Mini Review

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To the question for use of aluminum alloys for car parts

Abstract

The idea of reducing the mass of cars through the use of lightweight materials is not new. Among them are aluminum alloys, which at a relatively affordable price are significantly lighter than steel alloys. The decrease in the vehicle's own mass leads to an increase in their fuel economy, reduction in the amount of harmful substances and compounds released into the atmosphere, and plays an important role in reducing the "greenhouse effect". Structural materials in the manufacturing process of car parts are subjected to various technological treatments, including plastic deformation operations. Vehicle operation is associated with significant vibration loads. However, information on the influence of the mode of technology for manufacturing parts from aluminum alloys on the resistance to fatigue failure in air is limited, and in a corrosive environment it is practically absent. The paper considers the possibility of using lightweight high-strength aluminum alloys in the automotive industry, taking into account the increase in their operational reliability by optimizing the manufacturing technology of parts. The results of the study of the influence of the degree and rate of plastic deformation during technological processing on the kinetics of fatigue fracture and the operational properties of some aluminum alloys are presented.

Keywords: car parts, aluminum alloys, degree and rate of plastic deformation, cyclic durability

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Introduction

The idea of reducing the mass of cars through the use of lightweight materials is not new. Among them are aluminum alloys, which at a relatively affordable price are significantly lighter than steel alloys. A review of domestic and foreign literature data shows that in the world practice work is actively being carried out to expand the use of aluminum alloys in the automotive industry. This is due to the fact that an increase in their share in the design of the car allows you to:

I. Significantly reduce the mass of vehicles and fuel consumption.

II. Reduce production costs.

III. Use (without readjustment) existing equipment and a sufficient range of semi-finished products.

IV. Reduce the complexity of manufacturing (by reducing the connecting nodes and the transition to extruded elements).

V. Reduce the number of parts subjected to machining, etc.

At the same time, reducing the vehicle's own mass, increasing their fuel efficiency, improves the environment - it reduces the amount of harmful substances and compounds (including a powerful carcinogen such as benz-a-pyrene) into the atmosphere, and also plays a crucial role in solving the greenhouse problem effect "caused by CO_2 emissions. So, for example, according to.[1–3] the share in fuel economy from a decrease in the vehicle's own weight is 45%, a decrease in tire rolling resistance is 25%, an improvement in engine and transmission performance is 30%. In the automotive industry, the manufacture of parts from structural materials is carried out according to various processing modes, including plastic deformation (rolling, stamping, pressing, etc.). Under operating conditions, automobile parts, in most cases, experience significant vibration loads.[4] However, when choosing technological equipment, they are often guided by any criteria (for example, manufacturability, efficiency of the shaping process, etc.) except for the ability of stamped products to resist the effects of cyclic loads, since information on the resistance of aluminum alloys deformed to different levels of fatigue fracture air are very limited, and in a corrosive environment are practically absent.[5–9]

Moreover, with the strict requirement of reducing the metal consumption of machines and technical devices, it can be difficult to avoid the appearance of fatigue cracks in critical parts. However, in some materials they can appear relatively early and most of their "life" parts are forced to work with cracks. Therefore, for a full assessment of their performance, it is desirable to have not only the parameters of cyclic durability and fatigue strength, but also the maximum information on the damage accumulation process at all stages of the fatigue failure of structural materials: the stage of crack initiation, their subsequent development up to the complete destruction of the sample. This makes it necessary to improve the fatigue test methodology. However, in the literature, information on the kinetics of damage in the process of fatigue failure of pre-deformed metal materials in general and aluminum alloys in particular is practically absent. Therefore, research in this direction is of both theoretical and practical interest. In this paper, we consider the possibility of expanding the field of application of light high-strength aluminum alloys in the automotive industry, taking into account the increase in their operational reliability due to the optimization of technological modes of parts manufacturing. The results of a study of the influence of technological processing modes (the magnitude of the degree and rate of plastic deformation) on the kinetics of the process of fatigue failure and the operational properties of some aluminum alloys are presented.

