SMIRT 4 San Francisco Aug. 15-19, 1977

Comments on Fracture Toughness of Structural Steels

G. R. Irwin, Dept. of Mech. Eng., Univ. of Maryland

Paper G3/1

Abstract

The comments given here deal primarily with two basic ideas for representation of fracture toughness of structural steels. One of these is the minimum toughness concept. The other idea is the representation of crack extension as a function of crack growth, usually termed an R-curve.

In the 1960-1965 time period it seemed probable that, in addition to plane-strain at the crack front, conditions of rapid loading and of crack arrest would result in a similar minimum resistance to crack extension for a structural steel at given temperature (1). Subsequent investigations suggest that the loading time necessary to achieve a minimum plane-strain initiation toughness decreases with increase of test temperature (2). The temperature regime in which this behavior has been shown is generally less than the NDT temperature. At test temperatures above that temperature, toughness increases rapidly, the specimen size necessary for plane-strain becomes inconvenient, and feasible loading times for evaluation of rapid-load initiation toughness tend to increase with specimen size. On general grounds, it seems plausible that crack arrest measurement of toughness might drop below rapid-load K_{Ic} values in a temperature range adjacent to and above the NDT temperature.

It seems useful to divide the fracture test temperature range into three regimes. It is suggested that NDT temperature plus 30 C might be selected as the upper bound of regime I. Regime II would then extend from this temperature to some higher temperature at which cleavage becomes unimportant in a minimum toughness evaluation. Regime III would extend upward in temperature from that point.

Suitable methods for determining the temperature elevation necessary to eliminate significant amounts of cleavage during plane-strain crack propagation deserve careful study. However, at temperatures approaching the operating temperature of light water nuclear reactors, the gradient of yield strength with increase of temperature is relatively small. If we assume this temperature regime is one in which plane-strain fracturing occurs without significant amounts of cleavage, then it is also plausible to expect that increases of strain rate are unlikely to decrease resistance to crack extension. These hypothesized conditions are favorable to toughness evaluations using specimens of moderate size and plasticity methods of fracture characterization. However, determinations of toughness based upon start of crack extension from a starting crack of high sharpness severity (low amplitude fatigue) may be unnecessarily conservative. Indeed the existing evidence suggests that R-curve methods, when properly developed for plane-strain applications, would provide a rational and appropriate basis for estimating crack propagation and crack arrest (3).

At present, fracture mechanics based methods are well established for measurements of minimum fracture toughness up to a temperature moderately above the NDT temperature (regime I). Crack arrest toughness evaluation techniques, which employ crack propagation, have been used and should be available soon in standardized form. These can be used to extend minimum toughness estimates to higher temperatures within regime II. However, application of these methods to material damaged by irradiation is inconvenient in comparison to test methods which use specimens of moderate size and plasticity methods of fracture characterization. Previous comparisons of such methods with large specimen K_{Ic} test results have been conducted in a temperature range in which crack propagation, dominated by cleavage, occurs directly from the starting crack or after a relatively small segment of fibrous crack growth. With increase of test temperature and increase of the initial fibrous crack growth, a substantial R-curve type increase of resistance crack extension seems probable even for conditions limited to plane-strain. Realistic estimates of fracture toughness should, then, attempt evaluation of plane-strain R-curves even though the available specimen size may require a plasticity method of fracture characterization.

It is apparent that the extension of fracture toughness evaluations into the third regime of testing temperature using methods which permit estimates of fracture failure in terms of load and crack size require considerable additional study. Although uncertainty regarding the practical meaning of a Charpy V-notch test shelf value of 68 joules (50 ft. lbs.) provides a stimulus for such additional study, there are other practical motivations. These are related to the fact that fracture behaviors in the regime III temperature range are likely to be encountered in future as well as current hypothesized accidents.

References

(1) G. R. Irwin and A. A. Wells, "A Continuum Mechanics View of Crack Propagation", Met. Reviews, 1965, Vol. 10, No. 38.

(2) P. B. Crosley and E. J. Ripling, "Crack Arrest Toughness of Pressure Vessel Steels", Nucl. Eng. and Design, Vol. 17 (1971), p 32-45.

(3) G. R. Irwin and P. C. Paris, "Elastic-Plastic Crack Tip Characterization in Relation to R-Curves", Fracture, Vol. 1, ICF-4, U. of Waterloo, Canada, 1977.