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Crack propagation sensitivity index concept of engineering components and its practical use

Toth L.
University of Miskolc, Hungary

ABSTRACT

The *crack propagation sensitivity index* **(CPSI)** of construction elements for the quasistatic and cyclic loaded components is proposed. Using this definition the reliability of the structural element **(RSE)** having crack like defects and the reproducibility (reliability) of the non destructive testing **(NDT)** results and determination of crack propagation resistance **(CPR)** of material creates a „closed-loop system", i.e. the requirements for the **RSE-NDT-CPR** are interconnected.

INTRODUCTION

The development in microelectronics is reflected in each area of the life among them in the engineering area as well. It's trend can be characterised by the Fig. 1 where the operation velocity of the Intel processors are summarised. In Fig. 1 can exactly be seen that the operation speed changed during the last two decades dramatically. In the year of 1978 the MIPS (million instructions per seconds) was only 0.33 and 17 years later in 1995 the P6 processors operate with a speed of 250 MIPS.

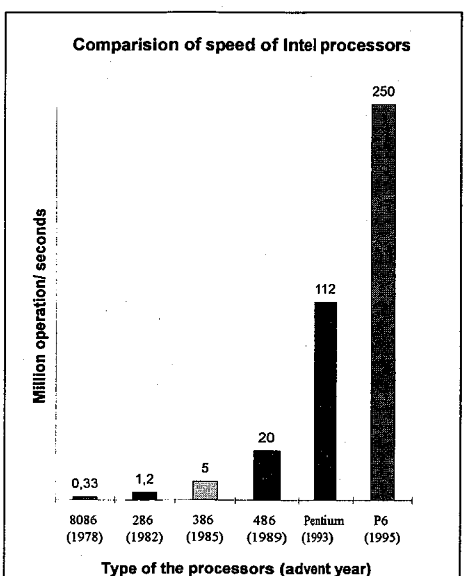

Fig.1.
Development of the operation speeds of the Intel processors

This development is also realised in all fields of the measurement technics, among them in the field of NDT methods are used in periodical control of the engineering structures.

The continuous use of up-to-date methods enables

- the observation and control of defects in structural elements of decreasing size with increasing reproducibility, and
- the detection of flaws in constructions which so far have been regarded as "defect-free".

If a crack like defect is detected than many questions will arise and need to be answered, such as:

- Does the structure need immediate repair?
- Can it continue to operate?
- If it can continue to operate, what are the conditions?

During the supervision of a given construction element the most important questions are the following ones:

- Which of these possible flaws is the most dangerous one?
- Which of these possible flaws is the most dangerous one?
- How can the dangerousness of a flaw be unambiguously characterised?
- How does the dangerousness depend on the type of loading?

Many questions can be posed and have to be answered for the estimation of the risk of the final decision.
One of the basic problems in reliability assessment is: how the *crack propagation sensitivity of the structural element* having crack like defect be defined in terms of characteristic numbers? The definition is basically important because the ***NDT observations - loading conditions - crack growth resistance test results*** are connected [49, 65, 104] by means of a *crack propagation sensitivity index of the structural element* using fracture mechanics.

2. Definition of the Crack Propagation Sensitivity Index

Crack propagation sensitivity index of structural elements

Quasistatic loading

The crack propagation sensitivity is the derivative of the ***K*** vs. ***a*** function (either the stress intensity factor or other fracture mechanics parameter vs. crack length). This is illustrated schematically in Fig. 2.

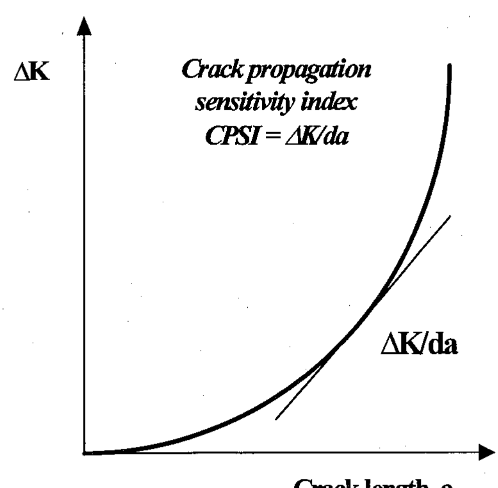

Fig.2. The definition of the *crack propagation sensitivity index (CPSI)* of the **quasistatic** loaded structural element

The CPSI of the quasistatic loaded elements depends on the

- type of the structure
- loading condition and (mode and value)
- crack length.

Cyclic loading

The crack propagation sensitivity is the slope of the *logarithm of residual life time* vs. *crack length* function as it can be seen in Fig. 3.

