APPLICATION OF THE ASPEF CONCEPT FOR ESTIMATION OF MATERIAL BEHAVIOUR UNDER CYCLIC LOADING

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Behaviour of materials during low-cycle fatigue is generally characterized by the C and n parameters of Manson-Coffin expression $N^n \Delta \varepsilon p = C$, while the parameters - denoted with the same leters - of Paris-Erdogan law $da/dN = C(\Delta K)^n$ can be used for characterizing the material resistance against the fatigue crack propagation. On the basis of results of both the literature and out investigations it has been verified that these C and n parameters are not independent of each other neither in Manson-Coffin, nor in Paris-Erdogan laws. The single, but a complex material property is in a close correlation with the specific absorbed energy till fracture (ASPEF) including both strenght and strain features of material.

INTRODUCTION

According to the behaviour of materials under cyclic loading three stages can be distinguished: low- and high-cycle fatigue and fatigue crack propagation. Within these stages between the life-time or the fatigue crack growth rate and the loading parameters ($\sigma, \Delta K$ or $\Delta \varepsilon p$) empirical relationships with two parameters were proposed. Among these, the most well-known are the followings:

Manson-Coffin (1, 2, 3) expression (1954)

$$N^n \Delta \varepsilon p = C \qquad (1)$$

which was proposed for low-cycle fatigue, Paris-Erdogan (4) expression (1961)

$$da/dN = C(\Delta K)^n \qquad (2)$$

proposed for describing the fatigue crack growth rate in a given range of stress intensity factor amplitude.

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The next relationship is generally used for analitical approximation of the endurance range of te Wöhler-curve

$$\sigma = C N^{-n} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

All these expressions contain both C and n parameters. According to the generally received practice these two parameters are called as constants characterizing the behaviour of material under the given loading conditions. Obviously the effective values of C and n parameters are not corresponding to each other for the different relationships (1)-(3) and they can be determined on the basis of experimental results. Consequently these parameters are not considered to have only physical content or background unless in some special cases (e.g. in Manson--Coffin relationship) and indirectly.

The question that should be raised is the next: Is it possible that a connection exists between the C and n parameters of any of these relationships? Considering the equations (2) the answer for this question is that this connection exsists. This fact was confirmed in previous paper of ours (4). Generally this question can be formulated as the next: Is it possible to find correlation between the parameters of these two-parameter-relationships when applying them for analysing testing result? We are convinced, that this interconnection should exist as the testing results reflect the reaction of the material for given loading conditions. This reaction represents the internal, complex feature of the material which does not change with varying the loading parameters. In this case the numerical value of the testing result will change, but the complex property of the tested material - which represents the reaction of the material for the given type of loading - cannot be changed, it is unvaried. This fact is reflected in the synergetic approach of fracture processes (5).

The Connection of Parameters in Paris-Erdogan Law

The connection of two parameters in Paris-Erdogan law for fatigue crack growth rate was proved in our earlier paper (6) on the basis of analysing a great number of our own and literature test results considering to steels, aluminium, titan and their alloys. In this paper it is completed for cast irons, too. The connection between C and n was established in the form $C = A/B^n$. The values of A and E constants are shown in Table 1.

The data for steels include the testing results of the following types of materials: Armco-iron, plain carbon steels, mild steels, eutectoid rail steels, microalloyed steels, HSLA steels, high-strength, hot-resistance, stainless and maraging steels and results for welded joints. The testing temperature was in the range of 77-873 K, and the load ratio was within the interval of $0.05 < R < 0.7$, mainly in the range $0.05 < R < 0.15$.

TABLE 1 - The Connection of the Two Parameters of the Paris-Erdogan Law for Different Type of Construction Materials

Material	Number of Data	A	B	r %	Application range
Steels	352	1.03E-4	27.2	98.9	$1.05 \leq n \leq 11.00$
Al and its alloys					
non-tempered	47	5.16E-5	5.09	96.5	$2.00 \leq n \leq 5.69$
tempered	23	4.58E-5	39.79	99.7	$1.87 \leq n \leq 14.43$
Ti and its alloys	43	2.25E-4	17.72	98.3	$2.04 \leq n \leq 6.21$
Cast irons	45	4.62E-5	18.14	98.8	$3.00 \leq n \leq 8.25$

Notes: unit of $\underline{B}$ MPa$\sqrt{m}$,
unit of $\bar{A}$ mm/cycl.,
r - correlation coefficient.

