Research of the fatigue behavior of multilayer steel material based on steel 08x18Ni10 and 08x18 at high values of cycle stresses under conditions of pure bending

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Abstract. In this paper, the authors studied the cycle durability of a multi-layered steel material based on stainless steels 08Cr18Ni10 and 08Cr18 at high values of stresses under the scheme of pure bending. The results showed that the cycle durability increases with increasing dispersion of the laminar structure. In addition, the authors studied the fractures after fatigue failure and analyzed their microstructure. The analysis showed that the nature of the fatigue failure of a multilayer steel material depends on the dispersion of the laminar structure.

Introduction
A new promising class of structural metallic materials are multilayer steel materials with ultrafine oriented multilayer (laminar) structure. Due to the high dispersion of individual layers (from micron to submicron thickness) and their large number (from several hundred to several thousand layers), such materials have a unique combination of physic and mechanical properties (especially strength and impact properties) [1-3].

One of the dangerous types of loading is cyclic loading. On the one hand, the fatigue characteristics of a material under cyclic loading will be large if it has greater strength [4]. On the other hand, it is known that the fatigue characteristics of a material strongly depend on its structural state. Subject to the Hall-Petch Act, \( \sigma \sim h^{1/2} \) (where \( \sigma \) – plastic strain strength, \( h \) – grain size), it can be said that the fatigue characteristics of the material will be large if it will have a greater dispersion of the structure. Thus, multilayer steel materials are very promising for their use in parts and structures operating under cyclic loading, for example, for helicopter torsions. Studies of such materials under cyclic loading with stresses less than their yield strength show that multilayer steel materials have high fatigue characteristics [5]. However, many parts and structures used in mechanical engineering work at high values of cyclic stresses, or they may experience short-term strong cyclic loading, i.e. overloads (for example, the same helicopter torsions). Therefore, the purpose of this work was to study the fatigue behaviour of multilayer steel materials in such conditions according to the scheme of pure flat bending.

Materials and methods for their preparation
In the production of multilayer steel material are widely used steel grades in mechanical engineering. Stainless steels of two grades were used for this study – 08Cr18Ni10 (austenitic class) and 08Cr18 (ferritic class). The production of multi-layer steel materials is carried out using the method of hot batch rolling according to the developed experimental technological route [2, 3].

In this technological route there are several repeating technological cycles (Fig. 1). In the first technological cycle, first, steel sheets with a thickness of 0.5 mm of each brand are taken and cut into dimensional cards with the surface treatment of these cards. After processing the surface of the card,
they are assembled into a multi-layered package, which consists of 100 alternating steel sheets through one through 50 pieces of each brand. Then the multilayer package is evacuated and undergoes hot plastic deformation at a temperature of 1000 °C. At the end of the first technological cycle, a steel laminated material with a thickness of 2 mm with a laminar structure is obtained, while the thickness of the individual layer is 20 μm and their number is 100. During the next technological cycle, the raw materials used are steel multilayer sheets obtained in the previous technological cycle, while each subsequent technological cycle consists of the same technological operations as the first cycle. In this study, two process cycles were used. At the end of the second cycle, the formed multilayer steel material with a thickness of 2 mm had a separate layer thickness of 1 μm, and the number of layers was about 1500.

**Fig 1.** Diagram of the experimental technological route for production a multiplayer steel material

**Experiment**

After the first and second technological cycles, samples of type IV were prepared according to GOST 25.502-79. These samples were studied for cyclic durability according to the scheme of pure plane bending with symmetric alternating loading, implemented in Schenk-Erlinger machine (Fig. 2). For testing, samples (1) were placed in jaws (6), which were fastened with bolted joints on the drive (2) and measuring (3) levers. Samples are set so that their centre of inertia is exactly on the axis passing through the middle of the sample (0) of the drive lever (2). By moving the runner block of the drive motor armature (10), the static displacement of the sample is adjusted in the vertical direction until the sample's inertia centre coincides with axis passing through the middle of the sample (0). The load was applied on the drive lever (2), which is connected by a crank cod (7) with drive motor armature (9) and an eccentric mechanism (8). The bending moment acting during the test in the sample is transmitted to the measuring lever (2) and causes an alternating rotation around the ideal axis (0). Calibration of the alternating rotation is carried out using a micro indicator (5), the probe of which touches the measuring lever (3) attached to the testing machine (11) using a balance spring (4). Knowing the geometry of the tested samples and changing the position of the eccentric mechanism (8), the required voltage was set. Because specimens were tested at high stresses, it was set to 750 MPa, which is much more than the yield strength for a multilayer steel material 08Cr18Ni10+08Cr18 (655 MPa), but less tensile strength (800 MPa).
Fig 2. Schrenk-Erlinger testing machine diagram for the fatigue testing under cyclic loading according to the scheme of pure flat bending:

0 – axis passing through the middle of the sample; 1 – test sample; 2 – driving lever; 3 – measuring lever; 4 – balance spring; 5 – micro indicator; 6 – jaw; 7 – crank cod; 8 – eccentric mechanism; 9 – drive motor armature; 10 – runner block of the drive motor armature; 11 – testing machine.

VEGA TESCAN scanning electron microscope was used to study the fracture surface microstructure.

**Results and discussion**

The results of studies on cyclic durability showed that cyclic durability for a sample of a multilayer steel material 08Cr18Ni10 + 08Cr18 after the first technological cycle, having a number of layers equal to 100, amounted to $3,05 \times 10^4$ cycles to the destruction. For a sample of a multi-layered steel material 08Cr18Ni10 + 08Cr18 after the second technological cycle, having a number of layers of the order $1500 - 9,9 \times 10^4$ cycles to the destruction (fig. 3). Thus, the cyclic durability increased by a little more than 3 times with an increase in the number of layers in a sample of a multilayer steel material (respectively, with a decrease in the thickness of an individual layer from 20 μm to 1 μm).
Fig 3. Test results on the cycle durability of steel laminate based on stainless steels 08Cr18Ni10 and 08Cr18 under the cycle loading according to the scheme of pure flat bending in the testing machine Achenk-Erlinger.

Studies of the microstructure of the surface of fatigue fractures showed that for a sample that had passed the first technological cycle, destruction occurred due to the initiation of fatigue cracks along the interface between the layers, and the propagation of fatigue cracks was carried out by opening the layers (Fig. 4 left). The development front of the main fatigue crack was perpendicular to the interface between the layers. For the sample that went through the second technological cycle, the destruction had a different character (Fig. 4, right). The development front of the main fatigue crack was parallel to the interface between the layers. This caused fatigue grooves to form along the layer along the border. In this case, a small part of the fatigue cracks originated along the interface between the layers and spread due to the opening of the layers.
Fig 4. Microstructure of fatigue fractures of samples of the multilayer steel material 08Cr18Ni10+08Cr18: left – after the first technological cycle; right – after the second technological cycle.

The research results showed that the fatigue behaviour of a multilayer steel material is most strongly influenced by the dispersion of its laminar structure. The increase in the dispersion of the laminar structure with an additional technological cycle made it possible to increase the cyclic durability by about three times. Analysis of fatigue fractures showed that the dispersion of the laminar structure also influenced the nucleation and propagation of fatigue cracks.

References
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