FRACTURE MECHANICS ANALYSIS OF WELD PIPES

Sergio Curioni, Alessandro Freddi

Dipartimento D.I.E.M. - Facoltà di Ingegneria
Università di Bologna
Via Risorgimento, 2 - BOLOGNA (ITALY) c.p. 40136
tel. 051-6443454 - telex 520620 ING.BO (I)

1.- Introduction

Weldments are locations with a higher probability of cracks or crack-like defects and also if international regulations focus their attention on flaws avoidance, it is necessary a better understanding of fracture toughness in welded structures. The important factor for material fracture are well-known: a complex stress-state, internal stress raisers, low temperatures, environment conditions, high velocity loading.

There is today a great demand for welding technologies and the safe operation of a component depends on the successful design and construction of a large number of welded joints. Due to the large volume of welding involved, the difficulty of joints realization and the arduous operating conditions, it is suitable foresee the occurrence of defects during the service life of components. The safety analysis of a structure must guaranty the integrity even if a crack is present; this can be done by the application of fracture mechanics concepts to welded structures.

The weldments are characterized by material disomogeneity and by a complex stress state condition; therefore a comparison of the applied load with a convenient material parameter is necessary.

In this paper after an evaluation of fracture elastic-plastic mechanics concept and the application in welded structures where the residual stresses are significant, the tearing instability modulus is utilized for different weld pipes procedures.

2.- Fracture mechanics

Due to the great differences in material parameters and residual stresses in welded joints in comparison with the base metal, there are some problems to predict the behavior of welded constructions; it is necessary utilize very carefully the usual fracture mechanics philosophy and a lot of research are in progress to evaluate the applicability of existing failure assessment concepts.

To characterize a welded joints it is possible utilize different factors:

-conventional parameters (as f.e. Charpy impact test data);

-fracture mechanics parameters (critical value of K, CTOD, plastic radius r_y, J-integral, J-resistance curve, tearing instability approach);

-microstructural parameters (utilizing theories for cleavage strength and void growth).

A Charpy test is much less expensive to perform than a fracture test, but the results obtained with non-instrumented hammer have not been successfully also if some correlations have been written between K_{IC} and CVN. In the instrumented impact test, transducers are attached to the hammer so it is possible measure instantaneous values of different parameters (force, deformation, energy, etc.). Are now in progress some tests utilizing this methodology to compare the results obtained with different experimental procedures.

In elastic-plastic analysis has been proposed different tip parameters to find an adequate replacement of the linear elastic stress intensity factor. From these parameters J seems to be the most promising although for fracture of reals metals there is not a rigorous interpretation of J. It is necessary to research a rational pathway through the degree of plasticity near the crack tip, geometric effects of specimen and work hardening of material, to avoid that fracture studies are a collection of unrelated tests without any rightness methodology. The advantage of J analysis is to use a simple one parameter model and to develop an easy methods for relating fracture data to design application.

As known, J is a "path-independent" parameter and will have the same value for all integration curves Γ. This result is correct for linear elastic material behavior and may be generalized to non-linear elastic-plastic material where, if a proportional loading exists, deformation plasticity and incremental plasticity are equivalent. We suppose that the stress system varies but little with deformation and a single parameter representing stress field intensity is adequate to characterize crack tip field.

If the crack propagation in some materials is insensity to stress triaxiality, then J (or other single parameter) will be an adequate fracture factor; if the mode of separation depend from the stress triaxiality, a single parameter is inadequate to characterize a material.

In conclusion, there still exists a large degree of uncertainty about the possibility to use a single parameter to describe the fracture mechanics answer for a variety of configuration in which the stress field alters with deformation degree. At the present stage of elastic-plastic fracture mechanics, the J-based theory seems to be the more convenient and useful engineering tool to investigate structural answer of a component.

The fracture of a structure can result from a combination of mechanical stresses, chemical influences and heat treatment; inspecting the macroscopic fracture cross-sections it is possible evaluate the type of crack propagation (transcrystalline or intercrystalline fashion) and acquire some information about the fracture mechanism. Also if many laboratories are working in this field, it is not yet found a correlation between the fracture toughness of a material and the microstructural parameters.

3.- Residual stresses

Residual stresses are usually present in a weld zone due to two mechanism:
- material solid state phase transformation with volume change;
- temperature gradients with shrinkage effect.

In a butt weld there is a tensile residual stress of considerable magnitude parallel to the weld in its near neighborhood and a compressive stress away from the weld.
Utilizing the J factor

$$J_{Ie} = J_{Ia} + J_{Ir}$$

where J_{Ia} is due to load applied to the structure and J_{Ir} depends from residual stresses field; if residual stresses were ignored the estimate critical crack length a_c might be in error on the nonconservative side.
The simulation of the thermomechanical process in welding is not easy to investigate for the different disciplines involved in the process (heat transfer mechanism, thermal stresses, material properties in the temperature interval considered); an evaluation of numerical and analytical systems is done to have an idea of the approximation achieved by different methods.

4.- J_{mat} evaluation

For tested material (welds zone and base material) the J-Δa curve has been drawn and different criteria have been used to obtain the J_{mat} values; the results obtained depend strongly from the criteria utilized as shown in figures. In this condition may be interesting apply a different approach method to take into account not only the material critical parameter but also the structural response to a crack.

5.- Tearing instability modulus

In current nonlinear fracture mechanics applications is remarkable the tearing modulus concept; in this model fracture instability results from a lack of balance between the rate of increase of the externally applied crack drive force and that of the material resistance to crack growth. To take into account such process, the resistance curve concept is necessary (and some means for accurately determining its slope) and J value for cracked structure at load conditions. Fracture instability occurs when

$$(dJ/da)_{app} > (dJ/da)_{mat}$$

The tearing modulus offers a convenient approach to evaluate the increase in load structure capacity as a function of small amount of crack growth permitted in ductile materials.
In this paper an engineering approach has been utilized to determine the driving force in CT-1 fracture specimen and a comparison has been done with experimental results obtained for weld and base material.