DEVELOPMENT OF FATIGUE FRACTURES IN STEEL WITH DIFFERENT TYPES OF SURFACE PLASTIC DEFORMATION

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The suggestion of safe damage, made in the process of designing of many new mechanizms, admits the normal operation of structure with a developing fatigue fracture. Criteria of fractures development resistance in parts are ones of the main indicators of their efficiency. This work shows the results of experimental research of fractures development under cyclic loading of smooth cylindrical specimen, manufactured from steel with σ_b = 1700 MPa.

INTRODUCTION

Specimen surface is strengthened by rolling with resistance to vibration, as well as by shot-peening with four different regimes. The tests were held on electromagnetic resonance installation under loading by symmetrical bending through an angle with the frequency $\sim$ 70 hz on different levels of voltage in the range of 650-950 MPa. The test installation was operated in self-oscillating regime which helped to fix the moment of the material fracture formation due to the change of the specimen self-oscillation frequency and to follow its development. Measurement accuracy provided the detection of an initial fracture of dimensions 0,1 ... 0,3 mm and being located on the surface, as well as some depth under the strengthened surface layer.

The results of endurance tests for specimen with ground and strengthened surface and voltage range

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800 MPa are presented in figure 1.

In order to describe the development rate of fatigue fractures with the values range from 10^{-5} to 10^{-2} mm/cycle, Paris-Erdogan equation is widely used.

$$\frac{dl}{dN} = C(\Delta K)^{n} \quad \ldots\ldots\ldots \quad (1)$$

where l = fracture length;

N = number of loading cycles;

$\Delta K = K_{max} - K_{min}$ = range of voltage intensity coefficient;

C and n = empiric parameters specified by material characteristics.

In order to determine the voltage intensity coefficient we shall use the method of "yielding", based on expression of D.Irving for strain energy, released on opening the fracture.

$$G = \frac{P}{2} \cdot \frac{d\,(f/p)}{dF} \quad \ldots\ldots \quad (2)$$

where P = loading;

f = sagging of specimen along the line of load application;

F = fracture area.

Taking into consideration a specimen dimensions accepted in this research and comparatively low levels of cyclic voltage in the fracture opening, the condition of plane-strain deformation should be observed. In order to check the observation of this condition we shall use the expressions specifying the specimen minimum dimensions under cycling bend, as well as the size of fatigue fracture

$$d_{min} \geqslant 2{,}3\,\frac{K_I^2}{\sigma_T^2}\,; \quad 2\,h_{min} \geqslant 0{,}9\,\frac{K_I^2}{\sigma_T^2}$$

where d = diameter of specimen cross-section;

K_I = coefficient of voltage intensity;

σ_T = material yield limit.

The tested material has $\sigma_T = 1500$ MPa, $K_{IC} = 75{,}8$ MPa with high values $K_I = K_{IC}$, there will be: $d_{min} = 6{,}4$ mm and $h_{min} = 1{,}2$ mm. When the specimen diameter is 7,5 mm, with high values of K_I, the real depth of a fracture $h > 2$ mm, in this case the condition of plane-strain deformation in the fracture opening is observed. In this case the voltages intensity coefficient can be determined by the following formula:

$$K = \left(\frac{E}{1-\mu^2} \cdot G\right)^{\frac{1}{2}} \quad \ldots\ldots\ldots\ldots \quad (3)$$

where E = elastic modulus;

μ = Poisson coefficient.

Substituting expression (2) in (3) and taking into consideration that with the specimen bend, the voltage $\sigma = \dfrac{32\,P}{\pi\, d^3}$, there will be

$$K = \sigma \cdot d^{\frac{1}{2}} \cdot M$$

where M = dimensionless coefficient, determined by the expression

$$M = \left[0{,}0048 \cdot \frac{d^5}{L^2} \cdot \frac{E}{1-\mu^2} \cdot \frac{d(f/p)}{dF}\right]^{\frac{1}{2}} \quad \ldots . \quad (5)$$

- distance from fulcrum to calculated cross-section. On the basis of the statistical treatment of the test results it is possible to calculate the relationship of specimen yielding f/p depending on the dimensions of a fatigue fracture F, as follows:

$$(f/p) - (f/p)_o = 4{,}4 \cdot 10^{-4} \cdot F^{1{,}5}$$

where $(f/p)_o$ = yielding of specimen without fractures

In this case $\frac{d(f/p)}{dF} = 6,6 \cdot 10^{-4} \cdot F^{0,5}$ . . . . (6)

Using expression (4), (5), (6), it is possible to get

$$K_I = 0,0139 \quad \sigma \cdot d^{0,5} \cdot F^{0,25} \quad . . . . (7)$$

According to the analysis of fatigue fractures it is specified

$$\bar{F} = 10^{c_1} \cdot \bar{l}^{\,c_2} \quad . . . . (8)$$

where $\bar{F} = F/0,25 \ \pi d^2$ = fracture relative area;

$c_1=0,4;\ c_2=2,0$ = for ground specimen;

$c_1=0,5;\ c_2=2,0$ = for strengthened specimen.