Research methodology

The paper presents the technology and the results of a comprehensive study of the kinetics of fatigue fracture of samples, including: alternating tests under cyclic loading; study of the initial microstructure and its changes on the surface of the sample at the optical ("Neophot", "AKASHI") and electronic levels ("Jeol-T20"); measurement and analysis of changes in the current deflection of the sample (micrometer dial gauge with a division price of 0.01mm);[10] observation and research of the moment of initiation of fatigue macrocrack, its subsequent growth and final fracture of the sample; fractographic analysis of fatigue fractures (MIR-12 optical comparator and Jeol-T20 electron microscope) and other methods. To solve this problem, aluminum alloys D19AM, D19AT, 01420 and V95pchT2, widely used in various industries, were selected. The samples were pre-deformed with different degrees (ε=0...40%) on a ДО-436 press (strain rate $\dot{\varepsilon}=0.08s^{-1}$) and a МЛ-3 hammer ($\dot{\varepsilon}=100s^{-1}$). Static tensile tests were carried out on an Instron-1115 machine, and fatigue tests were performed on a two-position machine according to a "rigid" symmetric cantilever bending with a frequency of 25Hz at room temperature in air and in a corrosive environment (widespread and quite aggressive with respect to steels and alloys 3% aqueous solution of sea salt).[9] The kinetics of the process of fatigue failure was studied on the MIP-8 setup (converted for load loading and equipped, with the aim of observing the occurrence and development of the process of fatigue failure, a phase synchronizer and an optical microscope with strobe light) according to the cantilever bending scheme with a rotation frequency of 50Hz. To measure changes in the current deflection of the samples under cyclic loading, a dial indicator was used. Finished stamped products such as corrugated panels were loaded on special stands along a pulsating cycle of zero shears with a force of 30kN and a frequency of 0.2Hz.

Research results and discussion

The mechanical characteristics of the materials under static tension, fatigue curves approximated by the corresponding equations, and probability distribution curves of cyclic durability after various processing conditions were obtained. It is established that the influence of the degree and rate of preliminary technological deformation of the investigated materials on the resistance to fatigue failure depends on their nature, structural state, amplitude and environment of alternating loading. The experimental results show that the alloy fatigue resistance varies ambiguously depending on the medium and the amplitude of alternating loading. So the cyclic durability of the V95pchT2 aluminum alloy (quenching-heating to 465 ... 475°C, holding - 1 hour, cooling in water; dressing - elongation in the freshly quenched state by 1.7%; aging - first at 120°C, 5hours, and then at 180°C, 6hours) in a corrosive environment less than in air (Figure 1). The decrease in durability under the influence of a corrosive medium is especially characteristic of low amplitudes of the amplitude of applied stress. For example, durability in a corrosive environment, compared with the test in air, decreases by about 1.15 times at σa=400MPa and about 6.3 times at an amplitude of 210MPa. A change in the surface structure of the sample during the fatigue failure of the V95pchT2 aluminum alloy after a different number of loading cycles N/Np (σa=248MPa, Np=$4.27\cdot10^4$ cycles) is as follows:

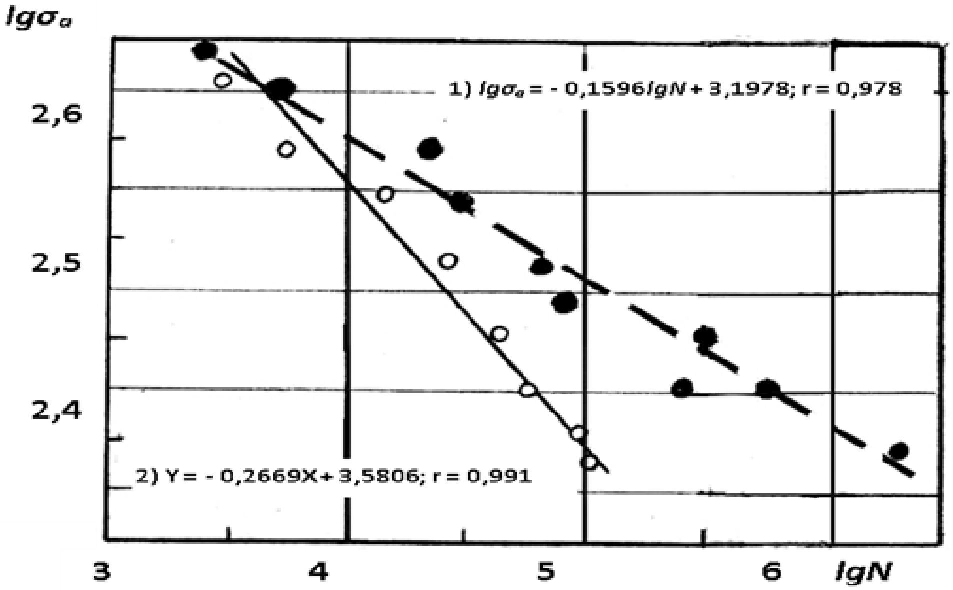

Figure 1 Fatigue Curves of V95pchT2 Alloy Tested in Air (1) and in a corrosive environment (2).

