Fracture Toughness Characterization of Several Aluminum Alloys in Semibrittle Fracture

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A more general definition of fracture toughness, which is appropriate to circumstances of semibrittle fracture in metals, has recently been advanced by the authors [1]. This definition, designated $\tilde{G}_c$, includes Irwin's r_y corrected G_c^* estimates as a limiting case and is a direct consequence of the necessary condition pertaining to slow, stable crack growth (characteristic of semibrittle fracture) as required by the general balance principles of continuum mechanics. Both the elastic and the crack tip plastic enclave strain evergy rates contribute to $\tilde{G}_c$, implying thereby that fracture toughness should be a measure of the total rate of strain energy absorbed at the onset of catastrophic fracture.

By utilizing the fracture toughness load-displacement test record, a compliance type calculation permits direct experimental evaluation of the generalized fracture toughness parameter, $\tilde{G}_c$. This parameter directly incorporates the nonlinear effects arising from slow crack growth and crack front enclave plasticity in the form

$$\tilde{G}_c = \tilde{c} \cdot G_c$$

where G_c is the elastic strain energy rate at onset of crack propagation, and $\tilde{c} \geq 1.0$ is a measure of the nonlinear effects referred to above [2,3]. The lower bound value of $\tilde{G}_c$ is of course G_{Ic} (opening mode, plane strain fracture); i.e., the plane strain fracture toughness corresponding to a $\tilde{c}$ value of unity.

A systematic program of testing has been initiated for the purpose of evaluating $\tilde{G}_c$ values for center-cracked sheet specimens over a range of initial crack sizes and sheet thicknesses. The initial tests have been conducted on aluminum alloys of varying ductility. The results are to be compared with corresponding Irwin G_c^* values (corrected for plastic zone size effects using the Irwin r_y correction). Load-displacement records have been obtained by the usual sheet testing procedures with the exception that, for many of the tests, the displacement is measured from the loading points instead of or in addition to the usual arbitrarily positioned displacement gauge.

From the tests which have been completed thus far, it has been possible to identify certain trends in the values of $\tilde{c}$. For 7075-T6 specimens of 1/16" and 1/8" thicknesses, having initial crack length to specimen width ratios ranging from 1.37 to 1.35 have been obtained. The corresponding fracture toughness values $\tilde{G}_c$ are 22 percent larger than Irwin's r_y corrected G_c^* estimates. For the more ductile 2014-T6 alloy, several test results on 1/16" thick sheet specimens yield $\tilde{c}$ values in the range 1.45-1.50. For these tests the net section stress to yield stress ratios were all in the vicinity of 0.5.

Some additional observations have been made from these

tests as follows:

(1) the position of the displacement measurement apparently makes little difference in the values for c,

(2) initial curvature of the load-displacement record corresponds to the formation of dimples at the notch tip, while further curvature includes the effect of stable crack growth, and

(3) out-of-plane displacements of thin sheet specimens become less of a problem when displacement measurements are taken at the load points.

A further part of this research effort has involved exploring some of the implications of our general definition of fracture toughness in relation to several other proposed methods for characterizing semibrittle fracture toughness such as the J-integral and the crack opening displacement [4,5,6,7].

References

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