A Fracture Driving Force and Failure Assessment Curve Analysis for Weldment with Mechanical Heterogeneity

M.Zhang Y.W.Shi J.Q.Fu J.X.Zhang

Department of Mechanical Engineering Xi'an Jiaotong University
Xi'an ShaanXi Province ,The People's Republic of China(710049)

Abstract

The purpose of this paper is to study the effects of material mis-matching on welded joints behavior, based upon the J-domination and the ideals of the conception of CEGB-R6, the J-integral of weldments which the strain hardens described by a simple power law is computed by elasto-plastic finite element method. The results show that the yield strength and the strain hardening exponent of base materials has an obvious effects on the crack driving force and the failure assessment curve(FAC) of weldments .To assess a weldment structure which contains defect in welding, the mis-matched of materials property should be taken into account by using J-estimation schemes and R6 procedure.

Key Words:

Weldment, J-integral, Failure assessment curve, R6 procedure, Fracture driving force.

Introduction

It is well know, welded structures are widely used in important engineering structure such as boiler, pressure vessels, off-shore structures and naval vessels, A complex thermal-treatment in welding process, weldments are more sensitive parts of a structure with regard to crack growth and failure because of the defects and the inherence characteristics. So it is necessary to establish and use acceptance criteria in order to judge the imperfections of welded structure.

A lot of weld and method has been done to evaluate the driving force and to assess the integrity of structure containing defects, which are the crack tip opening displacement design curve approach, the EPRI/GE J-estimation approach and the CEGB/H/R/R6 failure assessment route(Milne et al., 1988). In present, the third revision of CEGB/R/H/R6 has been publish and three options are given for describing the failure assessment curve in it. The option 3 curve is based directly on the equivalence of the FAC to a J-integral which is analyzed by finite element method.

For option 2 curves, the FAC was developed by reference stress method. The FAC of option 1 was chosen as an empirical fit to several materials which are used widely in engineering structure but biased towards the lower and safety bound. As a new method, R6-revision 3 which derived from COD and EPRI can analyze the course of crack from extension to fracture in structure.

No matter what approaches, the assessment of the severity of defect in structural component can be broken down into two separate tasks: determination of single-valued fracture parameters of crack growth resistance curve: and damnation of crack driving force in the component under consideration. For instance, the concept of former is similar to choose FAC and the later is to calculate Kr to assess defect with CEGB/R6 procedure.

In previous work, it has been proved that these approach is appropriate to assess cracked structure which the material is homogenous, but it is quite difficult to analysis the fracture behavior of cracked components for welded structure because of the inherent characteristic of the weldments(Zhang, 1988. Schwable, 1993; Finch, 1992). The mechanical heterogeneity of weldment effects not only the fracture toughness of weldment but also and load point displacement. It has found also that the mis-matched of weldment geometry and material has an obvious effect to toughness(Denys, 1988), crack driving force (Harrison and Anderson, 1988).

The objective of this paper is to extend knowledge of the influence of mis-matching on the driving force and failure assessment curve of overall welded joints performance and to indicate the safety margin of reliable to assess weld structure for substituting weldment instead of base material or weld material for CEGB/R/H/R6 approach.

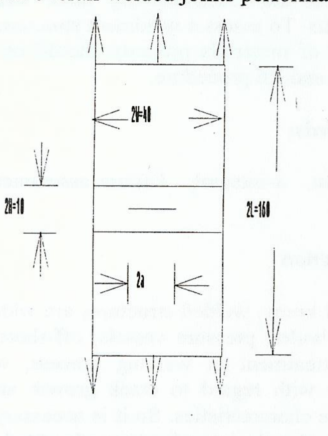


Fig.1 Dimensions of the tensile panels containing transfer mis-matched welds

Properties of materials and computation approach

Finite element procedure

All data used in augmenting and validating for the estimation equations were generated using the finite element method. The specimens were modeled as two dimensional center cracked geometric for panel in plane strain condition. In the finite element analysis, it was assumed that the weldment consist of both base metal and weld metal behaving in simple tension according to the pure power hardening law and the stress strain of both weld and base metal take the following form:

$$\varepsilon/\varepsilon_0 = \alpha(\sigma/\sigma_0) \qquad \varepsilon \le \varepsilon_0$$
$$\varepsilon/\varepsilon_0 = \alpha(\sigma/\sigma_0)^n \qquad \varepsilon > \varepsilon_0 \qquad (1)$$

Where ε, σ was the strain and stress, and σ_0, ε_0 were the yielding stress and yielding strain ways the strain hardening exponent.