a) 0%; the initial state; grains elongated in the rolling direction (along the axis of the sample).

b) 2.4%; in some grains, individual slip bands appear, oriented along the rolling fibers.

c) 7.4%; dense fibrous slip lines appear which, as a consequence of lateral slip, is characteristic of metals with high stacking fault energy.

d) 14.8%; In individual grains, wavy microcracks appear perpendicular to the direction of grain deformation;

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e) 29.3%; at the grain boundaries, there are many intersecting microcracks.

f) 51.0%; in almost all grains of a dangerous section of the sample, intersection of microcracks is observed, which accumulate mainly along the grain boundaries.

g) 73.8%; Microcrack passing through the body of grains in the direction perpendicular to the axis of the sample.

h) 96.0%; Developed microcrack.

The curves of changes in the current deflection reflect the total result of structural damage to the samples during their cyclic loading. The curves of deflection of the samples during fatigue differ significantly for annealed and hardened materials,[2] however, in all cases, with an increase in cyclic durability, the absolute value of the current deflection decreases. Moreover, all the deflection curves of the samples have three characteristic sections. In annealed samples, first the deflection decreases sharply due to the appearance of slip bands and, consequently, hardening of the material. Then, the hardening slows down and the process of softening of the samples begins. Under the dynamic equilibrium of these processes, stabilization of changes in the current deflection is observed. At the beginning of the stabilization stage, microcracks begin to form, which then develop into macrocracks. In this case, a noticeable macrocrack on the surface of the sample with a length of ~1.0mm is observed at the time of the inflection of the deflection curve (lz.tr.). In the third section, the intensity of the deflection change sharply increases as a result of the development of a macrocrack, which leads to a decrease in the living cross section of the sample and its complete destruction.
In hardened materials, from the very first loading cycles, the softening process somewhat prevails over hardening, which leads to an increase in deflection up to complete destruction of the samples. In a similar way, hardened materials behave under cyclic loading in a corrosive environment.

An analysis of the growth of the fatigue crack showed that the appearance of macrocracks ~ 1.0mm long on the surface of the sample corresponds to a moment of a more noticeable increase in the deflection of the sample, which reaches a significant value at a ratio of lтр/d≈0.15. It was found that the period before the initiation of a fatigue crack increases, and its development rate decreases with increasing cyclic durability until the alloy is completely destroyed. So, for example, if at σa=270MPa Nз.тр. is 53700 cycles, and the crack growth rate is 3.07мм/cycle, then at σa=200MPa Nз.тр. = 200000 cycles and its growth rate is 0.106мм/cycle. Corrosive-active medium, leading to the appearance of various types of corrosion lesions, determines the multi-focal nature of the occurrence and development of corrosion-fatigue failure. However, despite the significant features of this process, the curves of changes in the current deflection of the samples under cyclic loading in a 3% aqueous NaCl solution are qualitatively the same as in the air test. This is because the determining factor of qualitative data on the current state of materials during cyclic loading according to the parameter for changing the current deflection is, along with the hardening-softening mechanisms, a decrease in the living cross section of the sample.

Thus, the analysis of experimental data shows[6,10–12] that the curves of changes in the current deflection, together with metallographic, fractographic, and other methods of studying the kinetics of fatigue failure, are a very important integral characteristic of the processes occurring under fatigue and especially corrosion-fatigue loading of structural materials, when direct observation their structural damage is methodologically difficult, and sometimes impossible. The cyclic durability in air of samples from D19AM increases 7.2times (stress amplitude σ a=150MPa) with an increase in the degree of preliminary deformation on a hydraulic press from 0 to 29% (followed by heat treatment: annealing at 400°C, 30min; cooling 30°C per hour to 260°C, then in the air), and at ε=40% it decreases slightly (Figure 2), but remains higher (2.6 times) than undeformed ones. A partial deterioration in the resistance to fatigue fracture of an alloy deformed to 40% is caused by the enlargement of the inter metallic phase in its structure. When tested in a corrosive environment, the maximum increase in the durability of the D19AM alloy stamped on a hydraulic press is accounted for by a permanent deformation of 18%. Moreover, for all degrees of preliminary precipitation, the corrosion durability of the samples is 1.5 ... 2.0 times less than the durability in air.

