THE RELIABILITY ASSESSMENT OF THE CYCLIC LOADED STRUCTURAL ELEMENTS HAVING CRACK LIKE DEFECTS

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In reliability assessment of construction elements the material properties and structural elements' characteristics need to be considered. Among the material properties one of the most important is notch sensitivity. In additional to cyclic loaded material this phenomenon is defined for quasi static loaded material. The crack propagation sensitivity index is defined for quasi static and cyclic loaded elements. Using the phenomena of the sensitivity index the NDT requirement system and the reliability of fracture mechanics calculations can be closely linked in the case of quasi static and cyclic loaded construction elements.

INTRODUCTION

The main goal of the structural integrity assessment of a given construction element having crack like defects is to give an unambiguous answer about the working condition in the future. Of course, this decision has its own risk. The task of an expert or an expert system is to estimate its value. The measure of this risk depends on the following factors:

* the reliability of the NDT methods used in crack detection procedure,
* the scatter of the material properties which is taken into consideration during the fracture mechanics evaluation of the working condition estimation,
* the validity of the fracture mechanics model used,
* the real local loading condition of the element.

From these facts it naturally follows, that during structural integrity assessment knowledge of various fields are required (mechanical testing, NDT methods and

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on, ie. the stress intensity factor or other fracture mechanics parameter vs. crack length.

Cyclic loading conditions

The crack propagation sensitivity is the slope of the *logarithm of residual life time vs. crack length function.*

EXPERIMENTAL DETERMINATION OF THE NOTCH SENSITIVITY OF MATERIALS

The notch sensitivity index of quasi static loaded materials can be determined by tensile testing of round bar smooth and notched specimens recording the *load* vs. *change in diameter* (*F* vs. Δd) illustrated in Fig.1, The *true strain* vs. *true stress* can then be calculated throughout each test (recording is simpler for notched specimen). The ratio of the ASFE values measured on notched (W_T) and smooth (W_0) specimens vs. elastic stress concentration factor (K_T) has a hyperbolic character which can be fitted by power type relationship. The exponent (**b**) of this curve can be regarded as the *notch sensitivity of materials* in the case of quasi static loading condition. The shape of this curve for different **b** values is plotted in Figure 2. The values of the quasistatic notch sensitivity index for different steels are in the range of 0,7- 1.4.

Experimental determination of the cyclic *notch sensitivity of materials* is well known.

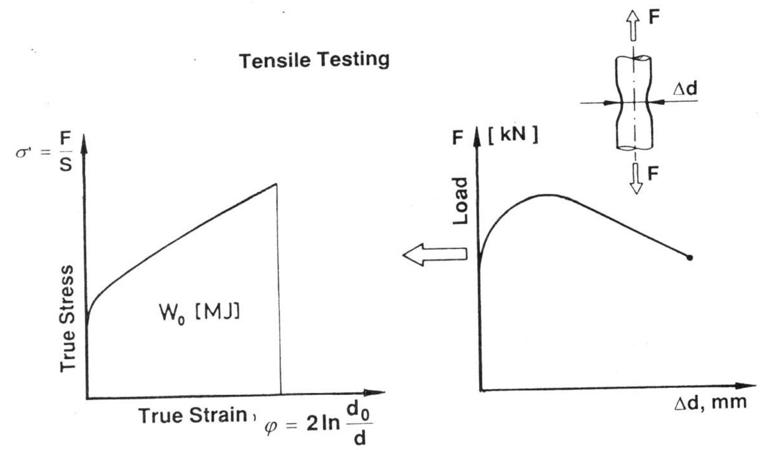

Figure 1 The *load-Δd* and *true stress-true strain* diagram of the smooth specimen

their applicablities, limits, reproducibility, fracture mechanics, experimental stress analysis methods, etc.).
During periodical control of a given construction element the first questions are the following:

* In which parts of this element could crack like defects occur?
* Of these possible flaws which are the most dangerous?
* How can the dangerousness of a flaw unambiguously be characterised?
* To what extent does this depend on the type of loading ?

Many-many questions must be addressed in order to estimate the risk of the given decision.
One of the basic problem is, how can the *notch sensitivity of the material* used and the *crack propagation sensitivity of the structural element* having a crack like defect be fully characterised. Both definitions are basically important because the *notch sensitivity of the material* is connected with the crack initiation behaviour, and the *crack propagation sensitivity index of the structural element* is linked to NDT observations-loading conditions-crack growth resistance test results via fracture mechanics calculations.

DEFINITIONS

Notch sensitivity of materials

Quasi static loading

The notch sensitivity index of materials is defined by the *exponent of the absorbed specific fracture energy* (ASFE) vs. *elastic stress concentration factor* curve. The ASFE value is the area under the true stress-true strain diagram determined by tensile testing of smooth and notched specimens with different elastic stress concentration factors.

Cyclic loading

There are plenty of definitions in the literature which detail the reduction in the fatigue limit of notched specimens (1). The earliest was proposed by Neuber in the form of

$$q=(K_T-1)/(K_F-1) \qquad (1)$$

where: q -is the notch sensitivity index

K_F-is the ratio of the fatigue limits determined on smooth and notched specimens with different stress concentration factors, K_T.

