Fracture Toughness

INTRODUCTION

ASTM standards E1737 and E1820 specify methods for measurement of plane strain fracture toughness (K_{IC}) of a wide range of metal alloys including ferritic reactor pressure vessel (RPV) materials. P-T curves are calculated using linear elastic fracture mechanics (LEFM) principles to analyze postulated 1/4 thickness (T) flaws in the vessel. Radiation damage is accounted for by using the measured Charpy curve shift, indexed at 30 ft-lbs of absorbed energy, to shift the ASME lower bound reference fracture toughness curve (K_{IR}) to higher temperature, thus closing the P-T window as the plant ages. There is considerable interest within NRC and industry in obtaining the reference fracture toughness curve directly through measurement of the materials in the RPV surveillance capsules. The NRC has funded the development of the "Master Curve" which has been shown to correctly represent the shape of the ASME reference curve. However, application of the Master Curve to a particular plant requires at least six measurements of plane strain fracture toughness at one temperature to adequately define the temperature dependence of K_I. Since conventional fracture toughness testing is performed statically, the loss of constraint is too severe for most plants to obtain valid plane strain fracture toughness using Charpy sized bend bars. The MPM technology overcomes this limitation by using the Charpy test which is performed dynamically and thereby inherently has more constraint due to the dynamic elevation of flow properties. A further advantage is that fracture toughness results can be obtained for all of the surveillance capsule specimens and thus most of the ASME reference curve can be measured directly (not just 6 points at one test temperature).

The Charpy test was not originally developed to yield plane strain fracture toughness data. However, finite element calculations performed by MPM and others has shown that dynamically tested Charpy sized specimens have sufficient constraint to yield plane strain conditions over the lower shelf and most of the transition region. This covers the test temperature range of interest for P-T curve applications. By instrumenting the Charpy test machine striker with strain gages, it is possible to measure the load-deflection curve during the fracture event. A typical Charpy test load deflection curve is shown in the Figure below. Just prior to peak load, a sharp crack forms at the root of the V-notch. This crack propagates in a slow tearing mode until the "brittle fracture load" is reached. At this point in the test, an unstable crack rapidly (~5-20 microseconds) propagates through the material and then arrests at the "crack arrest" load. The remainder of the test energy goes into propagating a ductile crack through the remaining ligament.

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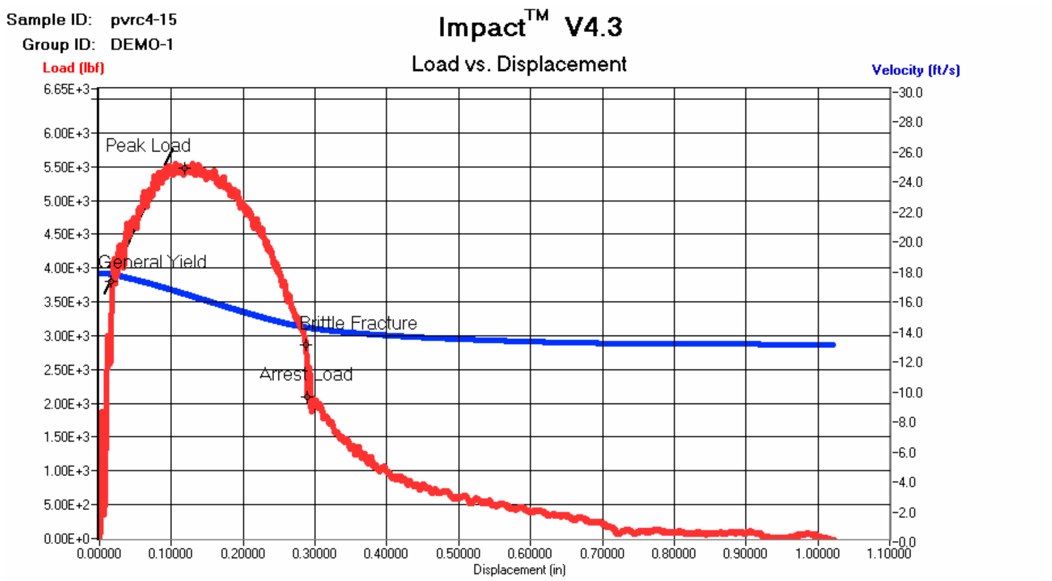
The brittle fracture load/deflection is needed for calculation of the crack initiation toughness and the brittle fracture arrest load/deflection is needed for calculation of the crack arrest toughness. The crack arrest toughness is of prime interest since it has been theoretically and experimentally shown that the crack arrest toughness is the lower bound toughness. We propose to develop a model which uses these critical loads and deflections to obtain plane strain fracture initiation and crack arrest toughness.

The first phase of work will focus on the development of the finite element solutions needed to obtain a closed form expression for calculation of toughness. If analytical expressions are too difficult to obtain, then a special purpose finite element program will be developed to calculate fracture toughness directly. The fracture toughness determined from the instrumented Charpy test will be compared with fracture toughness data reported in the literature.



	Load (lbf)	Displacement (in)	Velocity (ft/s)	Time (s)	Energy (ft lbf)
General Yield	3.8051E+3	1.563E-2	1.787E+1	6.790E-5	2.21300E+0
Peak Load	5.4770E+3	1.186E-1	1.657E+1	5.650E-4	4.43900E+1
Brittle Fracture	2.8591E+3	2.873E-1	1.432E+1	1.482E-3	1.09700E+2
Arrest Load	2.1026E+3	2.896E-1	1.430E+1	1.495E-3	1.10100E+2
End of Signal	0.0000E+0	1.021E+0	1.318E+1	6.037E-3	1.39000E+2

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