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Cyclic deformation of aluminium alloys after the preliminary combined loading

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ABSTRACT

This work explores sensitivity aluminium alloys under the influence of preliminary combined loading. There were examined 2024-T351 and D16ChATV aluminium alloys. The research was carried out under the conditions of tensile static and constant-amplitude fatigue tests on samples made of virgin material and after pre-combined loading. As a result of the research, it was concluded that the pre-combined loading leads to the modification of the mechanical properties of the tested materials. During the study reached similar results in increased strength for two aluminium alloys after the pre-combined loading, despite some differences in the structure of the output.

1. Introduction

In real operating conditions, the majority of structural elements and machine parts made of aluminium alloys are usually subjected to various types of loads. Almost always, these loads are complex. Conditionally, we can distinguish two basic types of their application. One type is preliminary load and another is the basic load. Real operating conditions make it quite difficult to separate their application into different stages. For most structures made of aluminium alloys, the basic load assumed as cyclic load. Despite the fact that the basic load largely determines the lifetime of the material, preliminary load also has a significant input on the lifetime of the material.

In recent years, much attention was paid to research on maintaining mechanical properties of structural materials at high strain rate of $\varepsilon = 10^3 \ldots 10^6\ s^{-1}$. At the same time, experimental tests have been conducted of the structure of materials that have been subjected to a high strain rate as a result of which, in the course of implementing deformation mechanisms, a new groups of structure elements were created (e.g. macro and micro groups) [1–6].

In order to describe the behaviour of materials under complex loads associated with a shock change in the strain rate, a large number of phenomenological models have been developed, allowing to perform calculations on the strength of structural elements with the shock change of the strain rate [7–11].

There are a number of studies that show that the preliminary load significantly affects the mechanical properties of the material and its strength. Special attention should be paid to the preliminary load applied by monotonic loading with an additional impulse component [12–15].

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Such a combined load (monotonic tensile load + additional impulse load) applied in one direction, initiates some changes in the behaviour of the material. Under the influence of external factors, the relative balance of the "sample - testing machine" system is disturbed. This in turn causes the initiation in the material of processes hereinafter referred to as dynamic non-equilibrium processes (DNP). The purpose of these processes is to adapt the material to the new conditional balance in response to the value of the parameters of external influences and the conditions for their implementation.

As a result of the application (DNP), two variants of the behaviour of the test material are obtained. The first is applied when under the respective conditions of combined load; external energy is completely absorbed by the material. This causes the creation of a new state of the structure, a so-called dissipative structure. The newly formed structure (state of material) obtains mechanical properties different from the input properties, corresponding to a new type of external loads. From the point of view of optimising the absorption of energy, the formation of this structure is optimal in a certain volume of the material. In turn, this should in some way reflect in the general (global) characteristics of mechanical properties of the material [1–4].

The second variant, where the material is not able to absorb adequate amounts of external energy, at the appropriate time, this causes an instantaneous failure regardless of whether the overall load level exceeds the threshold value.

In recent years, synergistic concepts were developed in strength physics and fracture mechanics, with a multi-level character and fractal type of strain and failure of the structural materials of different classes. However, the scientific approach and methodological basis for studying the structure and the physico-mechanical properties of materials is not yet able to provide adequate descriptions of actual analytical processes.

Determination of the impact of dynamic non- equilibrium processes on the change in mechanical properties of the material, especially fatigue strain and cracking at present is only possible by means of experimental tests.

The aim of this work is to:

— develop a method of experimental testing of the impact of combined preliminary load on the change of the material's mechanical properties;
— determine the characteristics of material fatigue at strain after the applying preliminary combined load.

2. Material and test procedure

Tests were carried out on samples taken from aluminium alloy D16ChATV and 2024-T351, plated on both sides, as delivered. The chemical composition and mechanical properties specified in the manufacturer's certificate are given in Table 1.

Flat samples with dimensions as shown in Fig. 1 were cut in the rolling direction from a sheet with thickness of 3 mm.

The test of the impact of additional impulse load was performed using a hydraulic machine ZD-100Pu equipped with a mechanical system to apply additional impulse load, as described in [2,3]. A general view of the test setup is shown in Fig. 2.

The processes taking place during the deformation and failure of the material during shock load applied during the main load were examined based on the analysis of the applied mechanical load. The system, in the form of a static indeterminate structure, consists of three parallel elements:

— The main element, which includes: spherical self-adjusting holders, dynamometer, strain gauge and a sample of the tested material;
— Two lateral, symmetrical elements in the form of bars with brittle samples with separate dynamometers.

After reaching a predetermined load level in the system, brittle samples are destroyed, which in turn causes additional impulse load on the sample.

In order to ensure simultaneous failure of brittle samples, mounting flanges are combined transversely using four bolts tightened with a torque tool with controlled value.

Additional pulse load was applied in elastic and inelastic areas of the static tensile test curve $\sigma = f(\varepsilon)$, in the range $\varepsilon = 0 \ldots 9\%$.

The time difference for fracture of brittle elements was in the range of 3 … 5 ms, and the difference is the fracture force load at the moment of fracture was less than 5–10%. The value of the additional load (impulse) was determined by corresponding cross-sectional diameter of brittle samples. Its value in the process of fracture for the each element measured via individual

Table 1
Chemical composition and mechanical properties of aluminium alloys.

Chemical composition [%]									
	Cu	Mg	Mn	Fe	Zn	Si	Ti	Cr	Zn
D16ChATV	4.4	1.4	0.63	0.18	0.16	0.11	0.07	0.01	0.01
2024-T351	3.82–4.04	1.75–1.77	0.56	0.08–0.18	0.16				

Mechanical properties in the rolling direction				
	R_m [MPa]	R_{02} [MPa]	E, GPa	A [%]
D16ChATV	442–463	316–328	69.35	18.8–21.2
2024-T351	459–466	339–345		21.5–24.7

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