Crack propagation sensitivity index of the structural element

Quasistatic loading conditions

The crack propagation sensitivity is the derivative of the ***K*** vs. ***a*** functi-

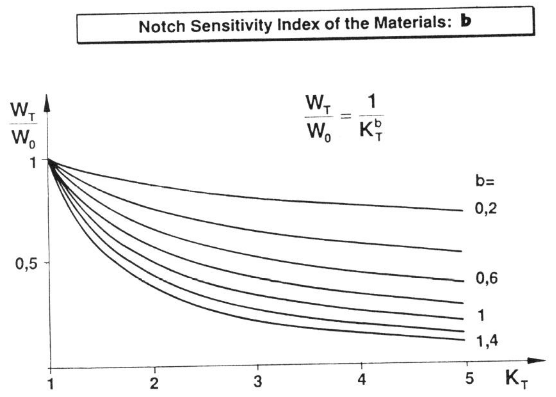

Figure 2 The shape of the normalised ASFE vs. elastic stress concentration factor for materials with different notch sensitivities

CALCULATION OF THE CRACK PROPAGATION SENSITIVITY INDEX OF THE STRUCTURAL ELEMENTS

According to the definition, the *crack propagation sensitivity index of the quasi static loaded structural element* is the derivative of the stress intensity factor (or other fracture mechanics parameters) with respect to crack length. This is illustrated in Figure 3.

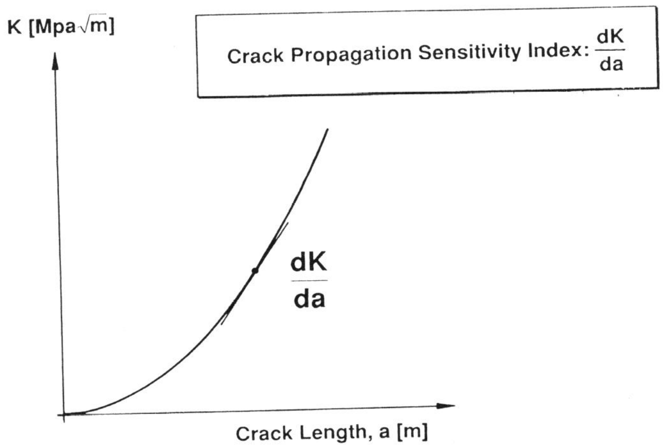

Figure 3 The definition of the *crack propagation sensitivity index of the quasi-static loaded structural element*

The solutions of the stress intensity factor calculations for different situations are given in handbooks (2-6) or they are contained in software (7,8), so there is no problem producing their derivative. It would be more practical if these derivatives were also included in the handbooks.

It is obvious that the *crack propagation sensitivity index* depends on

* the type of construction element,
* the crack position
* the crack length,
* the loading condition (mode I.,II. or III.) and
* the value of the load (linear dependence).

Thus, it naturally follows that when the NDT system requirement is prescribed for different construction elements the above mentioned parameters have to be considered for reaching the same reliability of the safety assessment.

According to the definition the *crack propagation sensitivity index of the cyclic loaded structural element* is the slope of the *logarithm of residual life time vs. crack length function*. This is illustrated in Figure 3. Considering that the residual lifetime vs. crack length can be calculated by

$$N_R = \int_a^{a_{fc}} \frac{1}{da/dN} da \qquad (2)$$

where the fatigue crack growth rate, da/dN=f(geometry, loading condition, crack position and length, material property).

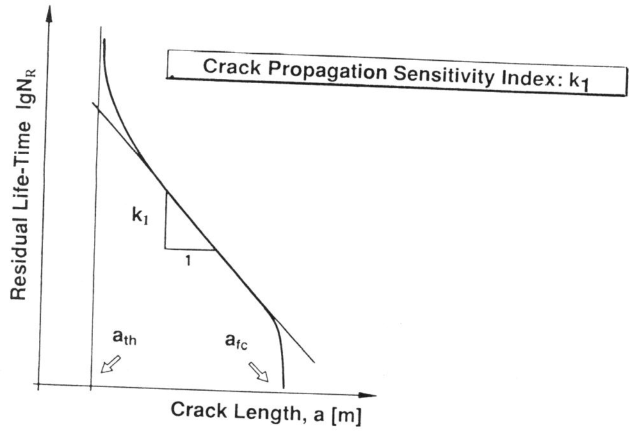

Figure 4 The definition of the *crack propagation sensitivity index of the cyclic loaded structural element*

From definition follows that the *crack propagation sensitivity index* depends on

* the type of construction element,
* the crack position
* the crack length,
* the loading condition (mode I.,II. or III.),
* the value of the loading (non-linear dependence) and
* the local fatigue crack growth resistance of material.

It naturally follows, that when the NDT system requirement is prescribed for different types of cyclic loaded construction elements the above mentioned parameters have to be considered for reaching the same reliability of the safety assessment.

CONCLUSION REMARKS

On the basis of the mentioned idea the following conclusions can be drawn:

1) Definition of notch sensitivity index for quasistatic loaded materials is proposed, which can experimentally be determined by tensile testing of smooth and notched specimens.

2) Definitions of crack propagation sensitivity indexes for quasistatic and cyclic loaded construction elements are proposed. The NDT system requirement and the reliability of the fracture mechanics calculations is closely linked by using of the crack propagation sensitivity indexes.

SYMBOLS USED

a = crack length (m)
a_{th} = propagation able crack length (m)
a_{fc} = fatigue critical crack length (m)
da/dN = fatigue crack growth rate (m/cycle)
b = notch sensitivity index of quasi static loaded material
k_1 = notch sensitivity index of cyclic loaded material
K_F = ratio of the fatigue limits determined on notched and smooth specimens
K_T = elastic stress concentration factor of the notched specimens
ΔK = stress intensity factor range ($MPa\sqrt{m}$)
N_R = residual life time (cycles)
W_o = absorbed specific fracture energy measured on smooth specimen (MJ/m^3)
W_T = absorbed specific fracture energy measured on notched specimen (MJ/m^3)
F = tensile load (N)
S = crossection area of the tensile specimen (mm^2)
d_0 = initial diameter of the tensile specimen (mm)

d = diameter of the tensile specimen during test (mm)
σ' = true stress in tensile specimen (MPa)
φ = true strain in tensile specimen

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