Symmetry conditions enable the modeling of one-fourth of the specimen which has an aspect of and 2, the meshes consist of eight-node isoparametric elements and the crack tip has a finite curvature $\rho = 0.004mm$.

Materials parameters being used in the analysis were given as fallow:

(1)For the mis-matching of yielding strength:

base metal:

$$\sigma_{yb} = 300,350,400,450,500,550,600,650,700(\text{MPa}),\ \ n_b = 10,\ \ \alpha = 1.0$$

welded metal:

$$\sigma_{yw} = 500(\text{MPa}),\ \ n_w = 10,\ \ \alpha = 1.0$$

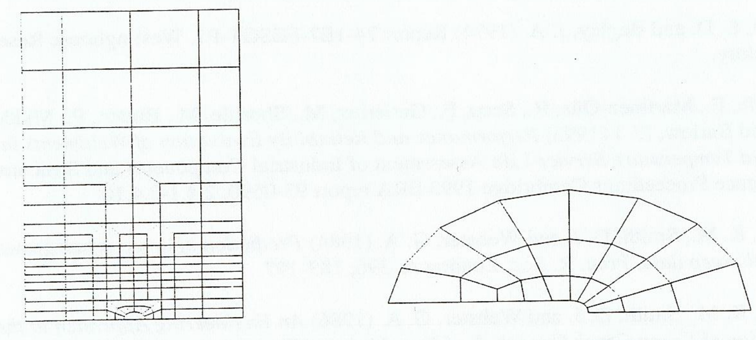
(2)For the mis-matching of strain hardening exponent:

base meal:

$$\sigma_{yb} = 500(\text{MPa}),\ \ n_b = 6,7,8,9,11,12,14,16,20.\ \ \alpha = 1.0$$

welded metal:

$$\sigma_{yw} = 500(\text{MPa}),\ \ n_w = 10,\ \ \alpha = 1.0$$



(a) Mesh arrangement *(b) Detailed view around the crack tip*

Fig.2 Typical of finite element mesh for calculation for a/W=0.5.

Selection of the failure assessment curves

The option 3 curve is based directly on the equivalence of the failure assessment curve to a J-integral finite element analysis. It has the potential for greater accuracy than the approximate curves of option 1 and 2. The result of option 3 is:

$$f(L_r) = (J/J_e)^{-1/2} \qquad (2)$$

The parameter Lr is diffident as the ratio of loading condition: $L_r = P/P_0$, and in this formulation, P is the total applied load, P0 is the plastic yield load of the flawed structure, for the crack geometrical the fig. 1, the P0 was given by reference of Miller

(Miller, 1988): $P_0 = k \cdot \sigma_0 \cdot (2W - 2a)$. J and Je are the values of the J-integral obtained for an elastic-plastic analysis and an elastic analysis respectively for same load.

Results of crack driving force

The effect of strength and strain hardening exponent of base material on fracture driving force of welded joints is shown in Fig.3 and 4. For the same weld metal, the driving force curves of weldment with lower strength of base material lies above that the base metal yield strength is higher (Fig.3),and the greater the base metal strain hardening exponent is, the bigger the fracture driving force of weldment should be(fig.4)

