Improvement of car repairability based on the material destruction assessment during its operation

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Abstract. Parts and structural elements of vehicles during operation are affected by cyclic loads and various temperatures. At the same time, more than 80% of all types of metal structures destruction are fatigue-like, which leads to huge financial losses, and often to fatal accidents. Therefore, issues of improving the reliability and safe operation of automobile parts subjected to cyclic loads in air at different temperatures are important in modern industrial science. That’s why, it is necessary to know the laws of fatigue behavior of structural materials obtained by different types and modes of technological processing in specific operating conditions in order to predict their operational reliability increase. Changes in the metal during fatigue are directly reflected on the curves of changes in the samples current deflection, since they reflect the antogonism of two mutually opposite processes - hardening and softening, directly related to the processes that occur in the material structure during fatigue.

This article presents the possible analysis of the fatigue failure kinetics of some test structural materials using the curves of the samples current deflection. The assessment of structural materials destruction allows us to choose structural materials for car parts, taking the conditions of its operation, types and modes of its manufacturing technology into account in order to increase its maintainability and service life.

Keywords: vehicles, metal parts of a car, reliability, safety, fatigue resistance, materials damageability.

Introduction

When operating in corrosive environment metal parts and structural elements of a car are subjected to vibration loads, that can lead to their fatigue failure, and consequently to accidents, even those with casualties [17-19]. Fatigue failure of structural materials depends on the material characteristics, its processing procedures and loading conditions (medium and voltage amplitude) [7, 8, 14].

In the course of manufacturing process a car part is put through various technological processing procedures (thermal, volume and surface plastic, welding, etc.) [9]. Apart from the influence of a large number of internal and external factors [20], the complexity of full-scale testing in different environments [15, 26] complicates the elaboration of reliable criteria for assessing the fracture resistance of metals and alloys under cyclic loads.

In this regard, and taking into account the intensive development of volume plastic deformation advanced technique, the problem of creating fatigue fracture patterns in order to predict and increase the service life of strain-hardened metal materials and, consequently, decrease materials consumption is very important.

The process of fatigue failure of metallic materials is tentatively divided [10, 16] into three stages:
1) the period before the onset of fatigue microcracks;
2) subcritical crack growth;
3) quick rupture.
The curves of cyclic hardening (softening) reflecting the processes of structural changes [24] are important when describing material behaviour under cyclic loading. Hardening is a preparatory stage in the process of fatigue of metal materials, after which at certain values of alternating stresses for a certain number of cycles, loosening occurs that ends with the fatigue fracture onset and expansion.

All this structural damage, which is the result of hardening-softening antagonism directly related to the processes that occur in the structure of the material during fatigue, affects the sample running deflection in the course of cyclic loading.

The purpose of the work carried out in NSTU named after R.E. Alekseev is to increase the maintainability of a car through establishing patterns of metallic materials destruction during its operation.

The object of research is strain-hardened metallic materials widely used for car elements construction.

The subject of research is the laws of fatigue failure of automotive structural materials of various classes and structure.

Exploratory procedure
In this work fatigue failure of automotive materials was carried out on cylindrical corset-shaped samples made of the same-supply bar stocks for each structural material. The characteristics of the samples are presented in table 1.

| Material         | Sample initial state | Material microstructure |
|------------------|----------------------|-------------------------|
| Copper M1        | Cold-rolled          | Grain size 0.04-0.08 мм |
| Copper M1        | Annealing 540°C 2h vacuum 1,33 * 10 Pa. Furnace cooling | Grain size 0.04-0.08 мм |
| Brass J63T       | Cold-rolled          | Grain size 0.04 мм      |
| Aluminium alloy B95пчТ2 | Hardening 465-475°C (выдержка 1ч), water, correcting (stretching when fresh-hardened 1,7%); aging (120°C, 5h, 180°C,6h) | – |
| Steel 20XI3      | Hardening 1030°C, oil, tempering 600 – 640°C. | Martensite |
| Steel 14X17H2    | Hardening 1030°C, oil, tempering 620 -660°C. | Martensite |
| Steel 35XFCa     | Hardening 900°C, storage 20 min, oil, tempering 425°C | Troostosorbite |

The samples were tested using the symmetric cantilever bending scheme with a rotation frequency of 50 Hz on a MIP-8 machine equipped with a phase synchronizer and an optical microscope (x37) with stroboscopic illumination in order to observe structural changes, the occurrence and development of fatigue cracks on the surface of a cylindrical sample with continuous cyclic loading. To provide corrosive medium for testing material a special device to the fatigue machine was designed and manufactured [2, 3].

The initial microstructure of the samples was determined using an AKASHI optical microscope. In addition, dangerous section samples with an etched surface were removed from a fatigue machine for detailed study and photographing once in a certain number of loading cycles.

The outcomes and their consideration
It was shown previously [1, 23] that the curves of changes in the deflection of the sample during the tests reflect the peculiarities of the kinetics of the material fatigue behavior.

