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NUMERICAL AND EXPERIMENTAL APPROACHES USING FOR EVALUATING FATIGUE LIFE OF A CYLINDRICAL SAMPLE FROM 09G2S STEEL

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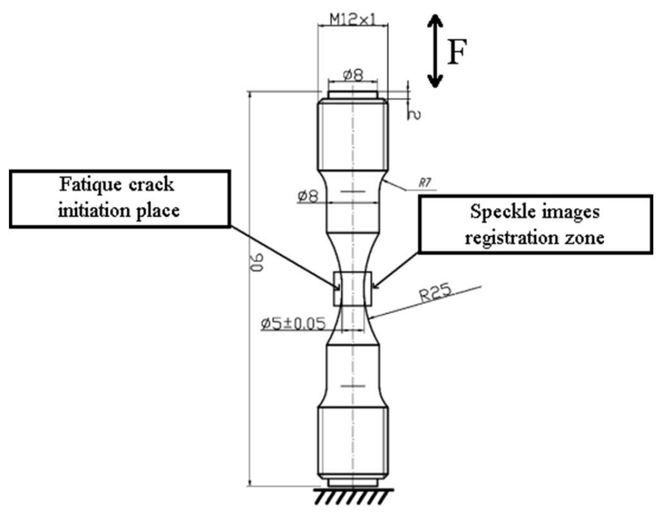
INTRODUCTION:

Questions of durability prediction and constructions elements resource estimation do not lose the relevance. The solution of the fatigue strength estimating problem of real products is complicated by the fact that structures elements during the life cycle experience a long cycle loads of a wide range of values. In the study of fatigue failure, an important problem is the development of methods for predicting the process, which are based on the experimental Woehler curves. Describing the processes leading to fatigue failure, there are difficulties associated with the existence of incubation stage which may not be accompanied by a change in any parameters recorded by means of nondestructive testing. The purpose of this work was to determine the possibility of constructing a material damage complex model based on fracture resistance experimental data and numerical simulation, using the example of structural steel 09G2S, taking into account the influence of a loads wide range covering various operating conditions inherent in the structure elements. The solution of this task will help reduce the design stage of a number of critical objects and structural elements, and also simplify the assessment of their residual durability.

MATERIALS AND METHODS

The study object was a cylindrical specimen with a radial polished neck of 5 mm diameter made of low-carbon structural steel 09G2S. To install the sample in the test machine grips the sample had threaded heads with an increased diameter to reduce the effect of the sharp concentrator on the threads. Cyclic loading is realized on a high-frequency resonant testing machine MIKROTRON ±20 kN (Rumul) under the uniaxial tension-compression scheme (R-ratio R = -1) with applied force control. During the cyclic loading, the level of applied force was increased every 100000 loading cycles, so the amplitude values of the applied load for each stage were: 5.75, 6.50, 7.25, 8.00, 8.75, 9.50 kN.



Fatigue specimen geometrical dimensions.

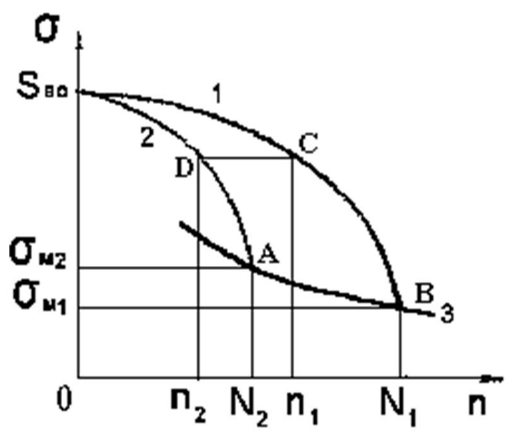
Numerical calculation of the material properties degradation degree under the influence of cyclic loading is carried out using the method of linear damage summation, which determines the resource of a sample expressed in the number of cycles before failure. Since the maximum Mises stresses σ_{max} in the sample under the design conditions arise practically at one point, therefore it is possible to view the resource by this point.

Taking into account the nature of the component loads and the adopted coefficient of dynamics, it is possible to determine the amplitude and average stresses σ_a, σ_m for each mode at the study point.