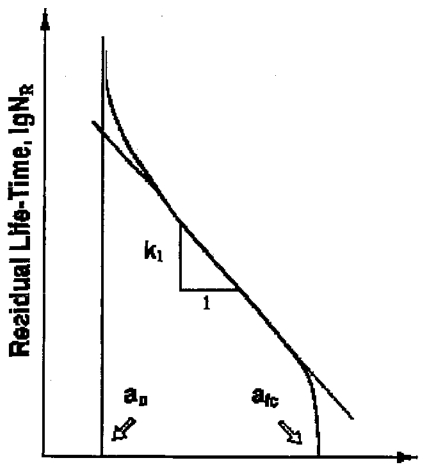

Figure 3. The definition of the *crack propagation sensitivity index (*CPSI≡k_1) of the **cyclically** loaded structural element

Considering the residual lifetime N_R be given by

$$N_R = \int_{a}^{a_{crit}} \left(\frac{da}{dN}\right)^{-1} da \qquad (1)$$

where the fatigue crack growth rate, da/dN is a function of geometry, loading condition, crack position, crack length and material properties, the *crack propagation sensitivity index(CPSI)* depends on

- type of construction element,
- crack position,
- crack length,
- loading condition (modes I., II. or III.),
- load level (non-linear) and
- local fatigue crack growth resistance of material.

Therefore, when the NDT requirement system is prescribed for different types of cyclically loaded construction elements made of different material, the above mentioned parameters have to be considered for reaching the same reliability of the safety assessment. This is illustrated in Fig. 4/a. and 4/b. for different structural elements and for the same element made of different materials.

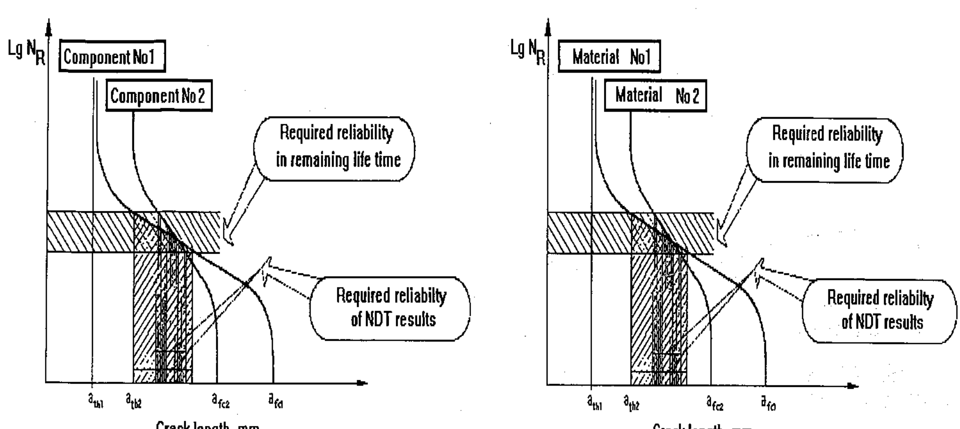

Fig.4. The effect of structural elements and materials on crack sensitivity index of cyclic loadaed components

3. PRACTICAL APPLICATION OF CRACK PROPAGATION SENSITIVITY INDEX

In this section the following problems will be discussed by worked out examples:

- effect of yield stress on the dangerousness of the crack like defects with different position in the same type of construction element,
- effect of crack growth resistance distribution on the dangerousness of the crack like defects with different position in the same type of construction element.

Selecting different type of steels with different yield stress, the parameters of the fatigue crack growth law represented by TOTH model [3, 4]

$$\frac{da}{dN} = \left\{ -\frac{1}{c} \ln\left[1 - \left(\frac{\Delta K - \Delta K_{th}}{\Delta K_{fc} - \Delta K_{th}} \right)^{n} \right] \right\}^{\frac{1}{b}} \tag{2}$$

are shown in Table 1.

TABLE 1. The characteristics of selected materials with different yield strength

Type of material	Yield Strength [MPa]	ΔK_{th} [MPa√m]	ΔK_{fc} [MPa√m]	c	b	n
ST 38	281	5.3	40.0	101.8	0.459	0.575
ST 52	334	5.9	46.0	122.9	0.458	0.524
H-60	379	5.4	44.8	202.4	0.523	0.608
H-75/3	673	5.8	63.2	316.8	0.586	0.486
NAXTRA	801	5.4	71.0	144.6	0.506	0.523
NK	1150	4.5	97.9	73.4	0.502	0.612
K13	1480	4.5	62.0	110.9	0.521	0.611

Selecting a plate type structural element with width **w=20 mm** and thickness **t=1** mm, the following calculations will be performed:

Determination of the a_{th} and a_{fc} values and the crack growth sensitivity index k_1 for:

- central cracked and edge cracked elements under tension and bending
- cyclically loaded with stress amplitude Δσ=*75% of the actual yield stress.*

The main goals of these calculations are to show that

- the same value of the safety factor based on the yield stress can not be used for reliability assessment of cyclically loaded structural components,
- the surface cracks are more dangerous than the embedded ones,
- the crack sensitivity index increases by increasing the strength of steels .

