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DYNAMIC STRENGTH PROPERTIES OF AN ULTRA-FINE-GRAINED ALUMINUM ALLOY UNDER TENSION CONDITIONS

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Abstract. Experimental and theoretical analysis of aluminum alloy 1230, subjected to static and dynamic tension is presented in the paper. The material was tested in two conditions - initial coarse-grained (CG) state and ultrafine-grained (UFG) state. Experimental results were processed using incubation time fracture criterion.

Keywords: dynamic impact, fracture, nanostructured material, strength criterion.

1. Introduction

Standard tests of construction materials for industrial applications include compression, tensile, bending, hardness, and fatigue tests. Such tests ensure, that the production satisfies existing safety and reliability rules. But in the case, when conditions are significantly different from quasistatic loads, additional tests and calculations are required. As a rule, such additional research is required, when material properties in high-rate loading conditions need to be assessed. Such loading conditions are typical for airspace and military engineering applications, however high-rate testing is also used for civil construction in seismic regions.

In order to increase strength and reliability of products and parts, designed for use under high-rate loading one has to perform experimental and analytic studies of the strength characteristics of the material.

Research in this direction was initiated in the second half of the 20th century. A separate direction of science – fracture mechanics was formed. At the same time, despite the fact that a large number of experimental and theoretical works in this area was carried out, some crucial problems remain unsolved. New materials, such as bulk new nanostructured materials [1, 2, 3], generate new problems and require additional research. A lot of research results, presented in scientific literature, are aimed at studying of influence of the refined material structure on strength and performance properties of the material [4-7]. Data on the study of the behavior of the ultrafine-grained materials under dynamic conditions is less frequent. This is partly due to the dimensional features of the currently obtained samples of the UFG materials. For example, severe plastic deformation (SPD) technique is usually capable of production of disk specimens 20 mm in diameter and 1-2 mm in thickness. Standard test procedures for such small are not applicable.

Experimental results in this paper were received for a model material – aluminum alloy 1230 (ASTM).

2. Material

The aluminum alloy 1230 was modified using severe plastic deformation by torsion on the Walter-Klement high pressure torsion press in order to obtain the refined grain structure. Working parameters: pressure - 6 GPa, number of rotations - 10, processing speed - 1 revolution per minute. The sample were manufactured at room temperature.

Measurements of the Vickers microhardness of the samples demonstrated the uniformity of the specimens. On average, the microhardness of the samples increased by 87%.

Several studies of metals and alloys [8-9] have shown, that severe plastic deformation substantially increases hardness of the material and, as a rule, the strength characteristics of materials. However, the SPD treatment might lead to reduction of plasticity, which can have negative effect on the behavior of the material in the dynamic loading range. Thus, multiple dynamic experiments are needed in order to determine possible characteristics of the external loads.

3. Experimental Techniques

Experimental studies of the dynamic tension regime were performed on the drop tower machine Instron CEAST 9350 at a strain rate up to 10^2-10^3 s^{-1}. The main advantage of this equipment setup is certified signal capture techniques and an automated test procedure, which reduces the error of the experiment. Experiments with quasistatic loads were performed on Shimadzu AG-50kNX.

The tension experiments were carried out on an aluminum alloy for different geometric dimensions of flat samples. The first type of the sample gemetry is shown in Fig. 1. The dimensions of the specimens correspond to ISO 8256 standard with the length and width of the working part equal to 10 mm and 3 mm respectively (Fig. 1, a). The second type of the sample geometry was developed considering the dimensional features of the samples obtained by SPD. The length and width of the working part are 5 mm and 2 mm respectively (Fig. 1, b). All the samples were cut using an electrical discharge machine ARTA 123 PRO with high accuracy and brought to a uniform roughness parameter using the polishing machine.

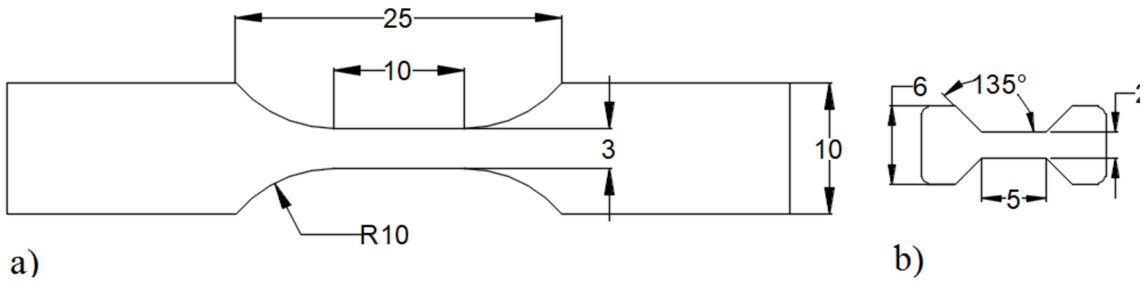

Fig. 1. Geometry size for samples of type "Sample I" a) and type "Sample II" b).

In Instron CEAST 9350 data signals are captured automatically using a force sensor and a velocity sensor. Fig. 2 shows examples of the stress chronograms for the "Sample II" type samples. The signals are quite stable and can be used to determine the threshold characteristics of the material under tension.

