INTRODUCTION

As is known, one of the ways to improve structural and functional properties of materials is the formation of the ultrafine crystalline (UFC) and the nanocrystalline (NC) structure in them. In metallic materials, such structures can be obtained by methods of severe plastic deformation. The scientific backgrounds of the expediency of application of thermomechanical processing by equal-channel angular pressing (ECAP) and complex (dynamic) angular pressing (DCAP) for improving mechanical properties of numerous commercial alloys have been substantiated in [1, 2]. According to [2, 3], the use of ECAP makes it possible to improve the strength properties of such alloys by 50% and retain sufficiently high plasticity (more than 10%) if using additional annealing. For creating high-quality structural UFC and NC materials, it is necessary to know the mechanisms of stress relaxation and fracture of such materials, as well as of the effect of material structure and deformation conditions on their mechanical and service properties. In particular, the study of fracture surfaces makes it possible to determine factors responsible for the changes in the mechanical properties of material upon the transition into a UFC state.

This work is aimed at an analysis of the relief of the fracture surfaces of UFC samples of the aluminum alloy V95 and at the association of the fracture mechanisms with the mechanical properties arising after quasi-static tensile tests to failure.

EXPERIMENTAL

The UFC samples were produced by the method of dynamic channel angular pressing (DCAP) [4–6], which is based on the scheme of equal-channel angular pressing (ECAP), but, owing to the employment of pulsed sources, is characterized by higher deformation rates (to $10^4$–$10^5$ s$^{-1}$). The high deformation rates and the specific stress–strain state generated in the material during deformation as a consequence of combination of mechanical shear and shock waves provide for a rapid kinetics of the formation of the UFC structure in the material. The samples were produced after one or two pressing cycles ($B_1$ route, $N_1 = 1, 2$) at the initial speed of the sample motion equal to 150 m/s. As the initial samples, hot-pressed annealed rods with a diameter of 14 mm and a length of 60–65 mm were used.

The electron-microscopy studies of the structure were performed using the transmission electron microscopes JEM-200 CX and CM30. The sizes of structural fragments in the alloy after DCAP were calculated from dark-field electron-microscopic images using a “Siams-700” program package.

The quasi-static tensile tests of flat samples with UFC and CC structures were performed using a
The center of the sample (Fig. 1). Three fracture-surface regions (with dimensions of 750 × 300 μm) were scanned in each direction at a magnification of ×2000. For each scanned region, profiles averaged over 80 lines were obtained in mutually perpendicular directions (along the \(OX\) and \(OY\) axes). To obtain information on the scale invariance of the relief in terms of the Hurst exponent (roughness index) and on the range of structural scaling, the one-dimensional profiles of the fracture surface were processed using the average-range method \([7, 8]\). As a result, a range of Hurst exponents (roughness index) and on the range of structural scaling, the one-dimensional profiles of the fracture surface were processed using the average-range method. The structural state of the sample after two DCAP cycles leads to the generation of a finer and more uniform structure; at the average size of structure fragments equal to 200 nm, the fraction of crystallites with a size less than 300 nm increases in comparison with that in the sample after one DCAP cycle and is equal to 85%. The structural state of the sample after two DCAP cycles \((N = 2)\) becomes even more nonequilibrium. A comparison of the histograms of size distributions of structure fragments indicates that the repeated pressing cycle leads to the generation of a finer and more uniform structure; at the average size of structure fragments equal to 200 nm, the fraction of crystallites with a size less than 300 nm increases in comparison with that in the sample after one DCAP cycle and is equal to 85%.

When designing new engineering materials, an important purpose is to achieve a good combination of a high fracture strength and high plasticity. Figure 3 displays tensile stress–strain curves of the UFC samples obtained using DCAP and of an initial CC sample. It can be seen that the UFC alloy V95 possesses an increased strength in comparison with the CC material.