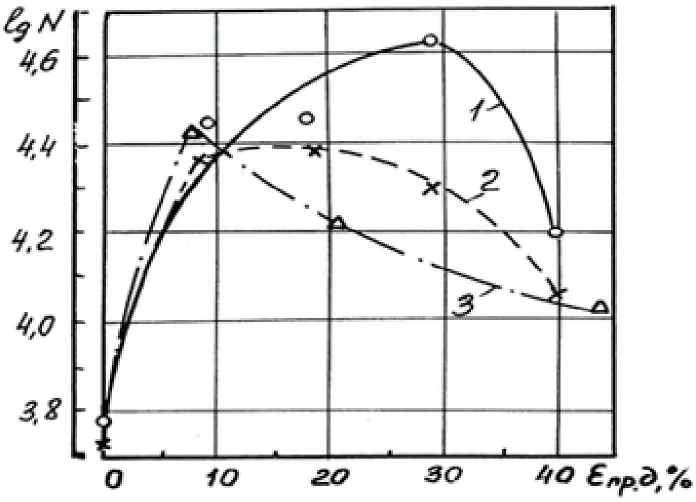

Figure 2 Change in the cyclic durability of the D19AM alloy after technological deformation (1 and 2 - on the press; 3 - on the hammer): 1 - in air; 2 and 3 - in a corrosive environment.

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Deformation on the hammer shifts the maximum corrosion resistance of the alloy to the region of the degree of deformation of 9%, at which failure occurs even a little (1.2 times) later than after precipitation on the press and testing in air. Corrosion-fatigue failure, initiated by damage to the surface, the formation of intergranular corrosion, caverns and ulcers on it, develops, as a rule, from several foci. Cracks are less oriented than when tested in air, and microcracks and oxidation products are observed on the surface of fatigue fractures. Field tests of corrugated panels made of D19AM alloy confirm the results obtained on the samples. The durability of sheet products stamped on a hammer is 2.9 times higher than that obtained on a hydraulic press, which is due to the significant physical hardening of the material at a high speed of their deformation. Moreover, stamping on a hammer significantly increases the stability of the mechanical characteristics of the panels (the spread of experimental data does not exceed 1%). For hardened and naturally aged aluminum alloy D19AT, with an increase in the degree of preliminary precipitation on the hydro press of flat samples, a monotonic decrease in the cyclic durability in air is observed, which intensifies when the amplitude of alternating loading decreases. For example, the durability of this alloy after deformation up to 29% decreases 3.16 times at amplitude of 300MPa and 4.32 times at 200MPa. The resistance to corrosion fatigue of the D19AT alloy with an increase in the degree of deformation, on the contrary, decreases more intensively at higher than at low amplitudes, and if, for example, the durability of the alloy after deformation is 29% in a medium of a 3% aqueous NaCl solution decreases by a factor of 3 at a applied stress of 300MPa, then at 200MPa - only 2.6 times. Moreover, the effect of reducing the durability of this alloy under the influence of a corrosive medium is more significant for its heat-treated state than for a deformed one.

So, at voltage amplitude of 200MPa, the cyclic durability of flat heat-treated samples of the D19AT alloy is 3.4 times lower in a corrosive medium than in air, and after precipitation by 29% - only 2.0 times. A similar dependence is observed at high amplitudes of loading. The cyclic durability of the 01420T aluminum alloy with symmetrical cantilever bending in air of flat samples cut along the rolling after quenching (460°C, 20min, cooling in water) is many times higher (for example, at σa=160MPa about 18.5 times) compared with the durability of the alloy after mechanical heat treatment: precipitation on the hammer to a degree of 18%; heating to 430°C, 30min, cooling in air; heating to 120°C, 5h, cooling in air, as a result of which sub grains and micropores are formed. However, this mechanical-thermal treatment reduces the durability of the alloy to a lesser extent (at amplitude of 160MPa by about 3.4 times) in the case of loading samples in a corrosive environment. In addition, it was found that, regardless of the processing mode of the 01420T aluminum alloy (hardening; deformation on a hammer and press with various degrees, up to 40%, and subsequent heat treatment) and the test medium (air and a 3% solution of sea salt in water) samples cut across are better resistant to fatigue than along rolling fibers (Figure 3). For example, the durability at a amplitude of applied stress of 160MPa of the hardened alloy is 3.54 times greater for samples with a transverse in comparison with samples with a longitudinal direction of the rolling fibers, which is confirmed by field experiments on corrugated panels. In addition, full-scale tests show that, with the same pulsating shear force (30kN), the cyclic durability of sheet products (panels) stamped on a hammer from 01420T alloy is ~1.72 times higher than that from D19AM alloy.

