APPLICATION OF DIMENSIONAL ANALYSIS METHOD TO GENERALIZATION OF RESULTS OF SPECIMENS FATIGUE TESTS AT VARIOUS LOADING CONDITIONS AND TEST TEMPERATURES

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ABSTRACT

The paper demonstrates the possibility of application of dimensional analysis method to generalization of results of the fatigue tests performed on various specimens and to finding the general rules of fatigue limit variations.

With allowance for the common knowledge of the fatigue process and taking into account the geometric features and material of the specimens, a number of variables is selected which, in the author's opinion, make the greatest contribution to forming the fatigue characteristics.

The selected variables are combined, with application of the dimensional analysis, into dimensionless groups which set up the relationship of fatigue limit variation.

The numerical realization of the relationship thus obtained has been implemented on the plain specimens differing in configuration and material at various loading conditions; the tests have been performed at normal and elevated temperature.

The processing of the test results has demonstrated that the fatigue limit variations relationship, incorporating the dimensionless groups, is of a general nature.

KEY WORDS

Dimensional analysis, generalized relationship, plain specimen, fatigue limit, multivariate regression analysis.

At present there exists a vast scope of materials regarding the results of tests of specimens differing from each other in shape, materials, methods of manufacture, methods of heat treatment, etc.

The purpose of the present paper is to generalize the available results of the fatigue tests and reveal general laws of variations of the fatigue limit of different specimens.

To reveal the general law of variation of the fatigue limit, a known method of dimensional analysis was used which, on the basis of conception about physical nature of the process and possible mathematical relationships (number of parameters), permitted to obtain a generalized relationship describing this process.

Since individual factors affect the process under investigation not separately but in combination, so, as a matter of fact, not individual parameters should be considered but rather their aggregates (complexes) determined for the given process.

Therefore new variables (complexes) in their essence are of a generalized nature and characterize the process as the whole.

To obtain the generalized relationship with due account of the known conceptions about the fatigue process and structural features of the specimens, the following parameters have been used in the present paper:

σ_{-1} - fatigue limit of sample
EI - rigidity of sample
ℓ - length of sample
S - cross-section area of sample
γ - density of material
σ_B - ultimate strength of material
σ_T - yield point of material

The physical relation of the selected parameters can be written in an implicate form as

$$F_1(\sigma_{-1}, EI, \ell, \gamma, \sigma_B, \sigma_T) = 0 \qquad (1)$$

Relationship (1) can be transformed, with the use of the known method of dimensional analysis, into a relation containing dimensionless groups composed of the selected parameters

$$F_2(K_1, K_2, K_3) = 0 \qquad (2)$$

where: $K_1 = \dfrac{\sigma_{-1}\ell^4}{EI}$ - group which characterizes relation between applied external load and inner elastic forces during oscillations,

$K_2 = \dfrac{EI}{\gamma \ell^3 S}$ - group which characterizes relation between inertial forces and inner elastic forces during oscillations

$K_3 = \dfrac{\sigma_B}{\sigma_T}$ - group which characterizes structural changes in material during fatigue testing.

For performing the numerical analysis of relationship (2), the results of fatigue tests performed on the specimens, which differ from each other in shape and material, at various test

temperatures and with various methods of loading, the specimens being of a plain type with working surface roughness not over 0.8 were used (these results have been published in 'Problemy prochnosti' (Problems of strength) magazine). The specimens have not been subjected to hardening or special methods of heat treatment and have not been coated.

The tests have been performed in accordance with a symmetrical cycle of bending loading at normal and elevated temperatures (from 300°C to 1000°C) in the atmosphere not containing corrosive media (inert atmosphere). The testing base has not been less than 10^7 cycles. The characteristics of material are taken from reference publications.

The range of variations of the groups values which were calculated for sets of the samples classified in accordance with the accepted schemes of loading is presented in Table 1.

Table 1. Range of Variation of Dimensionless Groups Values.

Line No.	Type of loading	Groups K_1	K_2	K_3
1.	Single plane lateral bending	2207-47110	1690-5173	1.03-2.06
2.	Pure bending with specimen rotation	0.81-341	19541-1698687	1.08-2.95
3.	Lateral bending of cantilever specimen with force plane rotation	1587-2335	4600-5200	2.02-2.67
4.	Lateral bending with cantilever specimen rotation	0.19-18.84	3717-284070	1.18-1.65

In various engineering calculations the type of function which establishes a relation of one dimensionless group to another is represented as a power series (taking into consideration only the first member of a series) unless the obtained data prove that the function is more complicated.

Therefore the experimental data have been processed with the use of relationship

$$K_1 = A \cdot K_2^{\alpha} \cdot K_3^{\beta} \qquad (3)$$

A preliminary analysis of the test results with the use of relationship (3) coordinates has demonstrated the availability of 4 groups of points differing in the scheme of loading and test temperature: (a) single plane lateral bending of cantilever specimen; (b) pure bending with cantilever specimen rotation; (c) pure bending with specimen rotation and lateral bending of cantilever specimen with force plane rotation; (d) pure bending with force plane rotation (at elevated test temperature).

