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Fatigue Crack Growth Prediction from Low Cycle Fatigue Properties

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The goal of this paper is the establishment of computation methods for the evaluation of the residual life of structural elements in the presence of initial damage which appears in the form of cracks. Initial cracks appear during the exploitation of structures in stress concentration zones. Therefore in this paper computation method for the evaluation of the residual life of structural elements with initial damage subjected to cyclic loading of constant amplitude is presented. Calculational methods for the evaluation of the residual life of structural elements with initial damage basically rely on crack propagation analysis. In this investigation for crack propagation analysis Strain Energy Density (SED) method will be used. This method uses the low-cycle fatigue properties of the material, which are also being used for the lifetime evaluation until the occurrence of initial damage. Therefore experimentally obtained dynamic properties of the material such as Paris` constants are not required when this approch is concerned. The complete method for the crack propagation analysis using low-cycle fatigue material properties is illustrated with the structural element in the form of a plate with a hole and a single initial crack. Results of numerical simulation for crack propagation based on strain density method have been compared with experimental results.

Analiza širenja pukotina koristeći niskociklične zamorne karakteristike materijala

Izvornoznanstveni članak

Predmet rada je usmjeren na uspostavljanje proračunskih metoda za procjenu preostalog životnog vijeka strukturalnih elemenata sa inicijalnim oštećenjima koja se javljaju u obliku pukotina. Inicijalne pukotine se javljaju za vrijeme eksploatacije postrojenja u zonama koncentracije naprezanja. Stoga je u ovom radu prezentirana proračunska metoda za procjenu preostalog zamornog životnog vijeka za elemente konstrukcija sa inicijalnim oštećenjima pod djelovanjem cikličnih opterećenja konstantne amplitude. Proračunske metode za određivanje preostalog životnog vijeka strukturalnih elemenata sa inicijalnim oštećenjima baziraju se na analizi širenja pukotine. U ovom istraživanju za analizu širenja pukotine će se koristiti metoda Gustoće Energije Deformacije (GED). Ova metoda koristi niskociklične karakteristike materijala, upravo iste one karakteristike materijala koje se koriste pri procjeni životnog vijeka do pojave inicijalnog oštećenja. Stoga u ovom pristupu eksperimentalno određene dinamičke karakteristike materijala takve kao što su Parisove konstante nisu potrebne kada se koristi ova metoda. Kompletna metoda za analizu širenja pukotine na bazi korištenja niskocikličnih zamornih karakteristika materijala je ilustrirana na strukturalnom elementu sa kružnim otvorom i jednom inicijalnom pukotinom. Rezultati numeričke simulacije širenja pukotine na bazi primjene metode gustoće energije deformacije su uspoređeni sa eksperimentalnim rezultatima.

Keywords
Crack propagation prediction
Fatigue
Low-cycle fatigue material properties
Residual life
Strain energy density method

Ključne riječi
Metoda gustoće energije deformacije
Niskociklične zamorne karakteristike materijala
Predviđanje širenja pukotine
Preostali vijek
Zamor

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1. Introduction

It`s a well known fact that the overall lifetime of structural elements subjected to cyclic loading can be divided into two periods, taking into consideration the aspects of calculation methods: period until the occurrence of initial damage [1] and period of crack propagation [2-4].

For the lifetime evaluation of structural elements until the occurrence of initial damage in the low-cycle fatigue domain the relations for which the magnitudes of

Symbols/Oznake

a	- crack length - duljina pukotine
N	- number of cycles - broj ciklusa
K_I	- the stress intensity factor - čimbenik intenziteta napona
K_c	- fracture toughness - lomna žilavost materijala
ΔK_{th}	- range of threshold stress intensity factor - opseg praga čimbenika intenziteta napona
ΔK_{th0}	- the range of threshold stress intensity factor for the stress ratio R = 0 - opseg praga čimbenika intenziteta napona za koeficijent asimetrije R = 0
E	- Young`s modulus of elasticity - Youngov modul elastičnosti
n'	- cyclic strain hardening exponent - eksponent cikličkog ojačanja materijala
$I_{n'}, \psi$	- constants which depend on the cyclic strain hardening exponent n` - konstante koje zavise o eksponentu cikličkog ojačanja deformacije n`
S	- stress - napon
e_a	- strain amplitude - amplituda deformacije
S_a	- stress amplitude - amplitude napona
$k`$	- cyclic strength coefficient - koeficijent cikličke čvrstoće
$\sigma_f`$	- fatigue strength coefficient - koeficijent zamorne čvrstoće
$\varepsilon_f`$	- fatigue ductility coefficient - koeficijent zamorne duktilnosti
b	- fatigue strength exponent - eksponent zamorne čvrstoće
c	- fatigue ductility exponent - eksponent zamorne duktilnosti
w_c	- energy absorbed during the cycle - apsorbirana energija za vrijeme ciklusa opterećenja
$R=S_{min}/S_{max}$	- stress ratio - koeficijent asimetrije
Y	- the corrective function for determination of the stress intensity factor - korekciona funkcija za određivanje čimbenika intenziteta napona
C, m	- Paris`s crack growth constants - Parisove konstante širenja pukotine
FEM	- finite element method - metod konačnih elemenata
SED	- strain energy density - gustoća energije deformacije
LCF	- a low cycle fatigue - niskociklični zamor