The experimental results obtained for the aluminium and its alloys 70 data has been evaluated by this time. In opposition of other authors we experienced, that the data arer grouped arround two different connections. One of these groups includes the data of deformable but non-tempered alloys, and the other one the data of deformable and tempered alloys.

In case of titan and its alloys 43 data has been obtained. Amoung them α and β modifications, test results of wellded joints - welded by electron beam - were analysed. The testing temperature range was $4 \div 673$ K, the load ratio interval was $0.05 \leq R \leq 0.5$.

The results of cast irons include 45 data for grey cast iron, nodular cast iron with pearlite with vermicular - graphite (in USA it is named compacted graphite). The testing was carried out at room temperature with a load ratio of $0.01 < R < 0.1$.

The Connection of Parameters is Manson-Coffin Law

The parameters of Manson-Coffin relationship for 40 different type of steels and their wellded joint are shown in Fig. 1.

According to this figure the following conclusions can be drawn:

- with increasing the value of n the value of C increases too, and a close connection exists between them represented by the correlation coefficient of 85 %;

- correlation coefficient obtained for this case was found to be less with 13-15 % than that of for the correlation of Paris-Erdogan law.

The latter conclusion follows from the fact that the testing of fatigue crack propagation can be regarded more exact than low-cycle fatigue test. In this latter case specimen geometry has a significant influence on the place of the crack initiation and the propagation rate and so, at least on the life-time, too (8).

Consequences of the connection between C and n

The results shown in the Table 1. and in Fig. 1. are valid only in that case when the testing was carried out in not a highly corrosive medium. Results of investigations in corrosive medium are significantly different from the detailed connections. This difference depends on the type of tested material and on the characteristics of the corrosive medium. This fact can be explained that the testing results reflect the reaction of the material to single (only mechanical) loading or a combined (mechanical loading and corrosive medium) loading conditions. Parameters referring to the detailed, two different type of circumstances naturally cannot give the same mass of values.

The consequence of the close correlation between C and n in both cases is the fact, that the fatigue resistance (crack growth and low-cycle) can be characterized by a single but a complex material property including both strength and strain characteristics. As it was shown in our carlier paper (9) for 18 different types of steels (from stainless up to eutectoid rail steels) there is a close connection between the exponent of Paris-Erdogan low and the ASPEF (10, 11) measured on a smooth cylindrical tensile specimen. The next expression was obtained

$$n = (5.0652 \pm 0.1168) - (0.00168 \pm 0.0001)\, W_c \quad \ldots\ldots\ldots\ldots (4)$$

with a correlation coefficient of 99.6 %, where W_c is the value of ASPEF.

The relationship between the exponent of Manson-Coffin law and ASPEF is shown in Fig. 2. According to this figure the next conclusion can be drawn:

- with increasing the W_c, the exponent of Manson-Coffin expression decreases,

- the value of correlation coefficient is significantly less - it is only 55.4 percent - then in case of fatigue crack growth resistance where the value of it is 99.6 percent.

The latter is included directly by two facts. On one hand, the value of W_c was estimated on the basis of traditional tensile testing data (ultimate strength, yield stress, percentage reduction of area) and on the other hand - as it has been emphasized - the results of low-cycle fatigue, so the values of $\underline{C}$ and $\underline{n}$ can be dependent on specimen geometry. In those three cases that were our own testing the values of ASPEF and the exponents of Manson-Coffin law were determined accurately. When analysing the data of different literatural sources we had to take into account the results obtained on mainfold type and size specimens.

SYMBOLS USED

N	=	number of loading cycles,
$\Delta\varepsilon p$	=	plastic strain amplitude (percent),
ΔK	=	stress intensity amplitude MPa m),
σ	=	applied stress (MPa),
Wc	=	absorbed specific energy till fracture measured by tensile test of a smooth cylindrical specimen MJ/m^3,
C,n,A,B	=	constants of material,
da/dN	=	fatigue crack growth rate (mm/cycle)

REFERENCES

(1) Manson, S.S., NACA Rept. 1170. 1954.