Writing down the failure criterion for a nonstationary load in the form $\sum \frac{n}{N} = 1$, introduce the damage function normalized on the interval [0, 1] and obtain

$$\omega = \frac{S_{B0} - S_B(\sigma_M, n)}{S_{B0} - \sigma_M} = \left(\frac{n}{N}\right)^m.$$

Consequently, in the experimental detection of the similarity condition for the materials kinetic curves the linear hypothesis of the damages summation will be applicable. This is easily verified on the basis of equal material damage in two states achieved with different load history $\left(\frac{n_1}{N}\right)^{m_1} = \left(\frac{n_2}{N_2}\right)^{m_2}$. From this equality it follows that the number of cycles n_2 at some level of stress σ_{M2} required to obtain a material state equivalent to achieved in n_1 cycles at σ_{M1} is equal to $n_2 = n_э = N_2 \left(\frac{n_1}{N_1}\right)^{\frac{m_1}{m_2}}$ or $n_2 = n_э = N_2 \left(\frac{n_1}{N_1}\right)^{\frac{m_1}{m_2}} \left(\frac{S_{B0} - \sigma_{M1}}{S_{B0} - \sigma_{M2}}\right)^{\frac{1}{m_2}}$.



Graphical interpretation of equivalent stresses

To determine the basic fatigue characteristics – fatigue strength of parts σ_{rp}, S parameter determining the slope of the fatigue curve in logarithmic coordinates, using accumulated experience we accept for steel 09G2S material fatigue strength σ_{-1}= 200 MPa, fatigue strength decrease coefficient for full-scale sample K = 3, cycle asymmetry sensitivity coefficient ψ=0.3. The registration of main fatigue crack formation stage was controlled by "machine-sample" systems loading frequency changing as well as using dynamic speckle-interferometry method.

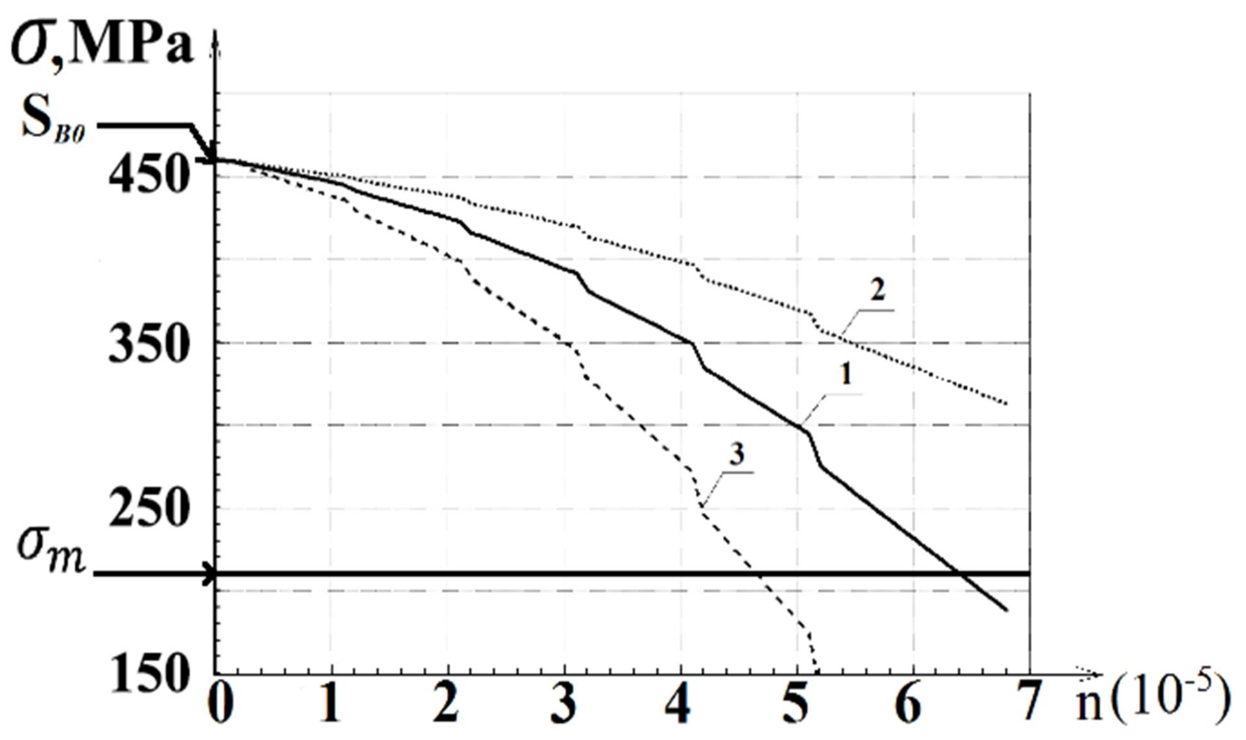
RESULTS AND DISCUSSION

For each loading level, the estimated number of cycles before failure NB was determined by formulas (1-4). The modeling results are presented in the table.

