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EXPERIMENTAL AND THEORETICAL ANALYSIS OF A CRACK GROWTH UNDER LOADING WITH VARIABLE AMPLITUDES

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The paper presents the results of influence of the loading amplitude upon growth of the fatigue cracks in the steel. Applying the computer measure system measurements of the crack length at each phase of propagation were carried out. Investigations were carried out on specimens with the thickness of 28.5 mm. Numerical calculations were carried out according to the modified Paris formula. The results of experimental investigations and numerical research are shown in a graphic form.

1. Introduction

In steelworks with sharp notches or material discontinuities fatigue cracks originate comparatively easy. It particularly refers to big welded structures working at variable loading amplitudes. Calculation of fatigue durability in such cases can be limited to analysis of fatigue cracks growth. Theoretical description of fatigue cracks growth at variable amplitudes introduces many difficulties because of variable amplitudes due to changes of stress intensity factors and the plasticization area sizes around its edge.

Exploitation loading in ship construction elements change over a wide range. Especially heavy overloads occur during surging waving. Their influence on fatigue durability of construction elements may be specified on the base of results of experiment carried out under conditions close to the exploitation.

Published results of examinations (cf Stephens, 1978; Glinka and Stephens, 1981; Kocańda and Szala, 1985; Edit. Newman and Elber, 1988; Borowiecki et al., 1992) point that deceleration or acceleration of fatigue crack growth mainly depends on material, state of tensions and plastic deformations appearing on the edge of the crack. Lack of the theoretical and experimental investigations into the growth of fatigue cracks in ship's steels at various loading amplitudes may be noticed in the attainable literature. That is why the idea of measuring the fatigue crack growth in DH 32 steel used in hull plating occured. The measurements were taken on CT specimens loaded according to a block programme built on a base of a real loading spectrum of exploitation.

2. Measuring stand

The measuring stand was composed of three basic systems:

1. A fatigue machine ZD 100 Pu controlled by a microprocessor connected to a microcomputer IBM PC/XT
2. A system for an automatic measurement of the length of the fatigue crack
3. An IBM PC/XT computer with an analog-digital card and a suitable software for analysis of results of investigations.

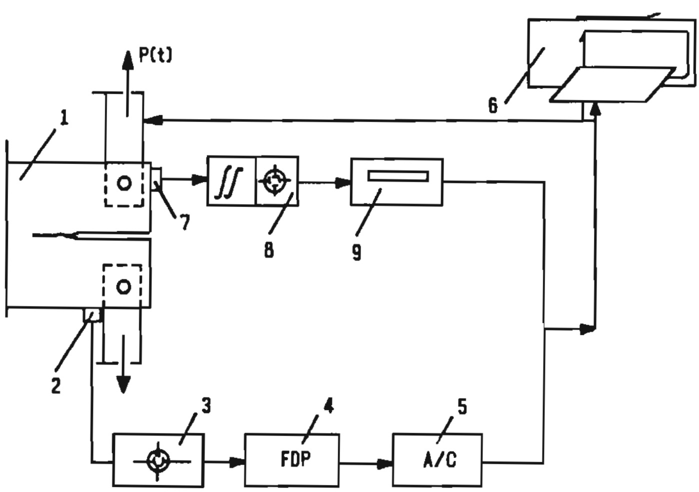

Fig. 1. The scheme of the measuring stand

The length of the fatigue crack in the specimens (1) was measured with ultrasonic defectoscope (2) equipped with gauges fixed to the specimen. Ultrasonic waves reflected by the crack return as an echo to the defectoscope head and are transformed then into adequate electronic impulses. Simultaneously there appears a voltage proportional to the length of the crevice in the analog output of the defectoscope. Because of the voltage pulsation a low-capacity filter FDP3 (4) is used which averages values of the voltage by isolating the constant component from the voltage signal. The signal goes to the microcomputer IBM PC/XT (6) by an analog-digital converter (5).

As the force loading the specimen changes cyclically, the recording of the measurements takes place at every specified number of cycles with a special set. The set is composed of an acceleration converter (7), vibrometer (8) and a counter with initial adjusting (9). While counting the number of cycles set on the impulse counter, a signal which controls storing the results in the computer memory, is generated. Thanks to the possibility of setting any number of frequency while saving the results, changes in the length of the crack may be measured at any cycle of loading which is especially important for the changes of loading amplitude in the last phase of the crack growth.