low-cycle fatigue material behaviour properties have to be obtained experimentally are being used. For the crack propagation analysis and evaluation of residual lifetime of structures two approaches can be used. First approach is based on conventional crack propagation laws such as Paris` crack propagation law, for which it is necessary to experimentally obtain dynamic properties of the material. The second approach for crack propagation analysis is based on the use of Strain Energy Density Method. This approach uses the low-cycle fatigue properties of the material, which are also being used for the lifetime evaluation until the occurrence of initial damage. Therefore experimentally obtained dynamic properties of the material such as Paris` constants are not required when this approch is concerned.

. This research is focused on the second stage, or in other words on prediction of residual life of a structural element with initial damage in the form of cracks. Regardless of which stage is in question, it`s necessary to develop new and improve the existing life prediction numerical models. In engineering practice the application of life prediction numerical models enables to reach life prediction of a structural element relatively quick. Every single life prediction numerical model has to be based on adequate criteria.Failure of structural element occurs during crack propagation, therefore that stage has to be monitored with special care. Since the presence of plastic strain leads to failure, it's important to include the influence of elastic and plastic strain into criteria, which makes life prediction for the crack propagation stage more accurate in an attempt to describe true behavior of structural elements during cyclic loading. One of criterions which take into account presence of both elastic and plastic strain is energy criterion. During the formulation of energy criterion various parameters can be used. It's best to use parameters by which it's possible to adequately define energy which absorbs within the material and subsequently leads to structural element failure. Therefore, models formulated by Weertman and Burck [5-6] were based on parameters associated with low-cycle fatigue properties. They have reached the conclusion that it's possible to determine the level of absorbed energy until failure occurs with knowledge of low-cycle parameters. Some time later, Liu [7] and many others used the parameters associated with low-cycle fatigue in order to determine life prediction of structural elements with initial damage. Chand and Garg [8] have also contributed heavily with their own models completed by modifying Weertman`s model through the use of Rice's method [9-10] of superposition.

The focus of this paper is to establish the methodology for residual lifetime evaluation of the tower structure of the overhaul facility CARDWELL II KB 210 A, Figure 1.

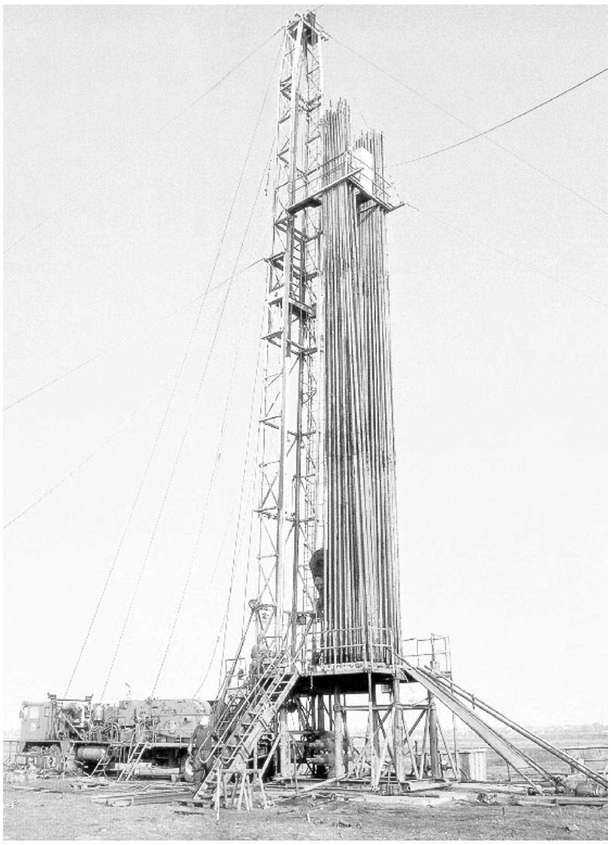


Figure 1. "CARDWELL KB 210A" repair facility tower

Slika 1. Toranj remontnog postrojenja "CARDWELL II KB 210 A"

