Mechanical behavior of coarse- and fine-grained Al-6101 samples of different geometry under tension

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Abstract. The paper presents the experimental data obtained during static tension of cylindrical samples of two structural states and two types of geometry from Al-6101 alloy at room temperature.

1. Introduction
Al-6101 alloy is widely used as a conductor for overhead transmission lines due to its increased strength and electrical conductivity. This alloy exhibits a tensile strength in the range from 255 to 330 MPa. This level of characteristics is achieved in it using traditional types of thermal or thermomechanical treatment [1, 2].

The approach based on the achievement of increased strength and electrical conductivity in alloys due to the formation of a regulated ultrafine-grained (UFG) structure using severe plastic deformation (SPD) has a great potential [3, 4]. The technique on the basis of equal-channel angular pressing according to the Conform scheme (ECAP-C) for producing long-length UFG semi-finished Al-6101 products (wires and wire rods) with a level of characteristics that has no world analogues was created in [5, 6].

For UFG Al alloys, it is important to study the features of their fracture, as well as the formation of pores and cracks during loading. Earlier in [7], such studies were carried out during tension of samples of coarse-grained (CG) metals, the geometry of which is shown in figure 1 (the rationale for using this geometry is given in [7]). The features of fracture and pore formation in UFG Al 6061 are investigated in our works [9], by using the method [7]. It is known that the geometry of the sample significantly affects the data obtained during tensile tests, and this influence is more significant for UFG materials [7]. In this respect, the influence of the geometry of the samples used in [7] on the behavior of CG and UFG Al-6101 alloys under static tension at room temperature was studied in this paper.

2. Object of study
The initial billets of Al-6101 alloy contained Si 0.3-0.7%, Mg 0.35-0.8%, Fe 0.50%, Cu 0.10%, Zn 0.10%, Cr 0.03%, Mn 0.003% in the form of bars with a diameter of 12 mm were used in this work. The initial billets were subjected to homogenization at a temperature of 550 °C for 2 hours and subsequent
quenching in water; after that they were subjected to natural aging (NA) for 6 days. To obtain UFG structure, part of the billets was processed by SPD via the ECAP-C method. The regime of obtaining UFG billets and a description of their microstructure features are presented in detail in [5].

![Figure 1](image1.png)

**Figure 1.** Samples with the working part diameters of 5 mm (a) and 3.2 mm (b).

Samples of a total length of 34 mm with a cylindrical working part with a diameter of 5 mm (sample No.1) and a groove ~3.2 mm in diameter (sample No. 2) were made from CG and UFG billets (figure 1).

Uniaxial tensile tests of the samples were carried out on a Shimadzu AG-50kNX testing machine at room temperature with a constant strain rate of $1.4 \times 10^{-4} \text{s}^{-1}$. Deformation of the working part of the samples was recorded using a Shimadzu TRViewX video extensometer. To register the deformation, horizontal marks were labelled on the surface of the working part of the samples at a distance of 3 mm from the center of the sample. At least 3 samples were tested for each microstructural state and geometry. Elongation was carried out to failure of the samples.

3. **Results**

Typical images of the CG and UFG structure of alloy samples are presented in figure 2 [9]. The grain size of the UFG sample was about 500 nm.

![Figure 2](image2.png)

**Figure 2.** Images of a typical microstructure of samples from alloy 6101 in CG (a) and UFG (b) states.

Figures 3-4 show the stress-strain diagrams for each geometry and each structure. Table 1 presents the mechanical properties measured from the stress-strain curves (figures 3-4).
Table 1. The mean values of mechanical properties for CG and UFG Al-6101 samples of different geometry.

| Structure type | Sample (No.) | Yield stress (MPa) | Tensile strength (MPa) | Relative strain (%) |
|---------------|--------------|--------------------|------------------------|--------------------|
| CG NA         | 1            | 85                 | 226                    | 50.9               |
|               | 2            | 92                 | 237                    | 18.29              |
| UFG           | 1            | 304                | 351                    | 32.83              |
|               | 2            | 310                | 406                    | 7.97               |

Figure 3. The stress-strain diagram for the sample with the working part diameter of 5 mm (a) and 3.2 mm (b), subjected to NA.

Figure 4. The stress-strain diagram for UFG sample with the working part diameter of 5 mm (a) and 3.2 mm (b).
4. Conclusions

One can draw the following conclusions during the analysis of the results:

Strength and ductility of the material are affected by the geometry of the investigated samples: Al-6101 samples with a narrower gauge length show higher strength, but they turn out to be the least ductile. The result on strength requires further analysis. The result on the ductility seems to contradict the data [8], where higher ductility was observed on the samples with a shorter gauge length. However, in our experiment, the same gauge length for both types of samples — 6 mm — was used to calculate and observe the strain via an extensometer. Sample No. 2 has a groove, respectively, it has a lower $\varnothing$ base/L0 ratio ($L_0$ is the gauge length of 6 mm), and in this regard, tests on sample No. 2 show lower ductility values than on sample No.1.

The strength indexes of UFG state are noticeably higher than those of CG during testing on samples of both geometries.

The sample geometry affects the mechanical properties detected in UFG material more strongly than in CG material: the difference in strength between UFG samples of different geometries is about 50 MPa, and between CG samples — about 10 MPa.

The obtained data will be used for further study of the influence of the structure and geometry of Al-6101 samples on pore formation under static tension.

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