Numerical modeling of the fatigue strength definition results

Load range, N	σ_{max}, MPa	σ_a, MPa	σ_m, MPa	σ_{rD}, MPa	N_B
11500	254	127	127	96,3	868075
13000	287	143,5	143,5	100,15	704333
14500	320	160	160	104	588771
16000	354	177	177	107,967	501651
17500	387	193,5	193,5	111,8167	437729
19000	420	210	210	115,667	387879

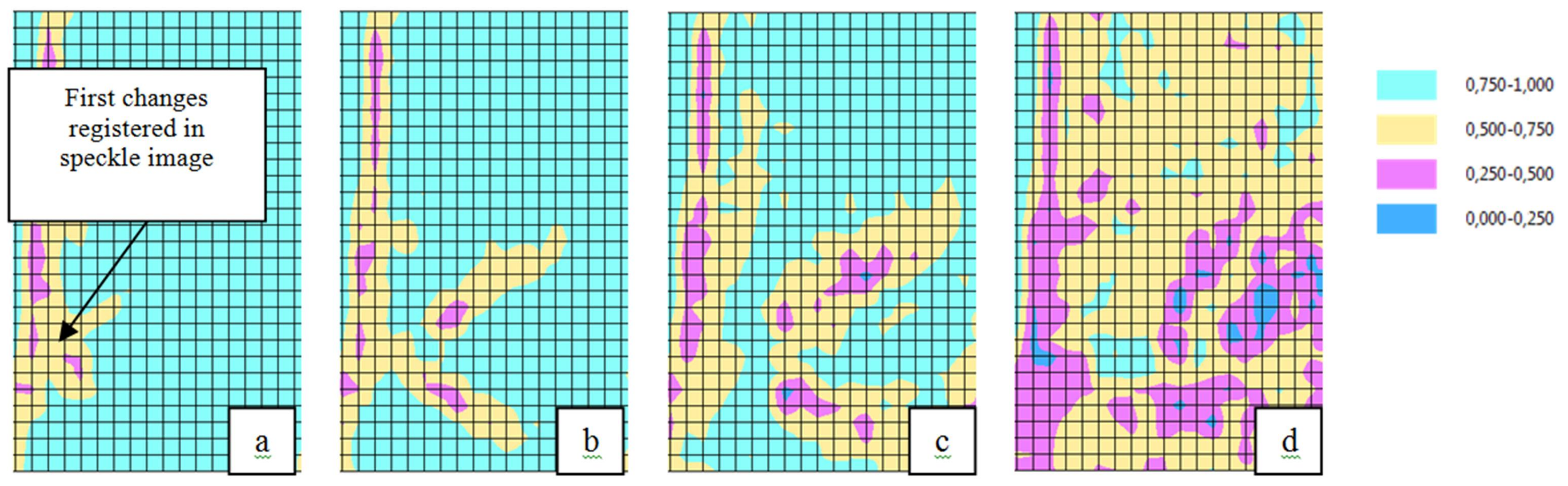
Graphical construction of the damage accumulation curves family in the sample under the action of the load spectrum, calculated from the data of the table, is shown in figure.



Damage accumulation curves in steel 09G2S sample for different power exponents m 1) m=2.05, 2) m=2.15, 3) m= 1.9.

From the data shown in the graph, it can be seen that the curve corresponding to the power exponent m = 2 corresponds most exactly to the experimental data obtained. The modeling results suggest that when the material degradation level reaches the peak amplitude of the cycle, macro failure will occur as a process of residual strength depletion at 640000 cycles of loading. Within the samples full failure occur at 629260 loading cycles in fact.

The results of the number of cycles determination before macro failure made it possible to numerically determine the number of cycles corresponding to the stage at which the material reaches a critical state, above which a macrocrack is formed.



Speckle images correlation field in the stage of fatigue crack formation (a), growth (b, c) and sample complete failure (d).

When 622000 cycles were reached, a fatigue crack was formed on the samples neck surface. In the course of further cyclic loading its development along the cross section of the sample was registered by an optical method in the direction perpendicular to the loading axis. The fatigue crack growth was controlled as the displacement of the localized plastic deformation zone at its top. At the time of the samples complete failure the speckle pattern completely decorrelated. The crack formation moment as well as its gorwth is confirmed by a change in the loading frequency recorded during the entire cyclic loading.

CONCLUSION

Based on the results of numerical calculation and experimental determination of the material properties degradation degree of a cylindrical sample made of 09G2C steel cyclically loaded according to a symmetric law, it is established that the results of the numerical calculation are confirmed by the results of the experiment until the macrocrack formation. With further cyclic loading at the stage of steady crack growth, the registration of the fracture kinetics was carried out using the dynamic speckle-interferometry method. The implemented approach made it possible to carry out a complex evaluation of the stagedness of the fracture process under uniaxial tension-compression conditions with a stepwise increasing loading level. This approach development in relation to the cyclic loading modes with a wide range of applied loads will allow us to reliably estimate the moment of material transfer to the state of irreversible damage and

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