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Damage Tolerance Analysis of Weld Joint

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Abstrak – This research explores the development and the implementation of damage tolerance analysis on weld joints. Two geometry types of weld joint are investigated subject to cyclic loadings. The experimental results are used for establishing residual strength diagram and crack growth diagram for both of types. The results show that the strength behavior may be quite different for different geometry types, even if the materials are the same.

Keywords - crack growth diagram, cyclic loadings, residual strength diagram.

INTRODUCTION

The presence of cracks in material may considerably reduce the material strength. The remaining strength is called the *residual strength*. Thus, it is important to determine the precise relationship between the crack size and the residual strength. Further, the knowledge about the *crack growth rate* is useful for determining the inspection time interval for the corresponding materials or structures. This kind of analyses is called the *damage tolerance analysis*. It is *mainly* based on the current state of material and the purpose is to prevent damage, or at least to Asses how tolerant the material is to damage. If the fatigue analysis is mainly useful in the design phase, the damage tolerance analysis is useful in operating time of materials or structures.

Two important *practical* tools in damage tolerance analysis are the *residual strength diagram* and the *crack growth diagram* (Broek, 1996). A residual strength diagram shows a relationship between the crack size and the residual strength. Therefore, it is useful for predicting how large the strength left (the residual strength) is in material simply by measuring the crack size through inspection. A crack growth diagram is useful for estimating the inspection time interval before a complete fracture occurs. These two diagrams differ for different materials; different components of a structure, even if the materials are the same; different crack locations; and different *initial* crack sizes.

Welded structures are important in practice where cracks frequently initiate at the weld joints. There are more then 50 basic types of weld joint geometry (Lawrence, *et al,* 1996). However, *no single publication* provides the residual strength diagram and the crack growth diagram *specifically* for any weld joint types, except those for the materials. Ghafur and Mursadin (2001) have proposed fatigue models of several important basic geometry types of weld joints. However, the results are only useful in the design phase of weld joints; while the inspections of weld joints in structures still require appropriate residual strength diagrams and crack growth diagrams.

The objective of this research is to develop the corresponding residual strength diagrams and crack growth diagrams for several important basic geometry types of carbon steel weld joints.

DAMAGE TOLERANCE ANALYSIS IN FRACTURE CONTROL

Fracture control is the concerted effort ensures safe operations without catastrophic failure by fracture. Very seldom does a fracture occur due to unforeseen overload on the undamaged structure. Fractures are usually the end results of crack growth from a small defect or flaw. Due to repeated or sustained service load, a crack may develop and slowly grow in size. Cracks and defects impair the strength of the component. Thus, during the continuing development of the

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crack, the structural strength decreases until it becomes so low that the service loads cannot be carried any more, and fracture ensues.

If fracture is being to prevent, the strength should not drop below a certain safe value. This means that cracks must be prevented from growing to a size at witch the strength would drop below an acceptable limit. In order to determine which size of crack is admissible, on must be able to calculate how the structural strength is affected by cracks (as a function of their size), and order to determine the safe operational life, on must be able to calculate the time in which a crack grown to the permissible size. Damage tolerance analysis is used to obtain this information.

Damage tolerance is the property of a structure is the property of a structure to sustain defects or cracks safely, until such time that action is (or can be) taken to eliminate the cracks by repairing or by replacing the cracked structure or component. Establishment of a fracture control plan requires knowledge of the structural strength as it is affected by cracks, and knowledge of the time involved for cracks to grow to the permissible size. Thus, damage tolerance analysis has two objectives, namely, to determine the effect of cracks on strength, and the crack growth as a function of time.

A residual strength diagram is useful for visualizing the effect of crack size on strength. Suppose that a new structure has no significant defects (a = 0), then the strength of the structure is the design strength (*Pu)*. However, experience has shown that it is acceptably low if the prescribed safety factor is adhered to. If cracks are present, the strength is less than *Pu.* This remaining strength under the presence of cracks is generally referred as the *residual strength*. This implies that the limit should be set somewhat above P_5. For example, one may require that the residual strength never be less than $P_p = g.P_5$, where g is the remaining safety factor and P_p is the minimum permissible residual strength.

Given that the shape of the residual strength diagram is known and P_p has been prescribed, the maximum permissible crack size follows from the diagram. In order for damage tolerance analysis to determine the largest permissible crack, the first objective must be the calculation of the residual strength diagram. If a_p (the maximum permissible crack size) can be calculated directly from P_p, it may not be necessary to calculate the entire residual strength diagram, but only the point (a_p, P_p). Howexer, this is seldom possible and rarely time saving. In general, calculation of the entire diagram is preferable. The residual strength diagram will be different for different components of structure and for different crack locations; permissible crack sizes will be different as well.