Using them, one can determine the moment of a fatigue crack onset leading to the deflection increase, and also evaluate its expansion speed. Such information becomes especially valuable when cyclic loading the materials under conditions other than normal, that is, when direct observation of the sample surface is inconvenient or impossible, for example, in a corrosive environment. Therefore, the MIP-8 fatigue machine was equipped with a dial gauge (accuracy 0.01 mm), which allowed scanning the in the current deflection of
the sample during fatigue loading both under normal conditions and in a corrosive environment (3% solution of sea salt in water).

The results of the analysis of the sample deflection changes during fatigue at room temperature demonstrate [4, 5, 21, 25] that the curves have three sections (Fig. 1):
1 - a sharp decrease for annealed or an increase for cold-rolled materials;
2 - stage of the deflection stabilization;
3 - its sharp increase associated with the sweeping destruction of the material. In this case, an increase in the sample deflection after the stabilization stage corresponds to the moment of macrocracks onset ~ 1.0 mm long on its surface (for example, Fig. 1).

![Figure 1](image1.png)

**Figure 1.** Dynamics of the current deflection of a sample from V95pchT2 aluminum alloy depending on the number of loading cycles at $\sigma_{a} = 248$ MPa (durability to complete destruction of the material $N_p = 1.15 \cdot 10^5$ cycles): a) initial state of the material; b) $N / N_p = 2.4\%$; c) $N / N_p = 7.4\%$; d) $N / N_p = 14.8\%$; d) $N / N_p = 29.3\%$; e) $N / N_p = 51.0\%$; g) $N / N_p = 73.8\%$; h) $N / N_p = 88.0\%$

Figure 2 shows structural changes in the surface of a V95pchT2 aluminum alloy sample depending on the number of loading cycles at $\sigma_{a} = 248$ MPa. The letter designations correspond to those on the curve of the current deflection of Fig. 1.

![Figure 2](image2.png)

**Figure 2.** Kinetics of the destruction of the V95pchT2 aluminum alloy depending on the number of loading cycles at $\sigma_{a} = 248$ MPa (durability to complete destruction of the material $N_p = 1.15 \cdot 10^5$ cycles): a) initial state of the material; b) $N / N_p = 2.4\%$; c) $N / N_p = 7.4\%$; d) $N / N_p = 14.8\%$; d) $N / N_p = 29.3\%$; f) $N / N_p = 51.0\%$; g) $N / N_p = 73.8\%$; h) $N / N_p = 88.0\%$; x 450
Figure 3 shows a developed fatigue crack on the surface of V95pchT2 aluminum alloy sample.

![Figure 3. A developed fatigue crack on the surface of V95pchT2 aluminum alloy; x450](image)

It is known [11, 12] that corrosion-fatigue fracture of metals and alloys is initiated by surface damage, erosion, cavities, intergranular corrosion on it and, therefore, develops, as a rule, from several sites. This determines the multi-site nature of the corrosion-fatigue fracture development.

However, despite the distinctive features of the corrosion-fatigue destruction process, the curves of changes in the samples current deflection under cyclic loading in a 3% sea salt solution have a qualitatively the same form as when tested in air [6, 13].

This is due to the fact that, along with the mechanisms of hardening and softening, a decrease in the clear section of the sample is the determining factor for obtaining qualitative data on the current state of materials during cyclic loading according to the parameter of the current deflection change. Therefore, despite the fact that it is rather difficult to distinguish clearly the process of corrosion-fatigue failure into a number of periods from a physical point of view, as the case when tested in air, nevertheless, such conventional division can be justified to facilitate the study of the fatigue failure kinetics. Some other authors hold the same opinion [22].

This approach allows us to divide tentatively the fatigue-and-corrosive destruction process into three distinctive phases:

- the incubation phase, which is characterized by processes associated with the adsorption of the medium on the surface of metal or oxide films through selective anodic dissolution, hydrogenation of the cathode
sections and other processes induced by cyclic mechanical stresses. These processes lead to the formation of pitting or microcracks with a depth sufficient for a noticeable concentration of mechanical stresses;
- the phase of corrosion-fatigue crack growth to critical sizes;
- accelerated rupture phase.
During the third phase corrosive medium has practically no effect on the nature and duration of the metallic material destruction, however, the duration of the first and the second phases is significantly affected not only by corrosive medium but also by the material properties and its structural state caused by the technological treatment and loading characteristics (the amplitude of the applied voltage and cycle duration).
The analysis of the obtained results demonstrates the dependence of the qualitative change in the samples current deflection from their live section alternation during cyclic softening, as well as in air under heavy loads when a fatigue crack originates around the entire perimeter of the dangerous section of the sample (the so-called “circular” crack onset and growth).

Conclusion
Thus, the current deflection curves in addition to metallographic, fractographic and other methods of kinetics analysis of the fatigue failure are a very important integral characteristic of the processes occurring under metal materials fatigue loading.
The assessment of structural materials destruction allows us to choose structural materials for car parts, taking the conditions of its operation, types and modes of its manufacturing technology into account in order to increase its maintainability and service life.

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