The dependence of mechanical properties of Al-6101 alloy on geometry of the samples with a groove during tensile tests

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Abstract. This paper presents data on the mechanical properties of 6101 aluminum alloy during tensile tests of cylindrical samples with a groove of various geometries. The values of ductility, yield, changes in geometry of the samples are provided. It was also shown that the parameters of ductility and strength depend on geometry of the sample for tensile tests.

1. Introduction
Al alloys are of great importance for the development of various areas of technology and industry, in particular, aircraft construction, light industry, electrical engineering, the production of power lines, etc. One feature of these alloys is their good processing ability by deformation techniques such as cold and hot rolling, drawing, etc.

Investigations of the fracture behavior, the formation of pores and cracks under loading of Al alloys are relevant, since various mechanisms, structures and their components are made from these materials. The geometry effects of the test samples on mechanical properties of the titanium alloy was shown earlier: it was revealed that the values of ductility and yield of the material increase with a decrease in the cross-section diameter of cylindrical samples [1, 2].

A developed technique of conducting static tension for cylindrical samples of Al 6101 alloy of various geometries was presented earlier in [3-7], and a study on pore formation in the samples under tensile strain was also carried out. Deformation in works [4-7] was stopped until the fracture was reached, tensile was performed until the pores emerged inside the material. The use of samples of different geometries was substantiated. This paper presents the mechanical properties obtained by tensile of the samples of the same type carried to failure. Thus, this work is a continuation of the previously initiated research to determine the fracture parameters of the presented objects.

2. Experimental technique
Cylindrical samples made of 6101 aluminum alloy with different geometries (with three different diameters) were considered as the object of research. We take \( l = 5 \) mm as the gauge length (base) of the sample and \( d_1 = 5 \) mm (the first type of geometry). Previous tensile tests of the samples with a groove have shown that all strain is localized in the region of the groove in the center of the sample relative to the total
length [4]. Therefore, for b) sample we take $l = 2.83$ mm as the gauge length and $d = 2.8$ mm; for c) sample we take $l = 3.54$ mm as the gauge length and $d = 3.3$ mm [4-7].

![Figure 1](image.png)

**Figure 1.** Engineering image of the types of test samples.

The samples shown in Fig. 1 were subjected to artificial aging (annealing at 550°C for 2 hours with subsequent quenching and further annealing at 170°C for 12 hours with subsequent quenching according to standard processing [8, 9]).

Mechanical tests for uniaxial tension were carried out at room temperature with a constant strain rate of $1.4 \times 10^{-4}$ s$^{-1}$. The deformation of the samples was recorded using a video extensometer. The cross-sectional diameter of each sample was measured with a caliper before tensile. The rupture surfaces of the fractured samples were examined using a scanning electron microscope (SEM).

3. **Results**

The obtained tensile diagrams $\sigma$-$\varepsilon$ are presented below.

![Figure 2](image.png)

**Figure 2.** The stress-strain diagram.

![Figure 3](image.png)

**Figure 3.** The stress-strain diagram.
Figure 4. The stress-strain diagram.

The rupture surfaces obtained from the fracture of parts of the samples were studied by SEM with SEI mode in order to examine these surfaces [10-13] and measure the diameter of the cross-sectional area of the necks of the fractured samples with high accuracy. The images from the microscope are shown below.

Figure 5. The image of the rupture surface of the fractured sample with the initial d=5 mm.

Figure 6. The image of the rupture surface of the fractured sample with the initial d=3.33 mm.

Figure 7. The image of the rupture surface of the fractured sample with the initial d=2.84 mm.
Table 1 presents the data obtained from the tensile tests and the analysis of the fractured samples.

**Table 1.** Mechanical properties obtained by static mechanical fracture.

| The sample diameter before tensile $d_0$, mm | The sample diameter after tensile $d^*$, mm | Ductility | $\sigma_{\text{yield}}$, MPa | $\sigma_{\text{strength}}$, MPa | $\sigma_{\text{fracture}}$, MPa | $\sigma_{\text{true fracture}}$, MPa |
|--------------------------------------------|-------------------------------------------|-----------|---------------------|---------------------|---------------------|---------------------|
| $5$                                       | $3.25$                                    | $42$      | $58$                | $179$               | $214$               | $152$               |
| $3.33$                                     | $2.53$                                    | $22$      | $42$                | $219$               | $291$               | $257$               |
| $2.84$                                     | $1.99$                                    | $14$      | $51$                | $230$               | $330$               | $298$               |

In the given table $\sigma_{\text{fracture}}$ is the fracture stress of the sample on the engineering curve. The true fracture stress is $\sigma_{\text{true fracture}}$.

\[
\sigma_{\text{true fracture}} = \frac{P}{S_{\text{fracture}}} \tag{1}
\]

where $P$ is the load at the moment of fracture (MPa) и $S_{\text{fracture}}$ is the area at the moment of fracture (mm$^2$, determined by the fracture area).

The obtained data show: as expected, the “a” sample demonstrated strength values close to those according to the State Standard (GOST 1497) for 6101 alloy after the used treatment, but it also showed very high values of ductility (significantly higher than those according to the State Standard (GOST) for this alloy). This is due to the fact that the “a” sample has a gauge length $l$ equal to the diameter of the base $d$, i.e. $l/d$ ratio is equal to 1, while for the State Standard (GOST) samples $l/d$ is 5. Respectively, all strain localized after necking is referred to a shorter base in calculations (in contrast to tests on the samples according to the State Standard (GOST). The samples with a groove showed lower ductility values than the “a” sample. This is due to the fact that we take $l=2.83$ and $l=3.54$ mm as the gauge lengths of the “b” and “c” samples, respectively – the distance between the edges of the grooves. However, the diameter is continuously changing on these bases, and hence the strain does not occur on a significant part of these bases (i.e. these areas do not contribute to the strain), and the strain is localized in the area with the minimum section (minimum diameter). At the same time, a significant dependence of the strength parameters on the sample geometry was unexpectedly revealed; with an increase in the groove depth (with a decrease in the minimum diameter of a sample), the strength parameters enhance. This fact is unusual and requires additional research and analysis.

The true fracture stress $\sigma_{\text{true fracture}}$ is significantly higher than the ultimate tensile strength according to the engineering tensile curve. This demonstrates that the material continues to strengthen intensively during deformation and after its localization.

Fractures after rupture have a dimple character, which is common for 6101 alloy after the used tensile tests. At this stage of research, no unambiguous dependence of the fracture types (size and depth of dimples, etc.) on the geometry of test samples has been revealed.

### 4. Conclusion

The following conclusions can be drawn basing on the obtained data:

The “a” sample showed significantly higher ductility than the ductility according to the State Standard (GOST) for a given alloy, which is associated with the peculiarities of the sample geometry.

The samples with the groove showed lower values of ductility than the “a” sample, which is associated with the peculiarities of the groove geometries.
It was unexpectedly found that the strength parameters enhance with increasing depth of the groove. This fact is unusual and requires additional research and analysis.

The true fracture stress $\sigma_{\text{true fracture}}$ is significantly higher than the ultimate tensile strength according to the engineering tensile curve.

Fractures after rupture have a dimple character, which is common for 6101 alloy after the used treatment; no dependence of the fracture types on the sample geometries is observed.

5. References

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