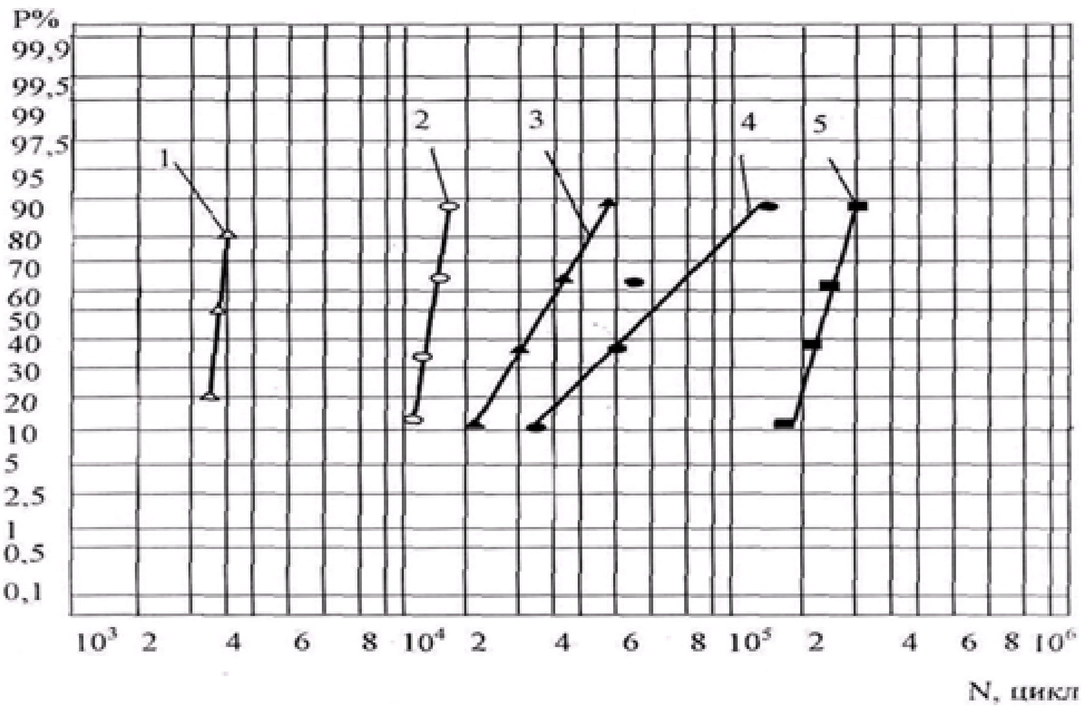

Figure 3 The influence of the processing mode of aluminum alloy 01420 on the probability distribution curves of cyclic durability: 1, 3 - mechanical-thermal treatment, 2, 4, 5 - hardening. Symmetrical cantilever bending with a frequency of 25 Hz at σa=100MPa in air (3, 4, 5) and in a corrosive environment (1, 2). Samples cut along (1, 2, 3, 4) and across (5) rolling fibers.

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Conclusion

A. The obtained experimental data indicate the fundamental possibility of expanding the range of structural parts of automobiles made of high-strength aluminum alloys, taking into account the design capabilities and optimization of processing conditions.

B. Preliminary volumetric plastic processing of aluminum alloys with varying degrees and speeds has an ambiguous effect on their resistance to fatigue failure in air and in a corrosive environment, depending on the amplitude of cyclic loading, and, as a rule, is much higher during stamping on a hammer than on a press.

C. Curves of changes in the current deflection, together with metallographic, fractographic, and other methods of studying the kinetics of the process of fatigue failure, are an important integral characteristic of the processes. Flowing during fatigue and especially corrosion-fatigue loading of structural materials, when direct observation of their structural damage is methodically difficult, and sometimes impossible.

D. Practical recommendations for optimizing the processing modes of the investigated materials have been introduced at a number of enterprises in the automotive and aviation industries of the Nizhny Novgorod region.

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None.

Conflicts of interest

Authors declare that there is no conflict of interest.

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