Threshold level of cast railway steel loading in the process of operation

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Abstract. The authors studied the pattern of fatigue cracks distribution in railway J02002-type grade steel at threshold level of operational loading. The study was based on simulation of operational load combining the conditions of straight and curved part of the road. The load level reduction was based on the pattern of the change of the tested sample hardness with the development of the crack. The authors found the relation between the load level reduction, the crack growth rate and the number of load units. They determined the coefficient of similarity of operation loading form, at which there is no fatigue crack growth in the steel under consideration.

1. Introduction

There exists the problem of assessment of railway structures resource. In particular, it concerns the bogies, because in the process of manufacture thereof the defects of casting inevitably occur to become the stress concentrator that provokes the development of fatigue cracks. The resource of the bogies greatly depends on the duration of fatigue cracks growth to the critical values. The process of accumulation the damages at pre-threshold cyclical load depends on many factors. The main of them are: the cyclical hysteresis of stresses and deformations at the tip of the crack and its correlation with the residual stresses [1-3], as well as the impact of environment.

Experimental studies of threshold level assessment at operational load are too expensive and call for significant time expenditures, however, the authors suggest the method that provides the prediction of threshold level at the straight road section based on reduction of the sample hardness with the development of fatigue crack in it [4].

The task of this work is to develop the method that provides the assessment of threshold level of operational load by simulating a more complex loading process, in particular, the combination of conditions of straight and curved road section.

2. Test methods

The tests were performed at a compact C(T)-type 125x120x10 mm sample of J02002 steel. The loading pattern corresponded to ASTM E399. The sample was cut out of cast truck bolster of a railway car and had an initial fatigue crack Lo=42.0 mm, from the load application line. Crack opening indicator was installed on attachable prisms attached to the butt end of the sample. In the process of the test, the authors were constantly measuring the load applied to the sample and the crack edges displacement with registration frequency of 5000 values per minute for each channel.
The test method was as follows:

- operational loading, that is, an analogue of a truck bolster loading process recorded during operation, was applied to the sample. It was performed in mild loading mode. Alongside with it, the sample response and the change of crack advancement speed V were recorded from the crack opening indicator. The length was measured using the marks applied on the polished side surface of the sample;
- after the crack growing ∆L by 0.5 mm and recording its initial speed, the sample loading was transferred to the severe stress mode. A signal previously recorded from the opening indicator, when the loading was performed in a mild mode, was used to control the crack edges displacement. In the process of severe loading, the sample response was registered from the load change indicator. At the first period of severe mode the loading signal completely corresponded to the mild mode operation signal, however, with the crack growth, the sample compliance ∆P increases, and the load level decreases. It was necessary to determine the change of load cycle parameters correlation. By doing so, the following dependencies were determined: the crack length change with the number of repeated blocks and the stress level reduction according to the crack length.

The rate of loading at servohydraulic test machine was determined by the types of operational loading load cycles, as well as the accuracy of reproduction thereof. In this experiment, it constituted 3 cycles per second (figure 1).

In the mild loading mode, the initial crack speed was $2.28\times10^{-7}$ m per block during reproducing the operational loading block corresponding to the rolling stock speed of 80-90 km·h$^{-1}$ along the straight and curved track sections.

Using the current loading readings in figure 2 (a), the displacement of point 1 was tracked in the graphs as a value corresponding to the maximum load in each block. The displacement of point 1, at crack growth figure 2 (b), was determined according to the crack growth value ∆L and the number of worked out blocks. The ∆L value was measured using a counting microscope.

![Figure 1. Type of operational loading block. (a) - in mild mode (loading control), (b) - under severe loading (crack opening sensor control).](image-url)
3. Research results

Based on the test results, we obtained the experimental dependences of the change in the specimen compliance in the form of functions $\Delta P(\Delta L)$, and the speed change with the decrease in the loading

Figure 2. Operational loading blocks during the movement of the car along straight and curved track sections in coordinates. (a) - load – time, (b) - load - crack edges displacement at the opening sensor installation points.

