Wedged Double Cantilevered Beam Specimens", Proceedings of Society of Engineering Science, p. 121, Vol. 12, October 1975.

COO-2422-03, "Crack Propagation in Double Torsion Beam Specimens -- Constant Deflection Rate", submitted to Journal of Applied Mechanics.

COO-2422-04, Technical Progress Report, October, 1975.

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2. Renewal Proposal (4 cys)
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