Knowing that the crack may not exceed a_p is of little help, unless it is known when the crack may reach a_p. The second objective of the damage tolerance analysis is then calculation of the *crack growth curve.* Under the action of normal service loading the cracks grow by fatigue at an ever-faster rate, leading to the convex curve. Starting at some initial crack size a_o the crack grows to a_p provided that one can calculate the curve, one obtains the time H of safe operation (until a_p is reached), after which the component or structure must be repaired or replaced. Alternatively, a_o may be the limit of crack detection by inspection. This crack will grow to a_p within a time of H. Because crack growth is not allowed beyond a_p the crack must be detected and repaired or otherwise eliminated before the time H has expired. Therefore, the time between inspections must be less than H; it is often taken as *H/2*. In any case, the time of safe operation by whatever means of fracture control follows from *H* (Broek, 1996).

Before any fracture control can be exercised, the residual strength diagram and crack growth diagram must be developed. The first step in damage tolerance analysis is the calculation of a_p, or the rather, of the residual strength diagram. Usually, the residual strength diagram is expressed in terms of stress rather than load. The residual strength, K_c can be calculated from.

$$\sigma_c = \frac{K_c}{\beta\sqrt{\pi a}} \quad \text{..} (1)$$

where K_c is the toughness of the material, β is the geometry factor defined by the details of the structure, and a is the crack size.

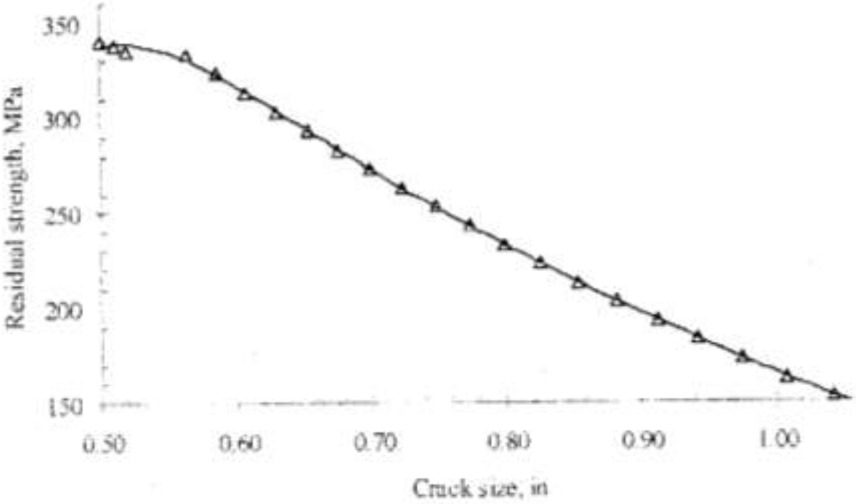

Figure 1. Residual strength diagram for transverse butt join of AISI 1020 carbon steel (28°C to 30°C and 75% to 90%)

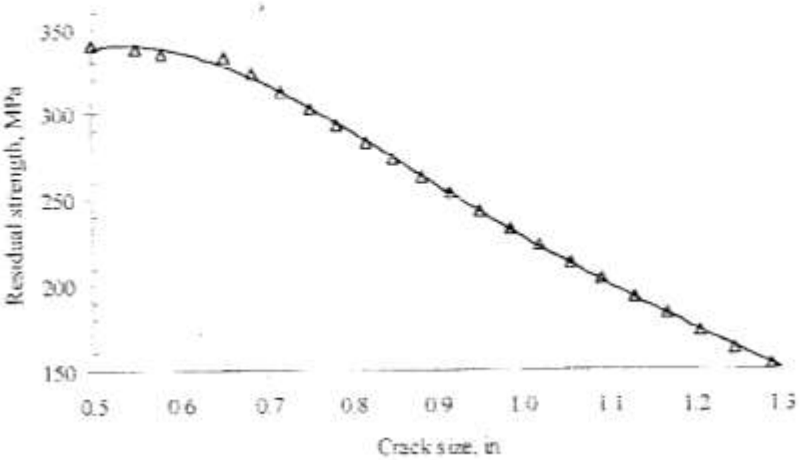

Figure 2, Residual strength diagram for partial penetration butt weld of AISI 1020 carbon steel (28°C to 30°C and 75% to 90%)

The second step is to calculate the crack growth curve. The rate of crack growth is a function of ΔK and R such that's

$$\frac{da}{dN} = f\left(\Delta K, R\right) \tag{2}$$

where $Kc = \beta \Delta \sigma_c \sqrt{\pi a}$ and R is the stress ratio (see Broek, 1996). The problem is to obtain the crack growth curve by integration of (2) as follows :

$$N = \int_{a_0}^{a_p} \frac{da}{f\left(\Delta K, R\right)} \tag{3}$$

Once the two diagrams are obtained, decisions on how exercise fracture control can be made in accordance with the foregoing.

The residual strength analysis provides the permissible crack size, a_p and the crack growth analysis provides the value of H, the time to exercise fracture control.