The overhaul tower is basically the lattice construction and its elements are made of S355 J2 G3 steel. It is subjected to changeable amplitude loading, and therefore it`s necessary to carry out the lifetime evaluation in order to design such structures properly for the period until the occurrence of initial damage, as well as for the period of crack propagation. The objective of the research presented in this paper is the establishment of crack propagation analysis, as well as residual lifetime evaluation for structural elements made of S355 J2 G3 steel. For that purpose the dynamic properties of the material necessary for modelling the crack propagation through the use of Paris` crack propagation law and the impact ductility of the material, which is the basis for determination of low-cycle behaviour properties of the material have been obtained experimentally.

The other part of the paper comprises the calculation and experimental residual lifetime evaluation for representative complex specimens - boards with a hole and a single initial crack subjected to cyclic loading of constant amplitude made of S355 J2 G3 steel. For the crack propagation analysis and residual lifetime evaluation of specimens with a hole and a single initial crack Strain Energy Density Method is being used. It has been aforementioned that this approach for crack propagation analysis utilizes low-cycle properties of the material, which means that for the computational residual lifetime evaluation of structural elements with initial damage low-cycle properties of the material are being used, or in other words the same properties which are being used for lifetime evaluation until the occurrence of initial damage. In order to verify the computational method for the crack propagation analysis and residual lifetime evaluation based on strain energy density the results have been compared to those obtained by experiments which involved the board with a hole and a single initial crack.

The objective of this paper is to develop an adequate and efficient numerical approach which enables life prediction of structural elements during the crack propagation stage. Besides that, formulated model is based on energy criterion. Within the scope of the suggested model / procedure the same parameters required for the stage which lasts until the occurrence of initial damage are being used. In engineering practice there are structural elements with geometrical discontinuities in the form of holes where the stress concentration occurs. One of the objectives of this paper is to establish an efficient approach regarding residual life prediction of structural elements of the above-mentioned tower with geometrical discontinuities in the form of holes initially damaged through the occurrence of cracks while being subjected to cyclic loading of constant amplitude.

2. Crack propagation model based on low-cycle fatigue properties

While predicting life of a structural element with initial damage it`s necessary to establish the functional dependency between the crack propagation gradient da/dN and the stress intensity factor K_I.

The severest damage accumulation occurs in the process zone [7, 11], therefore it`s necessary to define and calculate the energy which causes damage in the process zone. For the zone around the tip of the crack (process zone) it`s possible to define the energy generated through plastic strain ω_p in a cycle using length unit as a function of stress intensity factor range ΔK_I:

$$\omega_{\mathrm{p}} = \left(\frac{1-n'}{1+n'}\right)\frac{\Delta K_I^2}{E\, I_{n'}}\psi, \tag{1}$$

where: n' - cyclic strain hardening exponent, E – Young`s modulus of elasticity, In', ψ - constants which depend on the cyclic strain hardening exponent n'. For most metals the value of n' usually varies between 0,10 and 0.25, with an average value close to 0.15. Since the dependency for energy generated due to plastic strain ωp as a function of ΔKI is established, it`s necessary to establish the dependency between the crack propagation gradient da/dN and ωp. While establishing the dependency a fact that the crack propagates if energy which generates due to plastic strain during the cycle reaches the energy absorbed during the same cycle W_c must be taken into account:

$$\frac{da}{dN} = \frac{\omega_p}{W_c}. \tag{2}$$

In equation (2) energy absorbed during the cycle W_C can be defined if stress – strain relation, or the material behaviour equation, is known. Adequte relation for material behaviour which includes both elastic and plastic behaviour is known as Ramberg – Osgood equation [14]:

$$e_a = \frac{S_a}{E} + \left(\frac{S_a}{k'}\right)^{1/n'}, \tag{3}$$

where: e_a – strain amplitude, S_a – stress amplitude and k'- cyclic strength coefficient. If the material behavior equation is presented by equation (3), energy absorbed during the cycle W_c represents the area below the curve in S-e coordinate system, or:

$$W_c = \frac{4}{1+n'} \sigma_f' \, \varepsilon_f' , \tag{4}$$

where: σ_f' - fatigue strength exponent, ε_f' - fatigue ductility coefficient. Finally, if equations (1) and (3) get placed in equation (2), functional dependency between crack propagation gradient and stress intensity factor gets established. Subsequently, that dependency can be integrated from initial crack length a_i to final crack length a_c in order to obtain the relation which could be used for the prediction of life of structural elements which contain initial damage:

$$N = \frac{\left(1-n'\right)\psi}{4 E I_{n'} \sigma_f' \varepsilon_f'} \int_{a_i}^{a_c} \left(\Delta K_I - \Delta K_{th}\right)^2, \tag{5}$$

where ΔK_{th} is range of threshold stress intensity factor. ΔK_{th} is a material constant but it is sensitive to stress ratio $R=S_{min}/S_{max}$. A relation between ΔK_{th} and R is given below based on experimental results [8]

$$\Delta K_{th} = \Delta K_{th0}(1 - R)^{\gamma}, \tag{6}$$

where ΔK_{th0} is the range of threshold stress intensity factor for the stress ratio R=0, and γ is a material constant which varies from 0 to 1 [12-13]. For most of materials γ comes out to be 0.71 [8]. Equation (5) presents the law of crack propagation based on strain energy density method. It`s obvious that in this dependency cyclic characteristics of material from low-cycle fatigue domain are being used instead of dynamic parameters from more conventional laws for crack propagation by Paris, Forman and others. Main advantage of this approach is the use of same cyclic material characteristics being used for life prediction until the occurrence of the initial crack for the analysis of crack propagation.

3. Definiton of stress intensity factor

Equations which refer to crack propagation gradient and life prediction until the failure occurs are formulated as functions of stress intensity factor ΔK_I. Stress intensity factor (SIF) includes the geometry of a structural element and the type of outer loading into calculation. In the analytical relation for the stress intensity factor:

$$K_I = Y S \sqrt{\pi a}, \tag{7}$$

Y stands for the corrective function which describes the geometry of a structural element and the type of loading, a – crack length, S – stress. Within numerical examples uniaxial load which affect the cracked structural element have been analyzed, Figure 1. Since the structural element contains a hole of radius r and a single crack of length a_0, the corrective function looks like this for uniaxial loading [11]

$$Y = z\, Y_w\, Y_{b1} \tag{8}$$

and

$$z = \frac{1}{2}\sqrt{\frac{1}{\cos\left(2r\frac{\pi^2 w}{180}\right)}}; \quad Y_w = \sqrt{\frac{1}{\cos\left(\frac{\pi}{2}\frac{(2r+a)}{(w-a)}\right)}}; \tag{9}$$

$$Y_{b1} = 0.70833 + 1.29275\, e^{\frac{-(a/w)}{0.17197}} + 0.29223\, e^{\frac{-(a/w)}{4.81617}} + \\ + 1.10057\, e^{\frac{-(a/w)}{1.04267}}, \tag{10}$$

where r is radius of hole and a - the length of crack. Analytic expression for SIF (7) is verified using finite element method (FEM).

Figure 2 presents the appearance of a structural element which contains a hole and a single initial crack (w=50 mm, r=10 mm, t=5 mm, a_0=3.5 mm). To validate analytic equation for SIF (7) here finite element method is used. Stress intensity factor is calculated by using the finite element method. More precisely, stress intensity factor gets calculated by using singular finite elements for various crack lengths. Based on discrete values of stress intensity factor calculated by using the finite element method, analytical formula in polynomial form gets derived for the stress intensity factor necessary for the analysis of crack propagation.To validate analytic equation for SIF (7) here finite element method is used. A representation of the finite element analysis for structural element with hole and one crack is shown in Figure 3. Namely, Figure 3 presents stress distribution of damaged structural element for crack length a = 0.00127 m.