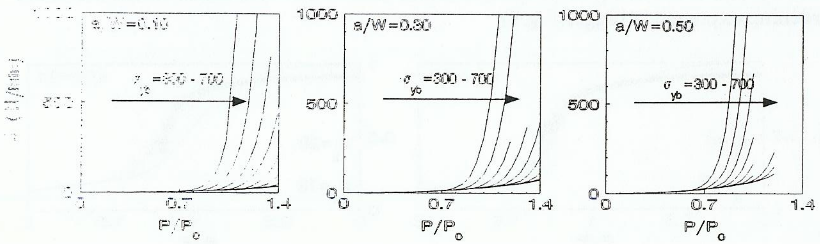


Fig.3 J-integral vs. load for different σ_{yb} *of weldment*

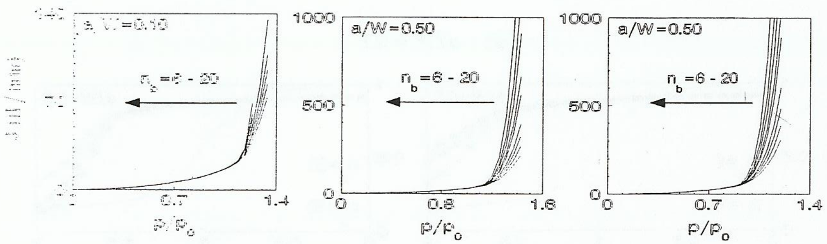
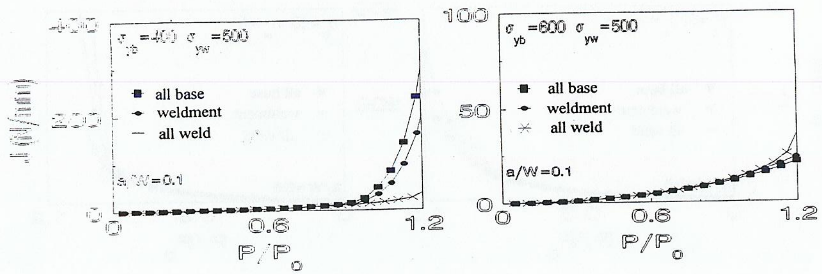


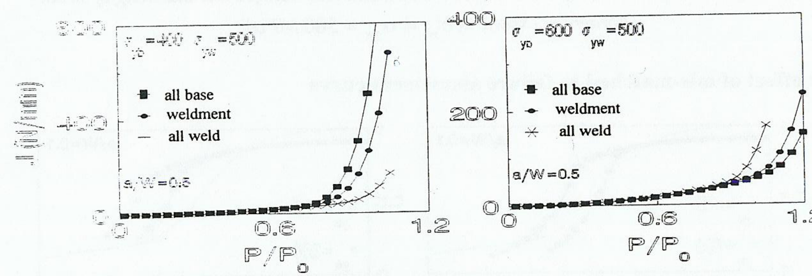
Fig.4 J-integral vs. load for different n_b *of weldment*

To give a direct illustration ,the analysis and comparison of the value of driving force for weldment with the result deriving from its all-base and all-weld metal have been made in Fig.5.

It should be found that, for the case of ratio a/w=0.1 and 0.5, the curve of driving force J verse load P/Po of weldment is situated between the computation curve of all-weld and all-base metal. On the same load level, the driving force changes smaller with the order material yield strength is lower what that weld metal).Compared with all-weld metal, the driving force of weldment are more coincident with all-base material, previously deformation of base material render the weld joints property come close to base material. On the contrary, in the case of under-matched weldment, the driving force obtaining from the property of all-weld metal is the biggest among the three results of the finite element computation. So it may be unsafety to substitute the driving force of weldment with its all-base material for under-matching condition.



