Effects of Pulsed Electron Beam Heating on the Fracture Resistance of High-Strength Aluminum

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In this study, we examine the changes in fracture behavior of high-strength aluminum plates (7075-T6) which result from thermal shock loading by a pulsed electron beam. In general, it is found that the stress intensity level for crack initiation is uniformly reduced by electron irradiation over the range of beam conditions investigated; whereas the plane strain fracture resistance parameter (K_c) exhibits a minimum value at intermediate electron dosages.

The electron beam generators(1) developed at the Naval Research Laboratory were utilized in this study to irradiate a 30-cm^2 central area of 30 x 90 cm plate stock, in thicknesses of 0.16, 0.23, and 0.5 cm. The energy fluence of the 50 nanosecond pulse length beam was varied between 30 and 300 calories/cm^2, and the mean energies of the incident electrons ranged between 280 KeV and 1 MeV. This range of beam conditions produced peak doses (or energy densities) of between 100 and 1000 calories/gram within the aluminum targets. After irradiation, transverse slits (1.25-mm radius, T-L orientation) were machined within the exposed region of the plates by an electrical discharge technique. The plates were then tested in tension, and

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(1) NRL Relativistic Beam Program, Record of the 11th Symposium on Electron Beam Technology, Boulder, Colorado, May 1971, 513.

the load and crack growth were measured until fracture. Standard tensile specimens were also machined from the irradiated plate and were tested with the load applied in longitudinal (rolling) direction.

The results of 0.16-cm thick plate tests on both irradiated and control (unirradiated) material are shown in the nominal stress versus crack length plots of Fig. 1. The irradiated plates exhibited considerable metastable crack growth before final rupture and produced pronounced acoustical emissions or pop-in effect on initial and subcritical crack extension. This is in contrast to the control tests which fractured after little crack growth and for which pop-in behavior was not audible. However, the subcritical crack growth of the irradiated plates extended to the boundaries of the exposed material, and the K_c parameters were of the same magnitude as the control tests, Fig. 2a.

For the 0.23- and 0.5-cm gage plates the crack growth behavior was similar to that shown in Fig. 1 except that the crack tip was within the irradiated region when final rupture occurred. In this case the K_c parameter showed an inverse dependence on peak dose, Fig. 2b and 2c. The reduction in K_c is greatest at the low-dose level and decreases as the energy density increases. The depth-dose profile through the plate thickness is determined by the energy fluence and spectrum of the absorbed electrons. The peak doses given in Fig. 2 were estimated from the

electron transport calculations of Spencer(2). Microhardness traverse of the plate thickness showed that the increase of K_c above 100 calories/gram is caused by the annealing of the irradiated material. In all tests of Fig.2, however, the K level for crack initiation is significantly decreased by electron bombardment and is apparently independent of dose.

Comparison of data from standard tensile tests from the irradiated and control materials was in agreement with the center-notched plate results. The decrease in flow strength with increase in dose was due to progressive annealing of the aluminum alloy, whereas the reduction in fracture strain was greatest at the lower dosage. From this minimum level, the fracture strain increased with increased energy density.

The degradation in the fracture resistance of the irradiated plate is caused by the microstructural damage associated with the thermal shock loading. The electrons are dissipated within a shallow depth from the incident surface. Their energy is converted, nearly instantaneously, to thermal energy of the lattice, causing varying degrees of heating, melting, and vaporization. Due to the steep temperature gradients produced in the target, thermal expansion of the heated material is constrained by adjacent material. This results in a nonequilibrium pressure dis-

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(2) Spencer, L. V., "Energy Dissipation of Fast Electrons" NBS Monograph 1, September 1959.

tribution which propagates toward the free surface of the plate and is reflected as a tensile wave. The tranmission and rarefaction of the pressure pulse causes spallation of a thin layer of material from the plate surfaces, typically 0.13-mm thick. Metallographic examination of the irradiated samples also revealed extensive intergranular cracking. These cracks are observed to initiate at second phase particles and to extend in the rolling direction.

It is highly plausible that the intergranular cracks act as highly localized stress intensifiers. Their sequential extension under load causes macrocrack growth at a stress intensity level significantly less than in the virgin material. In this crack growth mechanism, however, the crack driving force, the release of elastic energy with crack extension, is insufficient to sustain propagation across the plate, and the crack proceeds in a metastable, segmented fashion. As the peak dose is increased above 100 calories/gram, material is also removed from the incident face by melting and vaporization. Total reduction of the plate thicknesses are less than 10 percent, except for the 1000 calorie/gram shot. (In this case the plate thickness was reduced by approximately 25 percent.) At the higher dosages, however, the accumulative effects of microcracking and material removal on the fracture resistance, K_c, is negated by the reduction in flow strength through annealing.

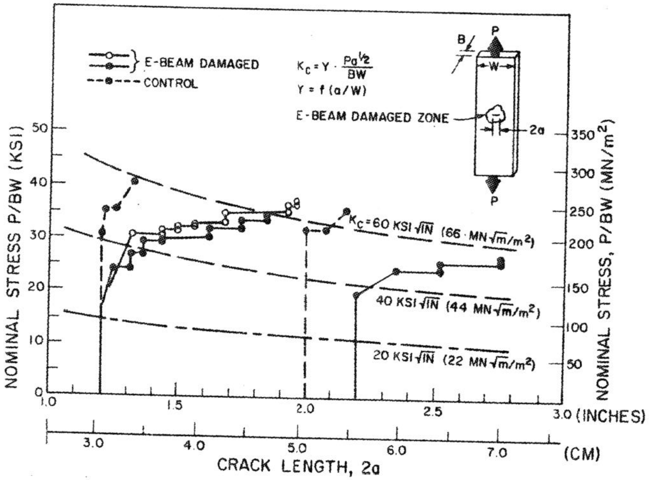

Figure 1 - Comparison of crack growth vs stress plots for center notched plates before & after electron beam heating.

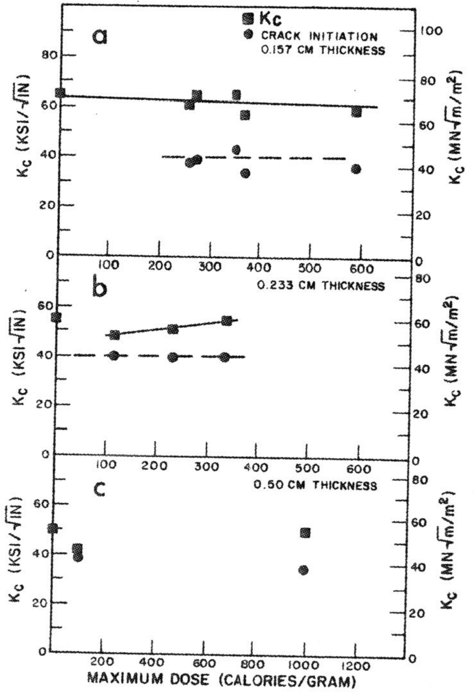

Figure 2 - Change in fracture resistance parameter, K_c, of 7075-T6 aluminum plates with maximum dose.