EXPERIMENTAL DESIGN AND RESULTS

Two types of weld joint geometry were investigated, namely, transverse butt joint and partial penetration butt weld. Up to 200 specimen of AISI 1020 carbon steel were used for every type. The "residual strength and crack size" data can be used to develop the residual strength diagram, while the "crack size and cycles" data can be used to develop the crack growth diagram. These, two diagrams were then developed for every geometry. Furthel, *analysis-of-variance*

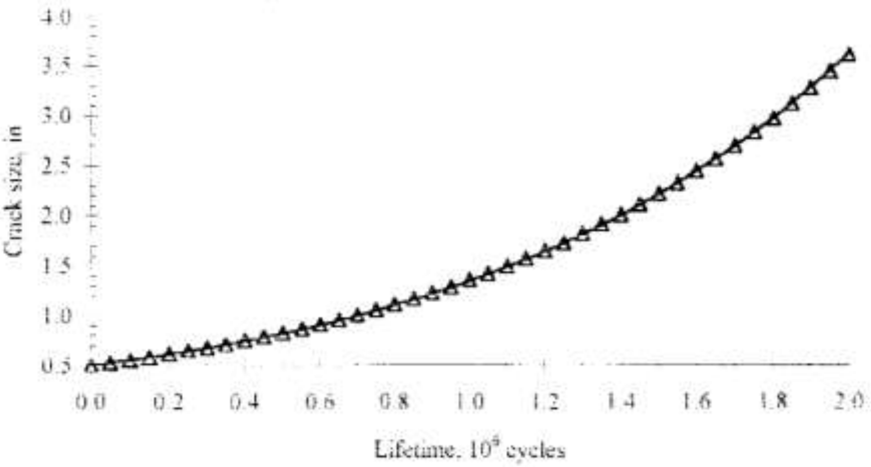

Figure 3. Crack growth diagram for transverse butt joint of AISI 1020 carbon steel (28^{o}C to 30^{o}C and 75% to 90%)

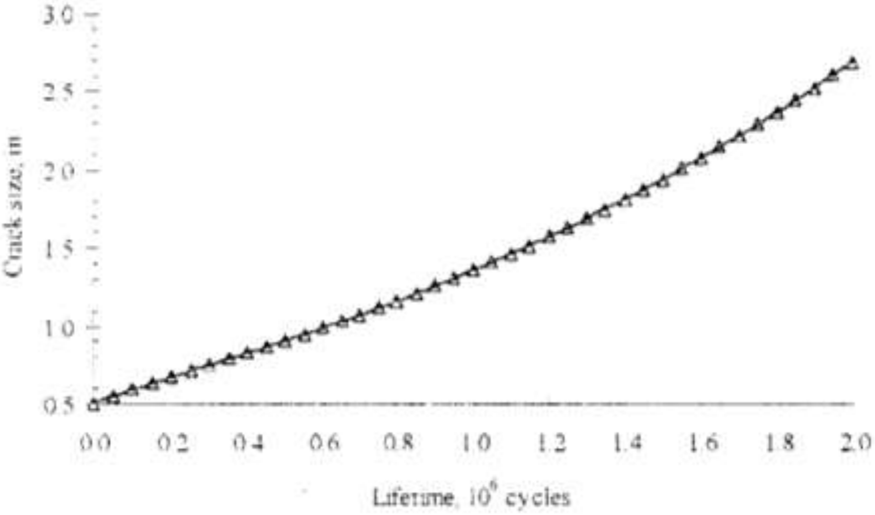

Figure 4. Crack growth diagram for partial penetration butt weld of AISI 1020 carbon steel (28^{o}C to 30^{o}C and 75% to 90%)

(ANOVA) techniques, a well-known statistical analysis tool were utilized as post analyses of the data.

Although the two geometry types have common yield strength of up to 345 Mpa, their strength behaviors are quite different under cyclic loading. As shown in Figure 1 and Figure 2 the curve for transverse butt joint. A 1-way ANOVA also confirms this significant difference at *significance level* of 5 %.

Crack growth diagrams are developed using "crack size and cycles" data of every geometry type. The crack growth diagram for the transverse butt joint and partial penetration butt weld are shown in Figure 3 and Figure 4, respectively.

Not like the residual strength properties, the crack growth properties of the two geometry types are not significantly different. A 1-way ANOVA at significance level of 5 % shows this surprising fact.

CONCLUSIONS

Different geometry types of weld joints result different strength behavior in terms of residual strength and crack growth rate. This research has explored the strength behavior of two geometry types of weld joints, namely, transverse butt joint and partial penetration butt weld. However, based on ANOVA, only the residual strength properties are significantly different. The difference between the crack growth properties of the two geometry types is not significant. This research may be extended to explorations of other geometry types of weld joints or mechanically fastened joints. The goal is to provide information about strength behavior of various joint types under service conditions.

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