

this indirect sense of assessing structural integrity that measurements of plane-stress fracture resistance (R-curve and K_{IC} measurements) can be beneficial when applied to structural components in service.

Summary and Conclusions

Specific R-curve results were obtained on two different heats of ASTM A572 Grade 50 steel over the temperature range -40 to +72 F (-40 to +22 C) by using a total of 24 CT specimens. Of this total, 14 specimens had in-plane dimensions corresponding to 2T and 4T specimens and were tested under load-control conditions; the remaining 10 specimens had in-plane dimensions corresponding to 4C and 7C specimens and were tested under displacement-control conditions. Twenty-two (22) of the specimens tested were of a 50-ksi yield-strength A572 Grade 50 steel, and the two (2) remaining specimens were of a 62-ksi yield-strength A572 Grade 50 steel. Both 1.5-inch-thick and 0.5-inch-thick (38 and 12.7 mm) specimens were evaluated from the 50-ksi steel; the two specimens of the 62-ksi steel were both 1.5 inches thick. All specimens were tested under static loading conditions ($\dot{\epsilon} \approx 10^{-5} \text{ sec}^{-1}$). The current study represents the first known attempt to evaluate the R-curve behavior of a high-strength structural steel. The specific results obtained from this pioneer study can be summarized as follows:

1. A steep transition was observed in the plane-stress fracture behavior for the $B = 1.5$ -inch specimens of the 50-ksi steel, with minimum K_{IC} values of 57, 155, and 318 ksi $\sqrt{\text{inch}}$ (63,

171, and 350 $\text{MNm}^{-3/2}$) occurring at temperatures of -40, +40, and +72 F (-40, +4.5, and +22 C), respectively.

2. No significant differences were observed in the K_{IC} behavior of the 50-ksi and 62-ksi A572 Grade 50 steels.

3. Greater overall resistance to fracture was observed for the $B = 0.5$ -inch specimens than for the $B = 1.5$ -inch specimens of the 50-ksi steel, with minimum K_{IC} values of 150, 273, and >380 ksi $\sqrt{\text{inch}}$ (165, 300, and >418 $\text{MNm}^{-3/2}$) occurring at temperatures of -40, +40, and +72 F, respectively. However, this difference in the minimum resistance to fracture for the 0.5- and 1.5-inch-thick specimens is partially the result of differences due to testing method (see conclusions 6 and 7).

4. With the exception of three specimens, the fracture instability for all specimens was catastrophic in nature. The excepted specimens, all tested at +72 F, included a 7C specimen with $B = 1.5$ inches that exceeded testing-machine capacity at $K_{IR} = 477$ ksi $\sqrt{\text{inch}}$ (525 $\text{MNm}^{-3/2}$) and $\Delta a = 0.86$ inch (22 mm), and duplicate 4T specimens that exhibited slow, stable crack extension corresponding to $\Delta a_c \geq 3.50$ inches (≥ 90 mm) at K_{IC} values of >380 and >503 ksi $\sqrt{\text{inch}}$ (418 and 550 $\text{MNm}^{-3/2}$).

5. The repeatability of results for three of four sets of duplicate specimens was within ± 15 percent of the average K_{IC} value measured. The repeatability of results for the fourth set of specimens was within ± 30 percent of the average K_{IC} value measured.

6. The choice of testing procedure (load-control vs displacement-control) was found to influence the results. The K_{IC} values for the 4T specimens tested under load-control conditions were 40 to 80 percent higher than the values for the corresponding 4C specimens tested under displacement-control conditions in direct comparison tests at three different temperatures. This influence of testing procedure was consistent and appears real, but could not be fully verified using statistical analysis procedures.

7. The effects of specimen thickness ($B = 1.5$ inch vs $B = 0.5$ inch) on K_{IC} behavior evaluated in direct comparison tests using only the load-control testing procedure were inconclusive. Results from 2T specimens tested at three different temperatures indicated a consistent influence, while results from 4T specimens tested at similar temperatures were consistent in indicating no influence. Local variations in fracture toughness were apparently large enough to mask the true effects of specimen thickness on K_{IC} behavior.

8. In relation to effects of specimen size, normal plane-stress fracture behavior (increasing K_{IC} values corresponding to increasing values of a_0) was generally obtained with both the load-control and the displacement-control testing methods at all temperatures. However, an inversion in this behavior occurred with each test method at -40 F (-40 C). These departures from expected behavior may be related to inherent variations in the local fracture toughness.

9. The K_c results of the present study were shown to be consistent with earlier K_{Ic} results obtained from tests on the same steel at cryogenic temperatures. The central concept in resolving obvious differences in the corresponding K_c - and K_{Ic} -transition temperatures was the apparent existence of an intermediate K_{Ic} shelf, a behavior supported by the results of each of three different and entirely independent methods of analysis (J-integral K_I -suppression effect and CVN specimen results).

10. For normal stress levels used in design ($\sigma_D = 3/4 \sigma_{ys}$), critical flaw sizes (a_{cr}) for the $B = 1.5$ -inch plate of the 50-ksi A572 Grade 50 steel were shown to be $a_{cr} = 1.80, 5.2, \text{ and } 23.0$ inches (46, 132, and 585 mm) for minimum representative behavior at $-40, +40, \text{ and } +72$ F, respectively.

11. For normal stress levels used in design, the critical flaw sizes for the $B = 0.5$ -inch plate of the 50-ksi A572 Grade 50 steel were shown to be $a_{cr} = 4.0, 16.0, \text{ and } >32.0$ inches (100, 400, and >800 mm) for minimum representative behavior at $-40, +40, \text{ and } +72$ F, respectively.

12. With two exceptions, the total critical flaw size ($2a_{cr}$) for cracks centrally located in a large plate subjected to uniform tension stress were shown to be in excess of seven times the plate thickness, ($2a_{cr} \geq 7B$) for all the 8 different combinations of plate thickness and temperature investigated for the A572 Grade 50 steels.

13. Values of a_{cr} calculated from measurements of plane-stress fracture resistance (R-curve and K_{Ic} measurements) can be applied validly only when the state of stress in the structural application is plane stress, and then only under the assigned material and test conditions (T , $\dot{\epsilon}$, and B). Accordingly, such values would be directly applicable to structures with large planar dimensions (direction of crack propagation), including the web location for large H-beams. Such a_{cr} values would not be directly applicable in confined structural regions, such as in the tension-flange region of H-beams (complete inapplicability) and the web region of H-beams with small web dimensions (indirect applicability of a_{cr} values for assessing the confidence level of structural integrity).

Many of the results above were obtained by using the COS analysis method under state-of-the-art conditions. Because this method of analysis is still undergoing development, the limitations of this technique are not precisely defined. Furthermore, many questions still remain concerning plane-stress fracture generally, even for results obtained under LEFM conditions. Nevertheless, the present studies have been an encouraging first step in the understanding of the plane-stress fracture behavior of A572 Grade 50 steel, and similar medium-strength constructional steels, and of the applicability of plane-stress-fracture data (R-curve and K_{Ic} measurements) to structural components.