3. The course of investigations

Investigations were carried out on CT specimens with a thickness of 28.5 mm. A sharp notch was made according to the standard PN-84/H-04333. The specimens of orientation *LT* (according to PN-88/H-04336) were cut out from one sheet of steel used in hull plating. Strength properties and chemical constitution of it are given in the Table 1.

Table 1

R_m [MPa]	R_e [MPa]	A_5 [%]	Z [%]	C [%]	Mn [%]	Si [%]	P [%]	S [%]
496	328	35	60	0.18	1.20	0.30	0.03	0.03

Measurements of the crack growth in the specimens were carried out in the conditions of programme loadings. The programme of loading spectrum of exploitation was measured on the North-American Line for the Polish Ocean Lines order. In order to measure the velocity of the fatigue crack propagation at different level of loadings, F_{min} was assumed to be invariable and F_{max} was being changed by loading coefficient $\alpha = 0.7, 0.8, 0.9, 1.0, 1.1$. Each block of the programme was composed of 27000 cycles – Table 2.

Table 2

	No.of cycl.	F_{min} [kN]	F_{max} [kN] $\alpha = 1.1$	$\alpha = 1.0$	$\alpha = 0.9$	$\alpha = 0.8$	$\alpha = 0.7$
1	500	51.5	104.5	95.0	85.5	76.0	71.3
2	1500	51.5	107.8	98.0	88.5	78.4	73.7
3	500	55.0	107.8	98.0	88.5	78.4	73.7
4	500	55.0	111.6	101.5	91.4	81.3	76.2
5	2000	51.5	111.6	101.5	91.4	81.3	76.2
6	500	51.5	115.5	105.0	94.5	84.0	78.8
7	500	51.5	118.8	108.0	97.5	86.5	81.2
8	1000	58.2	118.8	108.0	97.5	86.5	81.2
9	500	61.5	118.8	108.0	97.5	86.5	81.2
10	1000	55.0	122.6	111.5	100.4	89.3	83.7
11	500	55.0	130.1	118.3	106.5	94.5	88.7
12	500	55.0	137.5	125.0	112.5	100.0	93.8
13	500	51.5	137.5	125.0	112.5	100.0	93.8
14	1000	51.5	144.6	131.5	118.4	105.3	98.7
15	500	55.0	144.6	131.5	118.4	105.3	98.7
16	500	51.5	152.1	138.2	124.5	110.5	103.7
17	1000	51.5	155.4	141.5	127.4	114.3	106.2
18	500	51.5	170.5	155.0	139.5	124.0	116.3

The results of measurements of the crack length as a function of the number of loading cycles and various loading coefficient α are presented in Fig.2.

Fig.3 presents details of changes of the crack length registered during measurements (for $\alpha = 0.8$).

4. Numerical calculations

Numerical calculations were carried out according to the modified Paris formula

$$\frac{da}{dN} = C(\Delta K - \Delta K_{th})^m \tag{4.1}$$

where C, m, K_{th} are material constants determined experimentally on the base of investigations into the fatigue cracks growth, ΔK is a range of the stress intensity factor.

In virtue of own investigations it was assumed that $C = 2.31 \cdot 10^{-12}$, $m = 3.62$ and $K_{th} = 7.0$ MPam$^{1/2}$. Eq (4.1) was integrated step by step with