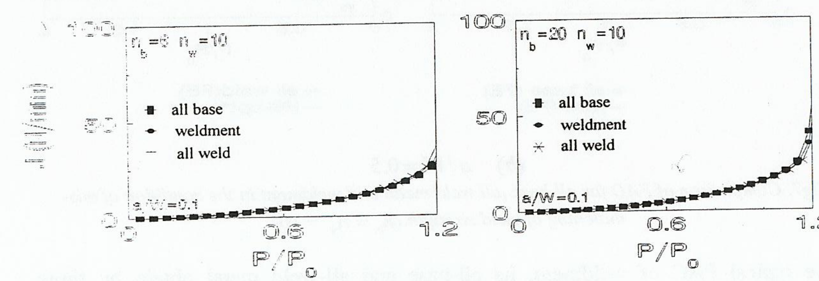
(*a*) $a/W = 0.1$



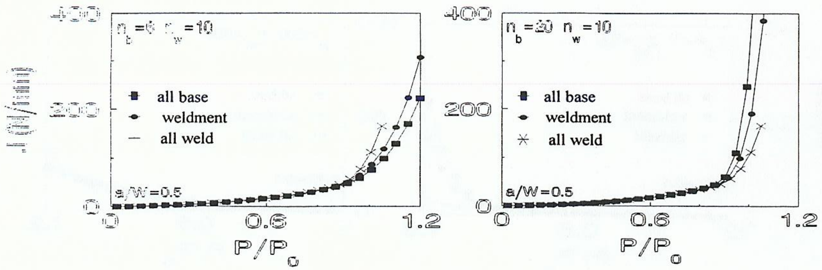
(*b*) $a/W = 0.5$

Fig5. Comparison of J vs. load for all base ,all weld metal and weldment for mis-matching of yields strength.($n_b = n_w = 10$)

Figure 6 illustrates the distinguish between weldment and homogeneity for mis-matched exponent. It can be seen that the effect of hardening exponent on fracture driving force is not evident as the mis-matching of yield strength. For all sorts of cracked geometric ratio of a/W, the driving force of welded joints is always between that of the all-weld and all-base metal for all mis-matched joints . In general terms ,to assess the weldment substitute material properties with its all-weld or all-base metal which the strain hardening exponent is bigger should obtain a conservative conclusion.



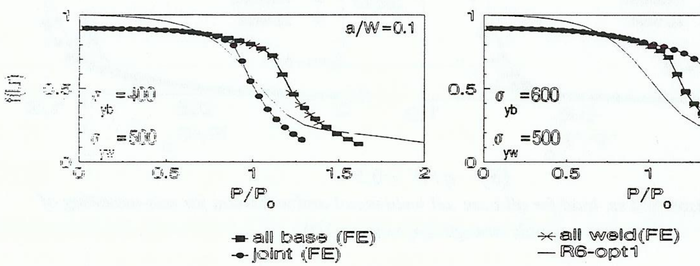
(*a*) $a/W = 0.1$



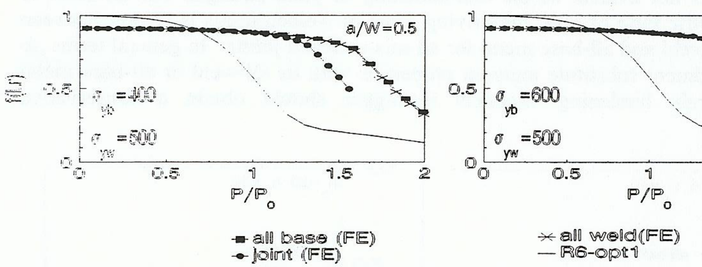
(*b*) $a/W = 0.5$

Fig.6 Comparison of J vs. load for all base ,all weld metal and weld for mis-matching of strain hardening exponent($\sigma_{yb} = \sigma_{yw} = 500\,MPa$)

