2.3 Residual Strength Methodology

The strength of a structure can be significantly affected by the presence of a crack and is usually substantially lower than the strength of the undamaged structure. To prevent catastrophic failure, one must evaluate the load carrying capacity that will exist in the potentially cracked structure throughout its expected service life. The load carrying capacity of a cracked structure is the residual strength of that structure and it is a function of material toughness, crack size, crack geometry and structural configuration.

The determination of residual strength for uncracked structures is straightforward because the ultimate strength of the material is the residual strength. A crack in a structure causes a high stress concentration resulting in a reduced residual strength. When the load on the structure exceeds a certain limit, the crack will extend. The crack extension may become immediately unstable and the crack may propagate in a fast uncontrollable manner causing complete fracture of the component.

In general, unstable crack propagation results in fracture of the component. Hence, unstable crack growth is what determines the residual strength. In order to estimate the residual strength of a structure, a thorough understanding of the crack growth behavior is needed. Also, the point at which the crack growth becomes unstable must be defined and this necessitates the need for a failure criterion. There are several criteria available; these criteria are tailored to represent the ability of a material to resist failure.

A material's toughness depends on thickness. When the thickness is such that the crack tip plastic zone size is on the order of the plate thickness, the toughness reaches a maximum value, $K_{c(max)}$. With increasing thickness of the plate, the plastic zone size reduces and thus the toughness gradually decreases, from $K_{c(max)}$ to K_{Ic}. When the thickness is large enough that the crack tip deformation is not affected by the thickness, plane strain conditions prevail at the crack tip. The toughness in the plane strain regime is virtually independent of thickness. For increasing thickness, the toughness asymptotically approaches the plane strain fracture toughness, K_{Ic}.

The critical K_{cr} for abrupt fracture mode is denoted as K_{Ic} for plane strain conditions and K_c for plane stress conditions; the conditions for plane stress or plane strain are determined by experiment. The test requirements necessary for generating K_{Ic} and K_c are discussed in Section 7.

When the crack extends by a tearing mode of fracture, which typically occurs in thin metal sheets or in tough materials, the crack extension is essentially slow and stable. The failure condition for tearing fractures depends on the crack growth resistance (K_R) behavior of the material and the applied stress-intensity factor K, which in turn depends on the crack and structural configurations.

The crack growth resistance curve (K_R) has shown good promise for materials where limited (small-scale) yielding occurs in front of the crack tip. Difficulties in estimating crack tip plasticity under large-scale yielding conditions, led Wilhem [1974] to an alternate failure criterion based on the *J*-integral [Rice, 1968]. For a basic introduction to the *J*-integral see Section 11.

An important element in the process of predicting residual strength of a structure experiencing ductile tearing is having a criterion that predicts the onset and rate of this phenomenon. Tests and numerical simulations have been performed to assess the critical crack tip opening angle ($CTOA_c$) criterion for predicting residual strength of structures containing MSD. Section 4 section details the theoretical background behind the $CTOA_c$ criterion, and describes experimental and computational investigations into it.