With the use of multivariate regression analysis, coefficients A, and of relationship (3) have been determined for each of the groups. The results of calculations are presented in Table 2.

Table 2. Values of Coefficients of Relationship (3).

Line No.	Type of loading	A	α	β
1.	Single plane lateral bending of cantilever specimen	132.10^8	-1.7651	0.1269
2.	Lateral bending with cantilever specimen rotation	57366	- 0.9886	-0.1727
3.	Pure bending with specimen rotation and lateral bending of cantilever specimen with force plane rotation	$8.99.10^8$	-1.4005	-1.2229
4.	Pure bending with specimen rotation (at elevated test temperature)	$2.19.10^8$	-1.318	-0.734

Note: Multiple correlation coefficients for groups 1, 2, 3 and 4 are equal to 0.84; 0.98; 0.96; 0.80 respectively

The graphic representation of the results of processing with the use of relationship (3) coordinates (H is the right-side part at A=1) is presented in Fig.1 wherein, apart from the experimental points, the lines of regression are shown in solid lines and the boundaries of 95% confidence interval are shown in dashed lines.

The obtained results prove that application of dimensional analysis method for generalization of the fatigue tests performed on various specimens permits to obtain the generalized relationship of fatigue limit variation.

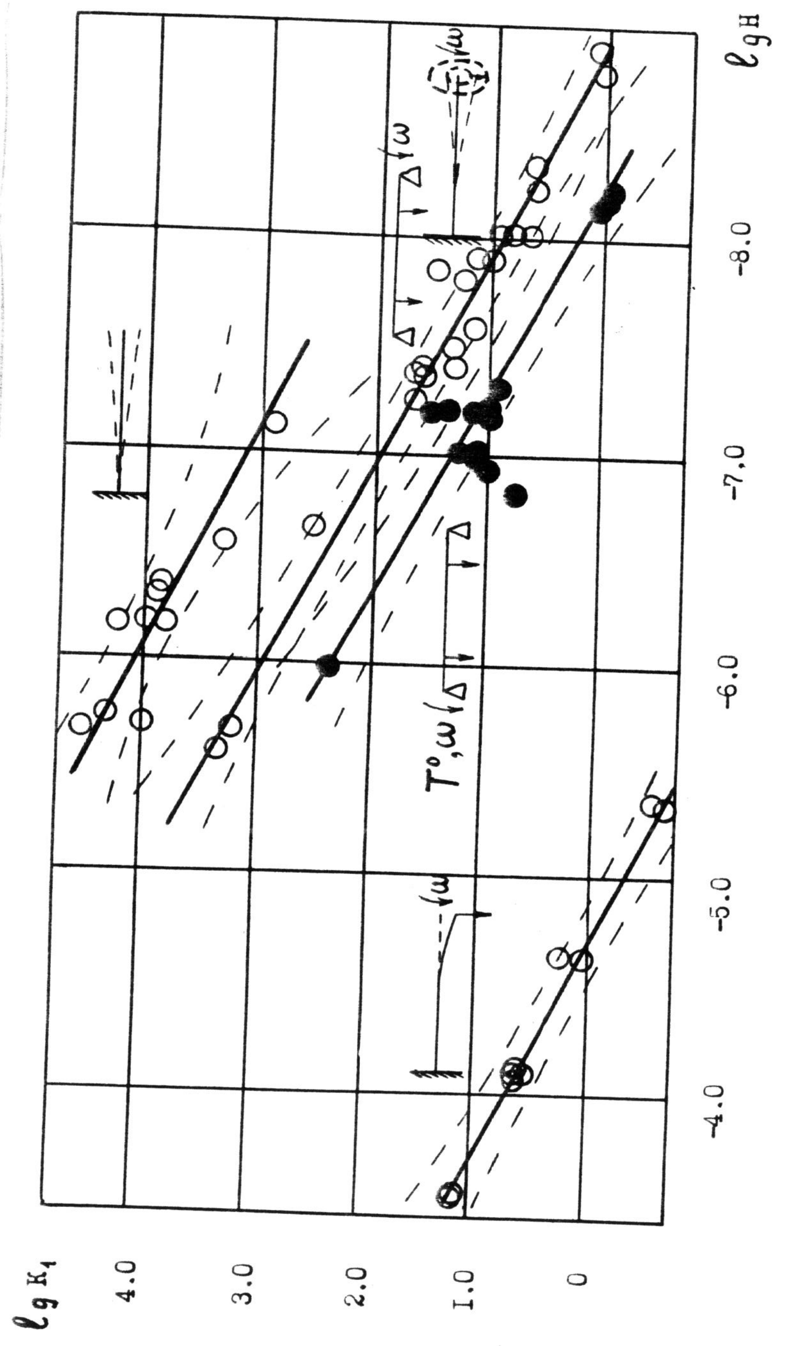

Fig.1. Generalized relationship of fatigue limit variation for plain specimens

o - room temperature

● - elevated temperature