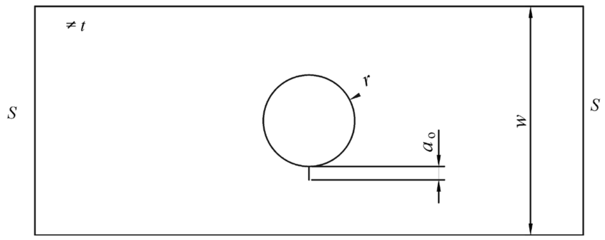


Figure 2. Geometry of cracked structural element

Slika 2. Geometrija strukturnog elementa s inicijalnom pukotinom

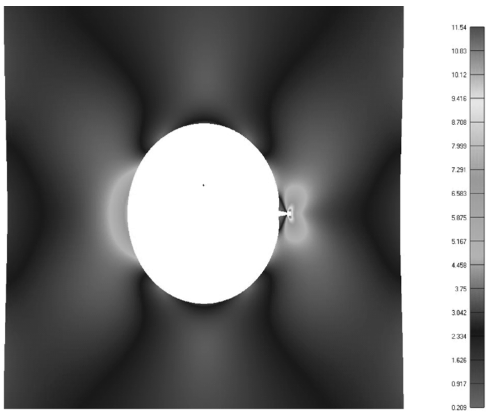


Figure 3. Stress distribution for structural element with a circular hole and one crack (F = 5 200 N and a = 0.00127 m) using finite element analysis

Slika 3. Raspodjela napona kod strukturnog elementa s kružnim otvorom i pukotinom (F = 5 200 N and a = 0.00127 m) dobivena primjenom metode konačnih elemenata

After stress distribution, as a result of finite element analysis for different values of crack length a, it is possible to determine stress intensity factors. Obtained values for stress intensity factors using numerical approach, (FEM), as well as analytical approach (Eq. (7) with Eqs. (8) to (9)) are listed in Table 1.

Comparisons in Table 1 shows good agreement between analytical results and numerical results for values of stress intensity factors for different values of crack length a. Due to that fact, relation for the corrective function (Eq. (8) with (9) and (10)) can be used in formulated procedure for crack growth prediction of damaged structural element presented in Figure 1.

Table 1. Comparisons FE and Analytic Solutions for Stress Intensity Factors

Tablica 1. Usporedba rješenja KE s analitičkim čimbenikom intenziteta napona

	a_0, mm	K_I^{FEM}	K_I^{Anal} (7)	Δ, %
1	1.27	12.8	12.23	4.45
2	2.50	15.4	15.60	-1.30
3	4.00	17.4	18.24	-4.83
4	6.00	19.6	21.07	-7.50

4. Comparisons numerical and experimental results

Procedure for the life prediction of structural elements during the crack propagation stage formulated in previous chapters will be applied on a structural element which contains a hole and a single crack subjected to constant amplitude cyclic loads. For the calculational crack propagation analysis and for the residual lifetime evaluation of structural elements with initial damage in the form of cracks, in-house software package “P-GED” based on the use of low-cycle fatigue properties of the material has been developed.

4.1. Crack propagation test

A structural element which contains a hole and a single crack on one side of the hole has been taken into consideration, Figure 3. An experiment with the objective to determine crack propagation was executed in order to verify the calculation procedure for the analysis of crack propagation based on strain energy density.

Testing was carried out using a servo-hydraulic MTS fatigue testing machine, Figure 4, with computerized control and data lagging. The crack length variation during cyclic loads was determined using the commercial thin foil `Krak Gage` and FRACTOMAT system from Rumul and logged on a computer. This system enabled a very accurate monitoring of crack length. The accuracy is ± 0.01 mm, which exceeds ASTM-617 - `Standard Test Method for Measurement of Fatigue Crack Growth Rates` standard by a factor of 10. Before crack growth measurements, specimens were fatigue-precracked in the tension-tension mode to obtain a sharp initial cracking. The crack was propagated at a constant applied load using MTS machine. Examinations were performed by applying constant amplitude cyclic loads. Specimen was analyzed under constant amplitude loads: S_{max}= 80 MPa and S_{min}= 8 MPa.