The effect of mis-matched to failure assessment curve



(*a*) $a/W = 0.1$

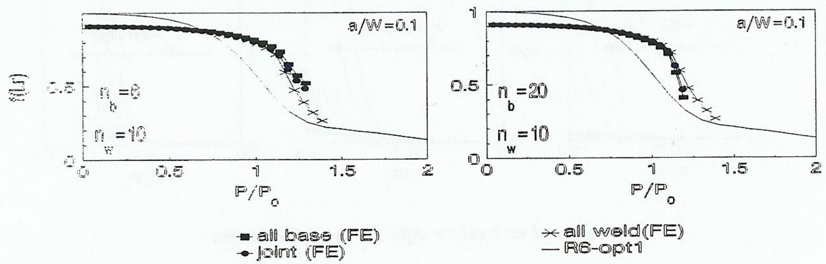


(*b*) $a/W = 0.5$

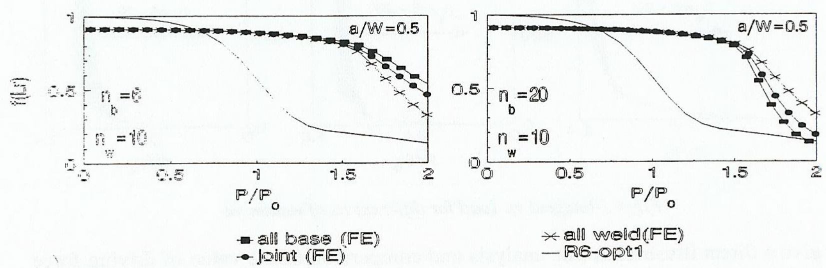
Fig7. Comparison of FAD for all base ,all weld metal and weldment in the condition of mis-matching of yield strength.($n_b = n_w = 10$)

Some typical FAC of weldment, its all-base and all-weld metal obtain by finite elements are compared in Fig.7 and 8. From Fig.7, the FAC of weldment is always under the FAC calculated by all-base and all-weld metal for over-matching condition. For under-matched weldment, the FAC of weldment tuned up to above the FAC of all-base and all-weld metal. With the increasing of normalized load P/P$_0$, the difference between weldment and its all-base or all-weld metal become large for any mis-matching of yield strength of weldments. One important rules could find from Fig.7 that, when the materials is homogeneous and the strain hardening exponent is in the same, it almost has little difference to its FAC. So it illustrated that weldments behavior is not a sample average of yield strength and strain hardening exponent over all-base metal and all-weld metal.

The FAC of weldment is always between the FAC of all-base and all-weld metal for any mis-matching of strain hardening exponent. The bigger the strain hardening exponent is, the less the safety margin of FAC will be. So it is conservative to assess welded joints substituting its property with all-base or all-weld metal which the strain hardening exponent is bigger(Fig.8).



(*a*) $a/W = 0.1$



(*b*) $a/W = 0.5$

Fig.8 Comparison of FAD for weldment ,all base and all weld metal in the condition of mis-matching of strain hardening exponent.($\sigma_{yw} = \sigma_{yb} = 500\,MPa$)

Summary and conclusion

In this article a brief view of the effects of mis-matching of welded joints to fracture driving force and failure assessment was given. From the point of engineering treatment view, being aimed at mis-matching of yield strength, substituting over-matched weldment with its all-base material is safety to compute fracture driving force but not conservation to calculate the FAC, much further work is need in this area. For under-matching of weldments, superseding the weldment by its all-weld metal properties to get the driving force and FAD can obtain a conservative estimation for cracked structure.

If the strain hardening exponent of base and weld metal to weldment is not equalization, it should be conservative to estimate the driving force and FAC substituting weldment with its all-base or all-weld metal which the strain hardening exponent is bigger in engineering practice.

Acknowledgment:

The authors gratefully thanks the financial support from National Natural Science Foundation of China.

References

Denys R.M., 1988, The significance of CTOD in transversely loaded weldments with weld metal overmatching in strength. Fracture Mechanics, Eighteenth Symposium, ASTM STP945,485~510.

Finch D.M.,Burdekin F.M.,1992, Finite element validations studies of revised PD6493/CEGB/R6:part 2-finite assessment methodologies applied to welded tubular joints. Int. J. Press. Vess. and Piping, 49,213~299.

Harrison J.D., and Anderson T.L., 1988, Developments in the application of the CTOD approach to fracture assessment of welded construction. Fracture Mechanics: Eighteenths Symposium, ASTM STP945, 468~482

Milne I.,Ainsworthe R.A., Dowling A.R. and Stewart A.T.,1988, Assessment of integrity of structures containing defects. Int. J. Pres. Vess. and Piping, 32,3~104

Miller A.G., 1988, Review of limit load of structure containing defects. Int. J. Pres. Vess. and Piping, 32, 197~327

Schwalbe K.H., 1993, Welded joints driving force considerations on the asis of the engineering treatment model(ETM). Int. J. of Fract., 62,1~24.

Zhang J.X., Shi Y.W. and Tu M.J.,1989, Studies on the fracture mechanics parameters of weldment with mechanical heterogeneity. Engin. Fract. Mech. 34,1041~1050.