IT WAS NOTED in Chapter 3 that elongation and reduction in area from the tensile test are broad indicators of ductility for certain purposes, but that there are no consistent and reliable correlations between these properties and the more definitive toughness parameters, including notch toughness, tear resistance, and fracture toughness. One illustration of this was the rather broad relationship between elongation and unit propagation energy in Fig. 6.7; it is further illustrated in Fig. 8.1, showing notch-yield ratio against both elongation and reduction in area from a series of tests in which each were measured for the same lots (Ref 19). Again, both show a broad correlation, but not of tightness adequate for correlative purposes.

On the other hand, there are fairly well-defined and useful correlations between both notch-yield ratio (NYR) and unit propagation energy (UPE).
and the fracture-toughness parameters, $K_c$ and $K_{ic}$ (Ref 1, 24, 36, 37). For example, NYR and UPE correlate well with $K_c$ from the same lots of material, as illustrated in Fig. 8.2 and 8.3. The relationship between UPE and $K_{ic}$ has been refined over the years for predictive purposes, as illustrated in Fig. 8.4; this relationship is sufficiently well defined that in situations where fully valid $K_{ic}$ values cannot be determined or when the greater expense of the more complicated tests must be avoided, tear test results can be used to estimate plane-strain fracture toughness values.

**Fig. 8.2** Critical stress-intensity factor, $K_c$ vs. notch-yield ratio (edge-notched specimen) for aluminum alloy and plate. EN, edge notched, Fig. A1.5; CC, center cracked, Fig. A1.6. Notch-yield ratio is notch tensile strength/tensile yield strength.

**Fig. 8.3** $K_c$ and $K_{ic}$ for 1 in. thick panels (Fig. A1.9b) vs. unit propagation energy from tear tests for aluminum alloy plates
These correlations are not surprising since the notch tensile, tear, and fracture toughness tests were all designed to measure the same material behavior from different perspectives: the ability to resist crack development and/or growth by plastic deformation at the site of severe stress raisers, including preexisting cracks. The fracture toughness test permits a calculation of the amount of stored elastic strain energy required to produce unstable crack growth. The tear test is a direct measurement of the external energy that is required to produce the crack growth; this is most useful when the energy is normalized based on crack growth area, as with the UPE.

Thus, while the fracture toughness test has the limitation that the specimens must be large enough to provide plane-strain conditions and enough recoverable elastic strain energy to produce unstable crack growth in an elastic stress field (a severe limitation for tough aluminum alloys, requiring massive specimens, if, indeed, the condition can ever be achieved), the tear test is limited only by the capacity of the source of external loading. Therefore, the tear test has been quite useful in screening tests for alloy development (Ref 19, 37), which is discussed in more detail in Chapter 11. In addition, it can even be used by extrapolation to estimate the fracture toughness of those materials that could rarely, if ever, be measured in a manner meeting all validity requirements.

Additional use has been made of these correlations through the use of notch-tensile testing as quality control for fracture toughness for those alloys where fracture toughness values are included in purchase specifications, as illustrated in Fig. 8.5 and 8.6 for 2124-T851 and 7475-T7351, respectively (Ref 60). In these cases, the relatively less-expensive notch-tensile test is sometimes used in plant production testing and fracture

![Fig. 8.4](image_url) Relationship between plane-strain fracture toughness and unit propagation energy from tear tests for aluminum alloy products
toughness testing is used only for those lots for which meeting the appropriate specifications is in doubt. At higher toughness levels especially, the correlation is weaker and the amount of retesting required by this approach may be unacceptable.

Several other interesting relationships have been observed (Ref 2, 19) that enable the results of notch-tensile and tear tests to be used to estimate behavior under dynamic/fatigue loading:

- The relationship between the NYR and the ratio of notch-fatigue strength to the tensile yield strength appears useful for estimating fatigue life in the presence of notches from notch-tensile tests, as

Fig. 8.5 Correlation of plane-strain fracture toughness and notch-yield ratio (specimens per Fig. A1.7a) for 2024 and 2124 plate

Fig. 8.6 Correlation of plane-strain fracture toughness with notch-yield ratio (specimens per Fig. A1.7a) for 7075 and 7475 plate
illustrated in Fig. 8.7. In this illustration, the notch fatigue strengths are for sharply notched rotating beam fatigue specimens. The value of this relationship can be rationalized on the basis that both tests measure in different ways the ability of materials to resist crack initiation and propagation in the presence of severe stress raisers.

- The relationship between tear resistance, as measured by UPE, and fatigue-crack growth rate is sufficiently well defined, as in Fig. 8.8, to potentially be useful for estimating the growth rate in terms of
stress-intensity factor in cases where fatigue-crack growth rate measurements are not available.

For the record, there does not appear to be any relationship between any measures of fracture toughness and resistance to stress-corrosion cracking (Ref 2, 19). This is well illustrated by looking at the relationship between plane-strain fracture toughness, $K_{IC}$, and the threshold stress-intensity factor for the initiation of stress-corrosion crack growth from tests of pre-cracked specimens, $K_{ith}$, in Fig. 8.9.

![Fig. 8.9](image-url)  
**Fig. 8.9** Comparison of fracture toughness and stress-corrosion resistance for some aluminum alloys. Stress-corrosion data are from ring-loaded 1/2 to 3/4 in. thick specimens in salt dichromate acetate-corrodent formula: 0.6M (31/2%) NaCl + 0.02M Na$_2$Cr$_2$O$_7$ + 0.07M NaC$_2$H$_3$O$_2$ at a pH of 4. $K_{ith}$, threshold stress intensity for stress-corrosion crack growth. $K_Q$, candidate value of $K_{IC}$, invalid in instance shown.