The a_{th} and a_{fc} values of elements cyclically loaded with stress amplitude equal to 75% of the actual yield strength are summarised in Fig 5a. and Fig.5b.

These figures are exactly proof that

- using the same value of the safety factor which is based on the yield stress, the crack like defects are more and more dangerous by increasing the strength,

- the surface cracks are more dangerous than the embedded ones which exactly emphasises both theoretical and practical importance of surface cracks [5-14].

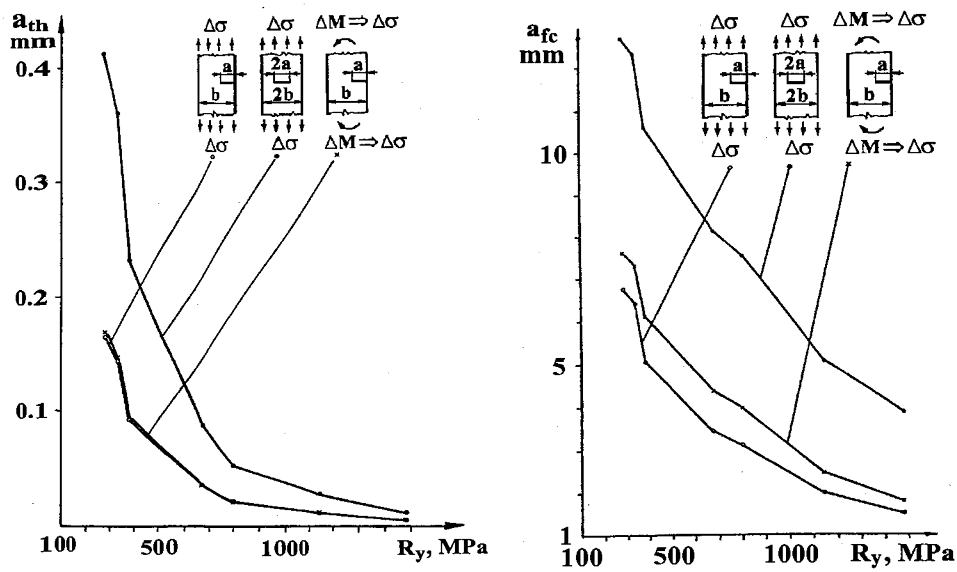

Figure 5.The a_{th} and a_{fc} values of elements cyclically loaded with stress amplitude equal to 75% of the actual yield strength

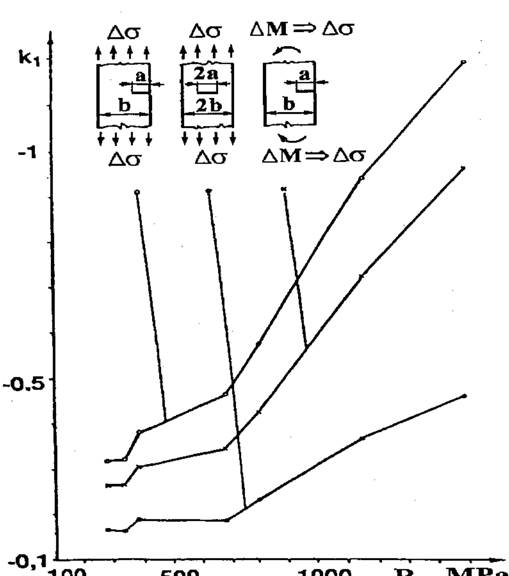

Figure 6. The crack growth sensitivity index of cyclically loaded elements

The *crack growth sensitivity index against the yield stress for elements cyclically loaded* is illustrated in Fig. 6. The loading stress amplitude was 75% of the actual yield strength. These curves strengthen the earlier conclusions which should be completed by the fact that, during supervisions, NDT methods have to be used to detect the crack lengths with better and better accuracy to reach the same risk in residual life time assessment. It has to be emphasised that the values of the *crack growth sensitivity index* arise about up to three times by increasing the yield strength. It can also be seen that a surface crack in a structural element under tension is the most dangerous case.

4. CONNCLUDING REMARKS

Considering the aim of this paper and the presented results, the following conclusions can be drawn:

1. The reliability assessment of cracked structural components needs to be to based on the co-operation of specialists working in the field of *NDT-Mechanical Testing-Fracture Mechanics*.
2. A system for characterisation *crack propagation sensitivity index (CPSI) of the construction elements* for *quasistatic* and *cyclic* loading conditions has been proposed.
3. The application of the *crack propagation sensitivity index of the construction elements* provides the possibility to join the reliability assessment calculation and the reproducibility of the NDT or crack growth resistance test results.
4. The effect of surface cracks on the reliability of structural components is more dangerous than that of other types of cracks, and therefore mechanical description and detection of surface flaws have to be central problems.

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