Figure 5 presents a specimen with an adequately positioned measuring foil. Specimen material is S355 J2 G3 steel with the following static (yield strength of 409 MPa and tensile strength of 551 MPa) and cyclic characteristics of the material, Table 2:

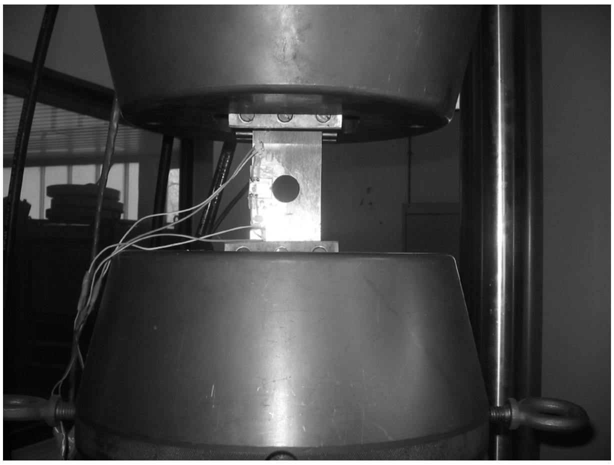


Figure 4. Experimental measuring of crack propagation with use of measuring foils

Slika 4. Eksperimentalno mjerenje širenja pukotine koristeći mjerne trake

Table 2. Low Cyclic Fatigue properties of S355 J2 G3 steel

Tablica 2. Niskociklične karakteristike čelika S355 J2 G3

Material properties / Karakteristike materijala	Value / Vrijednost
Modulus of elasticity, *E*, MPa / Young-ov modul elastičnosti	207650.0
Cyclic strength coefficient, *k*', MPa / koeficijent cikličke čvrstoće	1245.1
Cyclic strain hardening exponent, n' / Eksponent cikličkog ojačanja deformacije	0.1924
Fatigue strength coefficient, σ'_f, MPa / Koeficijent zamorne čvrstoće	1217.4
Fatigue strength exponent, *b* / Eksponent zamorne čvrstoće	-0.1104
Fatigue ductility coefficient, ε'_f / Koeficijent zamorne duktilnosti	0.6347
Fatigue ductility exponent, *c* / Eksponent zamorne duktilnosti	-0.5521

The values of $I_{n'}$=3.067 and ψ = 0.95152 that are used in this analysis (Table 2) were defined in reference [14].

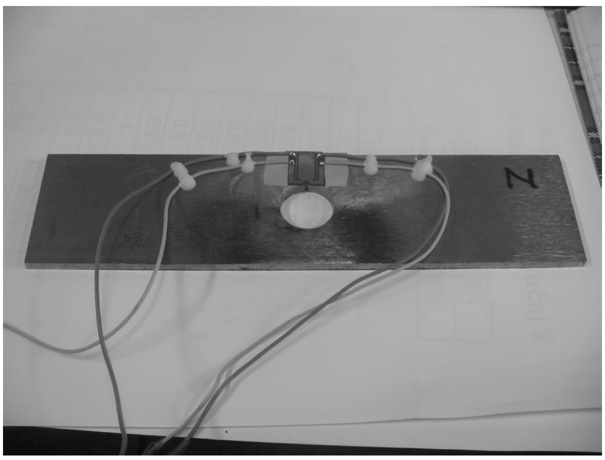


Figure 5. Appearance of specimen with the initial crack and measuring foil

Slika 5. Izgled epruvete s inicijalnom pukotinom i mjernom trakom

4.2. Comparisons results of numerical simulation with experiments

Experimental testing of crack propagation, as well as the numerical simulation of crack propagation using the strain energy density method, under constant amplitude loading (S_{max}= 80 MPa and S_{min} = 8 MPa) are presented in Figure 6 and Table 3. It`s evident that the results of numerical simulation agree well with those obtained by experiment, Figure 5.