Figure 3. Experimental functions. (a) - dependence of the crack growth rate on the decrease of the maximum loading in the block, (b) - dependence of the decrease of the maximum loading in the block on the crack length, 1 and 2- approximating experimental points of the function.
level V (ΔP) and performed the calculation assessment of the interval and regularity of the stress intensity factor (SIF) change taking into account all the experiment parameters (figure 3).

During the tests, the crack increased from 42 to 46.06 mm, while the maximum loading level decreased from 13.74 to 10 kN.

SIF was determined according to ASTM E399 for a compact sample.

The calculated SIF dependences in the test section of the sample only on the crack length change are shown in figure 4 (a). Determination of this dependence provides the assessment of the possible experiment duration and makes it possible to choose the initial conditions. Figure 4 (b) shows the distribution of the values of the cycles asymmetry coefficient, determined from the adjacent minimum and maximum values of the loading process. With the decrease in the average process level of the in the experiment, the sequence of the cycle asymmetry coefficients does not change.

The analysis of the loading process during its level decrease was carried out according to the ratio of the limiting values of the loading blocks amplitudes for mild and severe modes. It has been determined that with a decrease in the loading level with the development of a crack, the ratio of the extreme values of the loading cycles remains constant. That is, the ratio of the consecutively standing in the cycle of the minimum value to the maximum value remains constant. This serves as a measure of the observance of the similarity when the load level decreases. The loading amplitude changes accordingly.

The analysis of the loading process during its reduction was performed based on the correlation of the threshold values of load units amplitude for mild and severe mode. It is determined that during the loading level reduction with the crack development, the correlation of loading cycles extreme values remains constant. That is, the correlation of the minimal value to the maximum value, subsequently located in the cycle, remain constant. It serves as the measure of compliance with similarity during the load reduction level. At this, the loading amplitude correspondingly changes.

Using line 2 figure 3 (b), it is possible to obtain the threshold loading process assessment, expressed in the sequence of SIF values, corresponding to extreme values of cycling loading and the predicted crack value. Therefore, the threshold crack length, obtained this way under the experiment conditions and the loading level, corresponding to it, with the maximal loading in the unit equal to 9.61 kN, at similarity coefficient equal to γ = 0.70, make it possible to obtain the threshold unit loading assessment in the form of the corresponding sequence of cyclically changing SIF at which the crack terminates.
The possibility of obtaining the threshold process by multiplying each initial process extremum by similarity coefficient is shown in figure 5.

The initial loading process in SIF values sequence is shown in figure 5 (a). The predicted process of SIF changing corresponding to crack termination condition is shown in figure 5 (b). The coefficient of similarity of initial and predicted threshold process is 0.7, that is, the predicted process is obtained by multiplying the initial processes extremums by similarity coefficient.

![Graphs showing initial and predicted processes](image)

**Figure 5.** Obtaining SIF change threshold process. (a) – source process, (b) – predicted process, (c) – histograms of initial (1) and threshold (2) processes broken down by amplitudes spectra.

4. Conclusions

The authors have revealed the pattern of fatigue cracks development in J02002 steel, of which the freight car truck bolster is manufactured, based on experimental study of a compact sample. The authors used the records on operational loading specific for combination of straight and curved railroad sections.

The authors have developed a method to determine the threshold level of operational loading at such loading process type.

It has been established that, within the experiment conducted, the loading process implementation in the units remains similar regardless the loading mode, crack growth and loading level reduction.

Using the similarity coefficient, it was possible to determine the change of SIF similar to operational one at which the crack development terminated.

The analysis of the sample surface treatment with a heated air flow and a mechanical mixture of metal and corundum particles indicates the effect of copper particles deformation on the predominant diffusion of copper into zinc and the increase in the diffusion coefficient.
References

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