Peculiarities of the images of microscroches during load testing for fatigue fracture

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Abstract. The paper investigates the features of changes in the fractal dimension of microsection images during load tests for fatigue life. For this, the methods of the theory of fractals were used - the assessment of the fractal dimension of the images of microsections at different stages of loading, and their multifractal spectra were also determined. It was found that before the destruction of the sample, the multifractal spectrum degenerates into a monofractal.

1. Introduction
The safety of technical systems depends on many factors. One of them is the mechanical strength of materials - the ability to withstand functional loads with a given margin of safety. At the same time, the creation of new materials with specified enhanced mechanical properties and the determination of the relationship between the structure (structure) of a substance and its physical and mechanical properties are among the most important tasks.

To ensure the safety of technical systems, various methods of non-destructive testing are used, while it would be important to obtain methods of visual inspection for special microsections using methods that allow this.

2. Methods
Currently, for the qualitative and quantitative analysis of the structural properties of materials, computer methods of information processing are used. Fractal analysis is one of the emerging trends in digital image processing. The development of this direction is facilitated by the fact that most images can to some extent be considered fractals or multifractals.

Fractal image estimation methods are used to study the structural properties of materials, fractures (study of the properties of the microweave of structural materials) For example, in [1], the results of studies of the relationship between the fractal dimension of the surface of an object material and its mechanical properties (coefficient of friction, impact strength, dynamic modulus of elasticity, corrosion resistance, durability) are presented. A correlation was obtained between the mechanical properties of materials and the fractal dimension D of their surface.

The following works [2, 3] are devoted to the study of the correlation between the mechanical properties of materials and their fractal characteristics of the surface.
3. Results

To analyze the correlation between fatigue life and fractal dimension, an analysis of a series of microsections obtained in the study of 12GS steel (low-alloy structural steel for welded structures) was carried out during cyclic tensile stress tests. The microstructure of 12GS steel mainly consists of ferrite and pearlite. The structure of the material is granular, large grains of ferrite and small grains of pearlite.

When examining a microsection, its image can be presented in various forms - phases, boundaries, framework, etc. In this case, the fractal dimension can be determined in the following boundaries: $1 < D < 2$ and $2 < D < 3$ depending on the consideration of a flat image or presenting this image in three-dimensional form (taking into account the color of pixels).

It was found that up to 38000 loading cycles the image of a microsection remains almost unchanged (by the number of grains). During this cycle of loading, microcracks appear in the grains. The most intense increase in microcracks and their growth occurs in the range from 38000 to 65000 loading cycles, their accumulation occurs at approximately the same rate with a slight increase after 84000 loading cycles.

For the test of the sample with the limiting number of loading cycles $N = 95000$, in addition to the fractal dimension, other characteristics of the microsection image were calculated. With the accumulation of damage, the number of grains increases, while the characteristics of the area and perimeter of the grains decrease, i.e. the destruction of the grains occurs. The structure of the image becomes more heterogeneous. This is fixed in the image of the skeleton (figure 1 (b)). These images of the skeleton correspond to fractal dimensions $D_0 = 1.208$ and $D_{95000} = 1.253$. In this case, an increase in the index of fractal dimension indicates that the structure of the material has undergone changes - the appearance of a significant amount of micro-destruction (accumulation of damage occurs).

![Figure 1](image.png)

In figure 2 shows examples of calculating the fractal dimension of the boundaries between phases. The calculated fractal dimensions for the phases of the material and the boundaries between them showed that with an increase in the number of loading of the sample, the fractal dimensions of the image skeleton, the ferrite phases increase, and the fractal dimension for pearlite decreases. The fractal dimension of the boundary between the phases changes insignificantly.

The analysis of microsection images showed that the multifractal spectrum $f(\alpha)$ of the images changes to a monofractal spectrum after 61000 loading cycles. Also, with an increase in the number of loads $N$, the fractal estimate $D_0$ grows - from 1.6712 to 1.7485 (figure 3).
Figure 2. Image of a microsection (selection of boundaries between phases and particles of ferrite and cementite in pearlite) and determination of the fractal dimension of this image.

The second series of the experiment continued up to \( N = 112000 \) loading cycles. The microsection with the number of loads \( N = 112000 \) also had a monofractal structure. The width of the multifractal spectrum \( S \) decreased, and the left branch of the spectrum also decreased. A significant change in the width of the multifractal \( S \) shows that the multifractal spectrum degenerates into a monofractal. The number of fractal dimensions decreases in a given multifractal spectrum.

To clarify the structure of the material, microsection images were clustered using the k-means method. The k-means method is a method of cluster analysis, the purpose of which is to divide \( m \) observations (from the space \( \mathbb{R}^n \)) into \( k \) clusters, with each observation referring to the cluster (to the center centroid), who is close.

Figure 3. Multifractal spectrum of a microsection image at the number of loads \( N = 0 \) (a) and \( N = 95000 \) (b).

When examining the images, the number of clusters was selected 10. In figure 4, they are highlighted in gray. If for the image of a microsection before testing the structure of the material had only 5 clusters, the division into clusters did not change the image of the microsection. Whereas before destruction, the microsection image already had 9 clusters. As you can see, cluster number 1 (the darkest areas) reflects small fracture zones of the sample material.
Figure 4. The result of processing microsections using the k-means clustering method (10 clusters): (a) - with the number of loading cycles \( N = 0 \); (b) - with the number of loading cycles \( N = 112000 \)

4. Conclusion

According to some scientific publications, it is known that in the absence of loading with an increase in the fractal dimension of the material structure, the strength increases, in the case of fatigue strength tests when micro- and macrocracks appear on the surface of the material, then an increase in the fractal dimension is the first visual sign of the impending destruction of the sample. And before destruction, the thin section acquires a monofractal distribution of the scale elements of the material structure, which corresponds to the criterion of the transition of the system from one state to another [4]. That is, the multifractal spectrum one changes - the number of fractal dimensions in the multifractal spectrum decreases, the spectrum width decreases - the multifractal spectrum degenerates into a monofractal one.

References

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