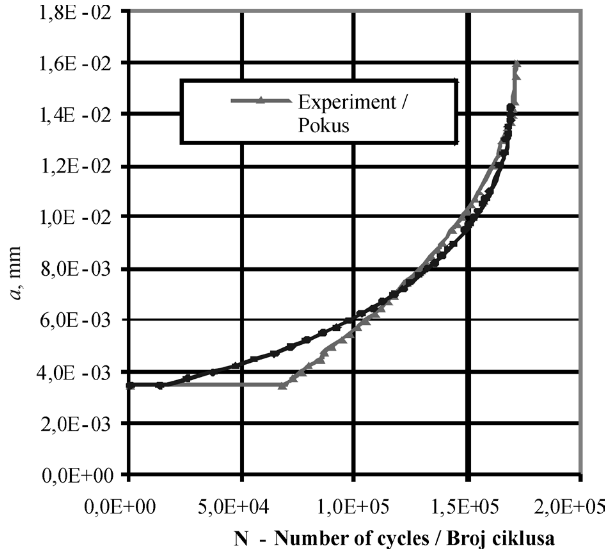


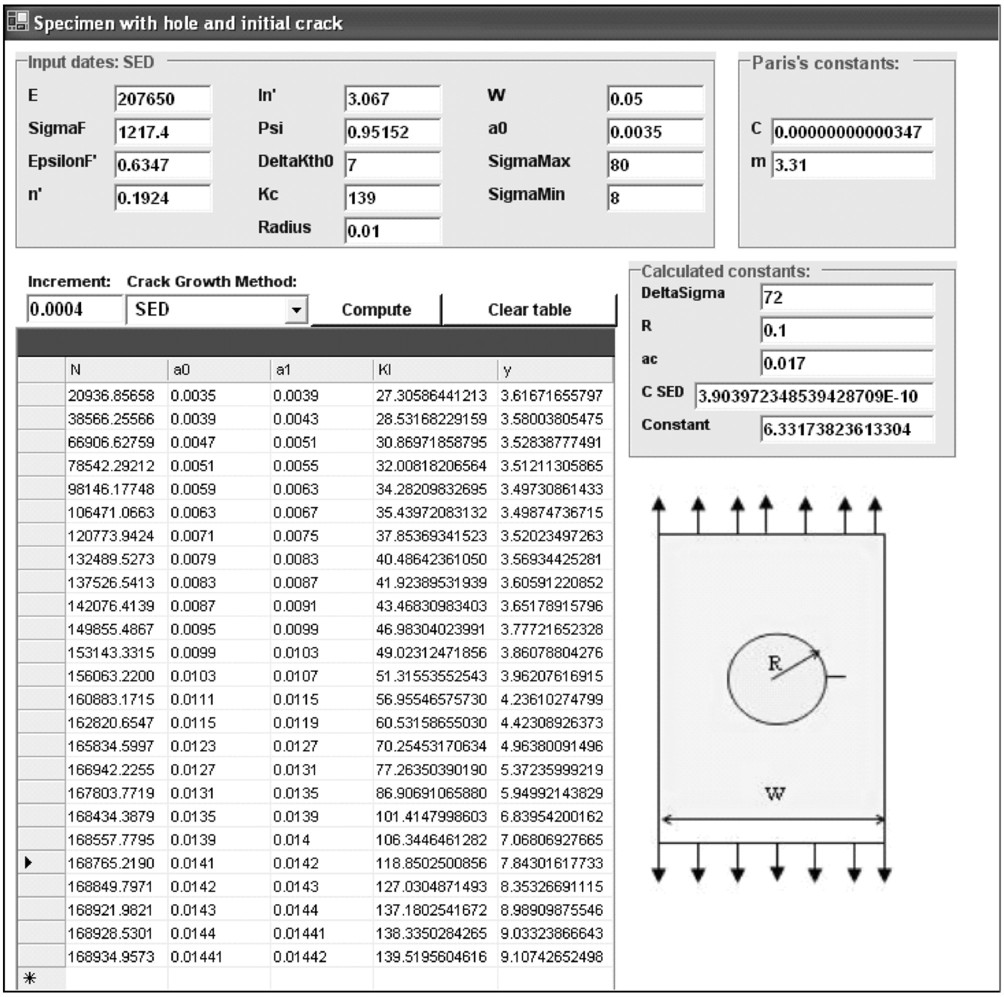
Figure 6. Analysis of crack propagation: Comparison of computation and experimental results (K_c= 139)

Slika 6. Analiza širenja pukotine: usporedba proračunskih i eksperimentalnih rezultata (K_c= 139)

In previous Table 3 are: SigmaF ≡ σ'_f, EpsilonF ≡ ε'_f, DeltaKth0 ≡ ΔK_{th0}, Psi ≡ ψ, SigmaMax ≡ S_{max}, SigmaMin ≡ S_{min}, Y-is the corrective function defined by eq. (8) and C,m – Paris`s constants. Numerical simulation results for crack propagation on a structural element which contains a hole and a single crack, based on strain energy density method (SED), points out that presented approach could be efficiently used in the analyses of residual life. As previously mentioned, presented strain energy density method uses cyclic characteristics of the material from low-cycle fatigue (LCF) domain instead of dynamic parameters from more conventional laws for crack propagation by Paris and others [15].