(2) Coffin, L.F. Jr., Trans. ASME Vol.76. 923. 1954.

(3) Coffin, L.F. Jr., Cyclic Strain and Fatigue Behaviour of Metals in the Creep Range. Proc. of the First Int. Conf. on Fract. Edited by T. Yokobori, T. Kawasaki, J.L. Swedlow. Vol.3. 1985. pp.1543-1566.

(4) Romvári, P., Tóth, L., Nagy, Gy., Analysis of Fatigue Crack Growth Laws (in Russ.) Probl. Proch. No.12. 1980. pp.18-28.

(5) Ivanova, V.S., Mechanics and Sinergetics of Fatigue Crack Growth (in Russ.) Fizika Himija Mech. Mat. No.1. 1986. pp.62-68.

(6) Tóth, L., Nagy, Gy., The Connection of the Constants of Paris-Erdogan Law and its Consequences. Proc. 8th Congress on Material Testing, Budapest, 1982. Edited by Scientific Society of Mechanical Engineers. Vol.1. pp.372-378.

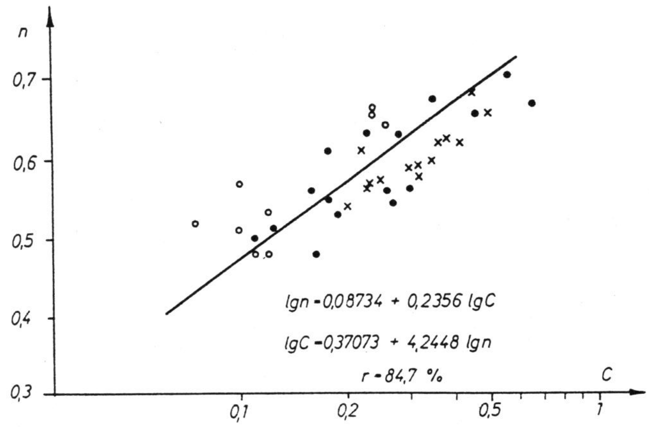
(7) Kataog Mechanickych Vlasnosti' Zvarového Spoja. VÚZ, Bratislava, Vol.I. 1980., Vol.II. 1981., Vol.III. 1982.

(8) Nagy, Gy., Effects of Specimen Geometry on the Fracture Place at Low-Cycle Fatigue (in Hung.), Thesis of MSc 1988. Technical University of Heavy Industry

(9) Tóth, L., Romvári, P., Application of ASPEF Concept for Estimation of Cyclic Fracture Toughness of Steels (in Russ.), Probl. Proch., No.1. 1986. pp.13-16.

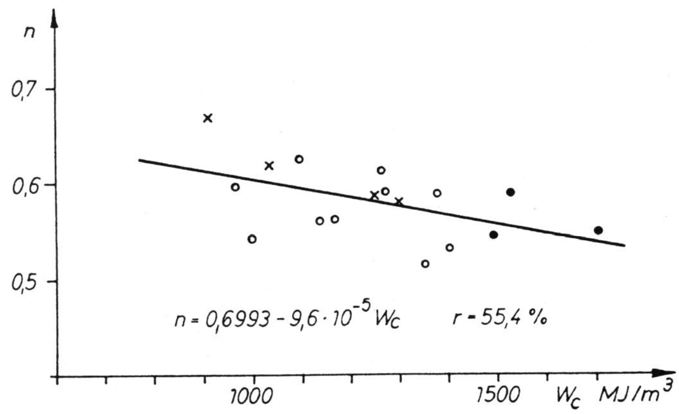
(10) Gillemot, L., Criterion of Crack Initiation and Spreading, Engineering Fracture Mech. Vol.8. 1976. pp.239-253.

(11) Gillemot, F., Czoboly, E., Havas, I., Fracture Mechanics Applications of Absorbed Specific Energy: Notch and Unnotched Specimen. Theor. and Appl. Fract. Mech. Vol.4. 1985. pp.39-45.



NOTES: x creep resistance steels,
o Cr-Ni steel,
• from reference (7).

Figure 1 Relationship between the two parameters of Manson-Coffin law



NOTES: x creep resistance steels,
o from reference (7),
• own test results.

Figure 2 Relationship between the exponent of Manson-Coffin law and the value of ASPEF measured on smooth tensile specimen.