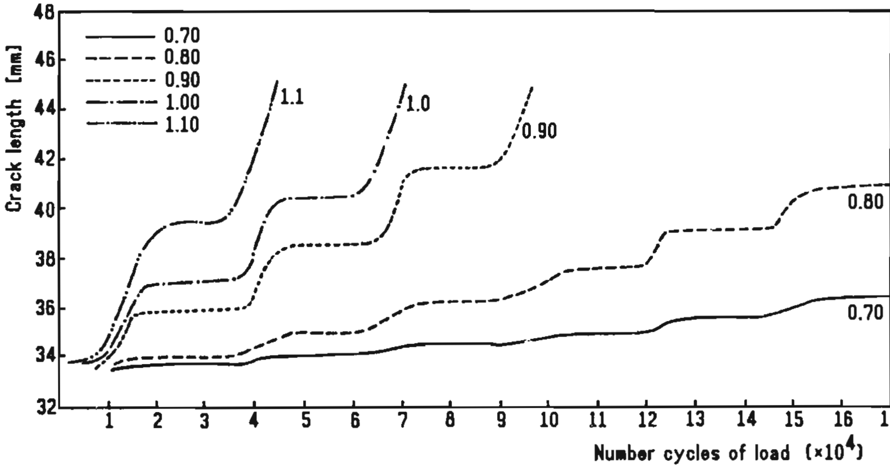

Fig. 2. The results of experimental investigations

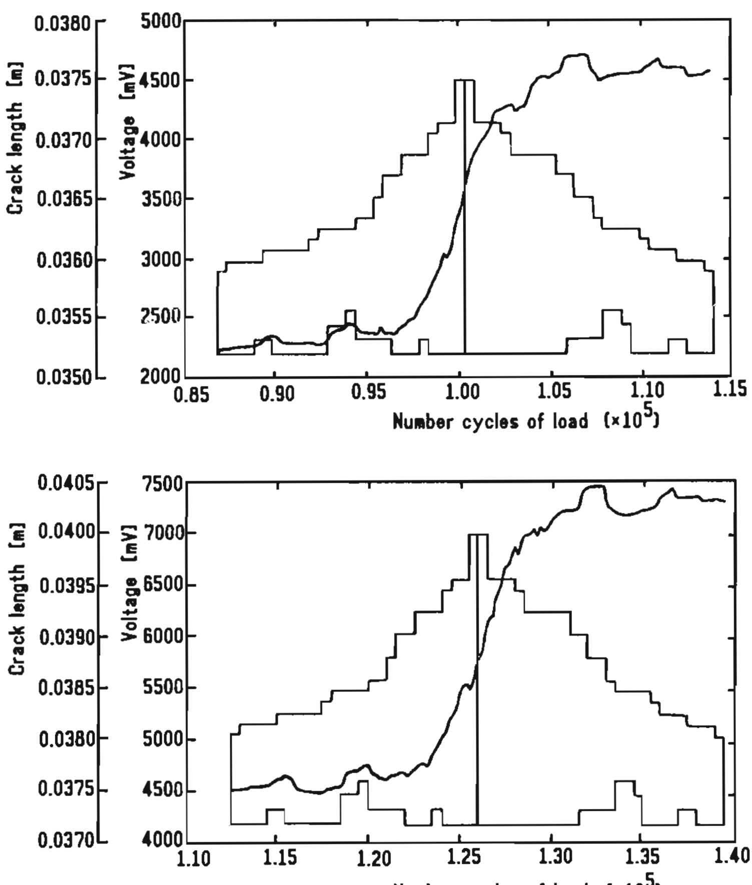

Fig. 3. The changes of the crack length measured during experiment

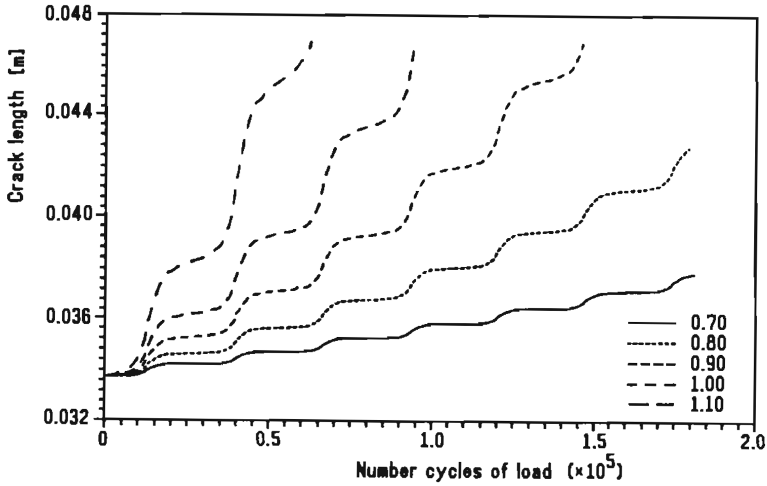

Fig. 4. The results of numerical calculations

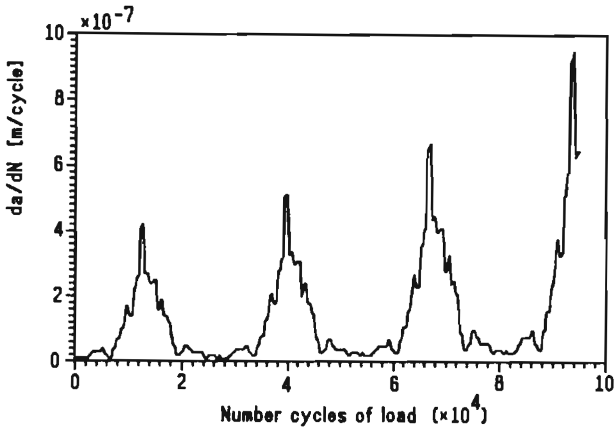

Fig. 5. The velocity of the crack growth as a function number of loading cycles

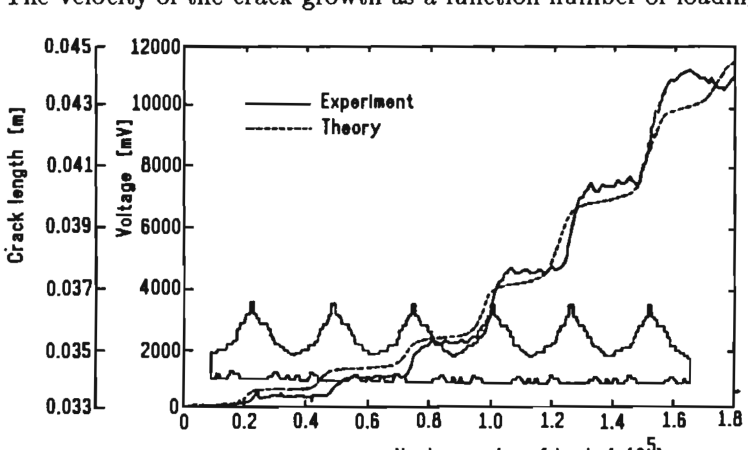

Fig. 6. The comparison of results of experimental and numerical investigations

the use of the own computer programme written in Fortran 77 and run on a microcomputer IBM 386.

The results of the numerical calculations done at the same parameters and sizes are presented in Fig.4.

Fig.5 presents changes in the crack growth velocity as a function of the number of cycles of loading.

Fig.6 presents the comparison of the results of experimental investigations and results of numerical calculations obtained for the loading coefficient $\alpha = 0.8$.

5. Conclusions

- The measuring system used to the investigations allows for analysis of decelerations of fatigue crack growth which was caused by local changes of force amplitudes in the loading spectrum.
- The carried out measurements of fatigue cracks propagation in the DH32 steel allow to estimate fatigue durability at loading of variable amplitudes.
- In spite of using only a simple theoretical model which describes the fatigue crack growth, satisfactory correlation between results of numerical calculations and experimental investigations was obtained.
- The purpose of further work should be to carry out more detailed experimental investigations. Results of the experimental investigations will be applied to create more general theoretical model describing the growth of the crack under variable amplitude of loading.

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Analiza eksperymentalna i teoretyczna wzrostu pęknięć zmęczeniowych pod obciążeniami o zmiennej amplitudzie

Streszczenie

W pracy przedstawiono wyniki badań dotyczących wpływu zmian amplitudy obciążenia na wzrost pęknięć zmęczeniowych w stali DH32 stosowanej na poszycia statków. Stosując skomputeryzowany układ pomiarowy wykonano pomiary długości szczeliny zmęczeniowej w poszczególnych fazach jej rozwoju. Badania wykonano na próbkach CT o grubości 28.5 mm. Przeprowadzono także obliczenia numeryczne stosując numeryczne całkowanie krok po kroku zmodyfikowanego wzoru Parisa. Wyniki pomiarów i obliczeń przedstawiono na wykresach.

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