Table 3. Complete numerical simulation results for crack propagation using strain energy density method and "P-GED" software

Tablica 3. Kompletni rezultati numeričke simulacije za širenje pukotine primjenom metode gustoće energije deformacije i "P-GED" programa



Specimen with hole and initial crack

Input dates: SED

E	207650	ln'	3.067	W	0.05
SigmaF	1217.4	Psi	0.95152	a0	0.0035
EpsilonF'	0.6347	DeltaKth0	7	SigmaMax	80
n'	0.1924	Kc	139	SigmaMin	8
		Radius	0.01		

Paris's constants:

C 0.00000000000347

m 3.31

Calculated constants:

DeltaSigma 72

R 0.1

ac 0.017

C SED 3.903972348539428709E-10

Constant 6.33173823613304

Increment: 0.0004 Crack Growth Method: SED Compute Clear table

N	a0	a1	KI	y
20936.85658	0.0035	0.0039	27.30586441213	3.61671655797
38566.25566	0.0039	0.0043	28.53168229159	3.58003805475
66906.62759	0.0047	0.0051	30.86971858795	3.52838777491
78542.29212	0.0051	0.0055	32.00818206564	3.51211305865
98146.17748	0.0059	0.0063	34.28209832695	3.49730861433
106471.0663	0.0063	0.0067	35.43972083132	3.49874736715
120773.9424	0.0071	0.0075	37.85369341523	3.52023497263
132489.5273	0.0079	0.0083	40.48642361050	3.56934425281
137526.5413	0.0083	0.0087	41.92389531939	3.60591220852
142076.4139	0.0087	0.0091	43.46830983403	3.65178915796
149855.4867	0.0095	0.0099	46.98304023991	3.77721652328
153143.3315	0.0099	0.0103	49.02312471856	3.86078804276
156063.2200	0.0103	0.0107	51.31553552543	3.96207616915
160883.1715	0.0111	0.0115	56.95546575730	4.23610274799
162820.6547	0.0115	0.0119	60.53158655030	4.42308926373
165834.5997	0.0123	0.0127	70.25453170634	4.96380091496
166942.2255	0.0127	0.0131	77.26350390190	5.37235999219
167803.7719	0.0131	0.0135	86.90691065880	5.94992143829
168434.3879	0.0135	0.0139	101.4147998603	6.83954200162
168557.7795	0.0139	0.014	106.3446461282	7.06806927665
168765.2190	0.0141	0.0142	118.8502500856	7.84301617733
168849.7971	0.0142	0.0143	127.0304871493	8.35326691115
168921.9821	0.0143	0.0144	137.1802541672	8.98909875546
168928.5301	0.0144	0.01441	138.3350284265	9.03323866643
168934.9573	0.01441	0.01442	139.5195604616	9.10742652498

5. Conclusion

The present paper is aimed at developing a computation fatigue crack growth model based on strain energy density (SED) method incorporating the cyclic deformation properties obtained from a low cycle fatigue (LCF) test.

Low-cycle properties of S355 J2 G3 steel of which the lattice construction of the tower of the CARDWELL II KB 210 A overhaul facility has been made of were obtained experimentally. In order to verify the computational residual lifetime evaluation based on a low cyclic fatigue properties of the material, the crack propagation analysis involving complex specimens with a hole and a single initial crack subjected to cyclic loading of constant amplitude has been carried out. For accurate measurement of crack propagation depending on the number of cycles measurement foils have been used.

Also it is more advantageous to from a model mainly based on LCF properties since they are easer to obtain experimentally. The complete computation procedure for prediction of residual life of structural elements which contain a hole and initial damage in the form of a crack is proposed. The proposed computation procedure is improved for the assessment of the residual fatigue strength because it doesn`t require additional experimental research for determination of necessary dynamic parameters. In this approach low-cycle fatigue parameters are being used. So, if the assessment of lifetime of a structural element is being made in the low-cycle fatigue domain, right after a certain number of cycles until the initial damage occurs, it is possible to determine the number of cycles until failure. For the prediction of residual life, or in other words the analysis of crack propagation, strain energy density method has been used. Methods of numerical simulation were based on strain energy density method where the cyclic characteristics of material instead of conventional dynamic parameters for the analysis of crack propagation have been used. Results of numerical assessment of residual life agreed well with those obtained by experiment. . It should be pointed out that one of main advantages which refer to the use of Strain Energy Density Method is the fact that this method utilizes low-cycle fatigue properties of the material used for lifetime evaluation until the occurrence of initial damage and that no additional tests for determination of properties of the material necessary for conventional crack propagation laws are required.

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