Due to expressions (7) and (8) it is possible to derive the following

$$K_I = 0,013 \cdot \sigma \cdot d \cdot \bar{F}^{0,25} \quad . . . . (9)$$

or $$K_I = 0,013 \cdot \sigma \cdot d \cdot 10^{0,25C_1} \cdot \bar{l}^{\,0,25C_2} \quad (10)$$

Under symmetrical loading cycle $\sigma_{min} < 0$ and $\Delta K = K_{max}$ and for the rate of fracture area growth is possible to derive the following:

$$\frac{dF}{dN} = C\,(K_{max})^n \quad . . . . (11)$$

On the basis of expression (10) using (8) and drawing 1, relationship is derived $dF/dN = f(K_{max})$ for specimen with different technology of surface strengthening (fig.2).

Parameters of equation (II) are determined by the method of least squares. Out of ratios (7) and (II) it is possible to derive the following:

$$N_{TPi} - N_{TPo} = \frac{4\left(F_i^{1-0,25n} - F_o^{1-0,25n}\right)}{C(4-n)\left(0,0139\,\sigma_{max}\cdot d^{0,5}\right)^n} \qquad (12)$$

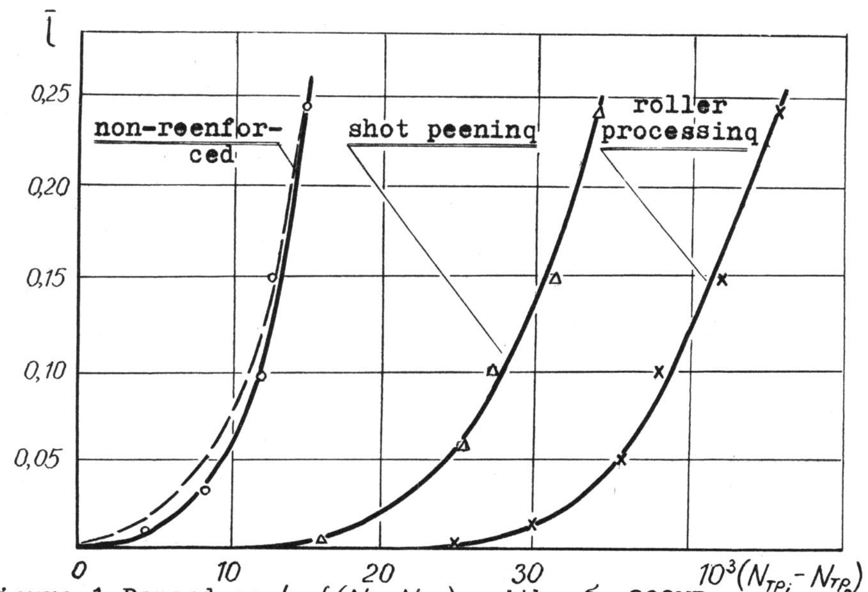
where N_{TPo} = the number of loading cycles, under which the fatigue fracture area approaches up to F_o, determined according to boundary conditions.

For comparison the calculation data on dependance (12) is presented in fig.1, which confirms the closeness of theoretical results and experimental data.

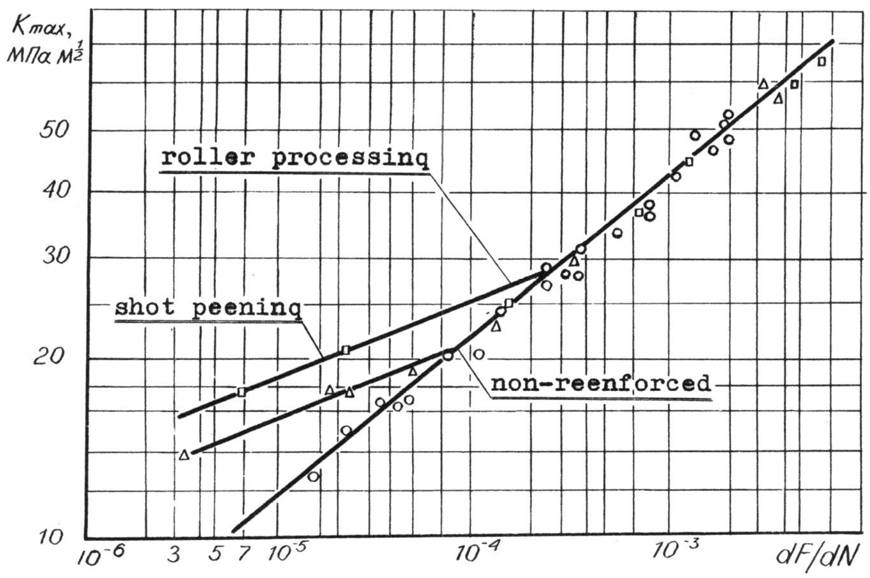
CONCLUSIONS

1. The strengthening of steel specimen surface is an effective means of fatigue fractures retardation on the initial stage of their development; it is possible to reduce the rate of their spreading by 4-10 folds depending on the method and regime of surface strengthening.

2. The number of cycles corresponding to the stage of fractures spreading in strengthened cylindrical specimen under bend loading can be assessed with the sufficient accuracy by formula (12).



Fiqure 1 Dependece $l = f(N_i - N_{TPo})$ with σ_a =800MPa
——— experiment, — — — design



Fiqure 2 Dependence $dF/dN = f(K_{max})$