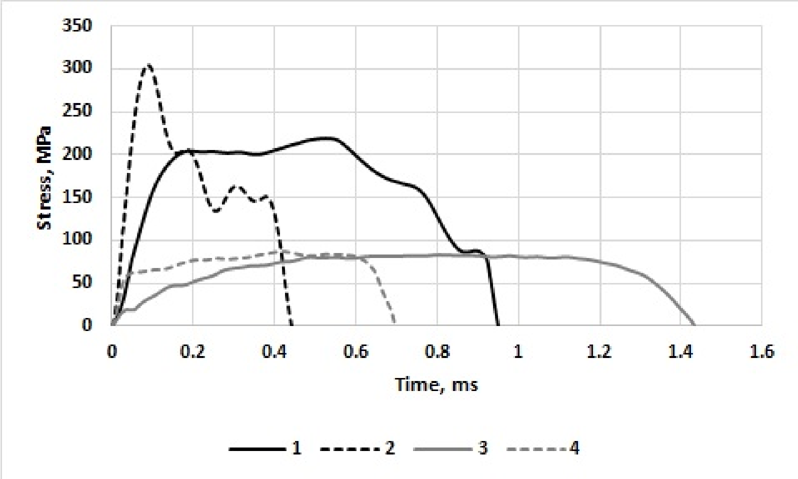

Fig. 2. Stress obtained during tensile test for samples of type «Sample II» for UFG and CG materials for different strain rate. 1 – $\dot{\varepsilon} = 304\ s^{-1}$ UFG alloy, 2 – $\dot{\varepsilon} = 642\ s^{-1}$ UFG alloy, 3 – $\dot{\varepsilon} = 328\ s^{-1}$ CG alloy, 4 – $\dot{\varepsilon} = 640\ s^{-1}$ CG alloy.

4. Results and discussion

Dependence of the threshold stress values for the studied materials on the strain rate are shown in Fig. 3. The obtained results demonstrate that the CG alloy has lower strength then the UFG alloy. With an increase in the strain rate, a nonlinear increase in the maximum stress value is observed for both materials.

This feature of the behavior of the material at high strain rates can be explained using incubation time approach. Incubation time fracture criterion was used for the fracture analysis [10, 11]:

$$\frac{1}{\tau_c}\int_{t-\tau_c}^{t}\frac{\sigma(s)}{\sigma_c}ds \le 1, \qquad (1)$$

where t is time, σ is the applied stress (linearly increasing with time load), σ_c is the ultimate strength under static loads, τ_c is the incubation time of fracture. The constants σ_c and τ_c are the parameter of the material.

Correlation between maximum stress and strain rate under tension is shown on Fig.3. Theoretical lines are constructed using criterion (1) with the following parameters of the material: for the CG alloy $E = 72$ GPa, τ_c = 0.8 μs, σ_c = 80 MPa; for UFG alloy E = 72 GPa, τ_c = 4.4 μs, σ_c = 200 MPa. A good agreement between the experimental data was obtained for different sample sizes and material states.

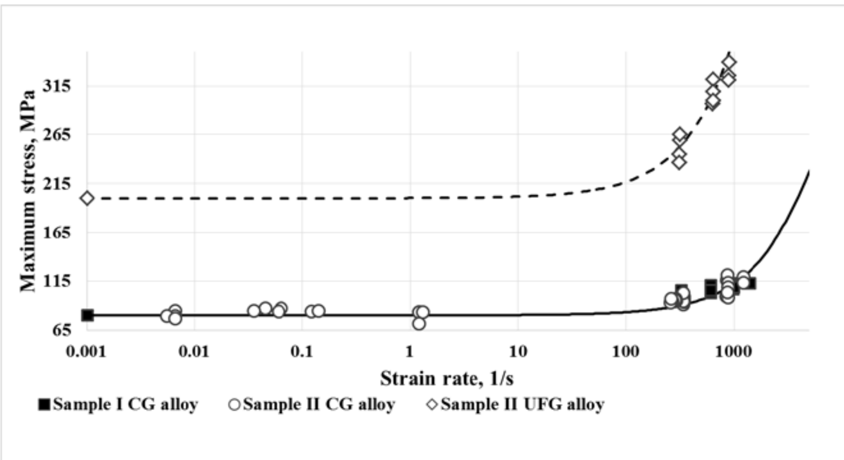

Fig. 3. Maximum tension stress versus strain rate. Lines constructed according (1) with material parameters: for CG alloy E = 72 GPa, τ_c = 0.8 μs, σ_c = 80 MPa; for UFG alloy E = 2 GPa, τ_c = 4.4 μs, σ_c = 200 MPa.

A direct comparison of experimental data CG and UFG alloy makes it possible to determine a significant increase of the strength characteristics of the material after severe plastic deformation not only in the quasistatic range of the loading parameters but also in the dynamic one. Maximum stress in static regime of tension increased from 80 MPa to 200 MPa. The material parameter τ_c (dynamic strength) increased from 0.8 μs to 4.4 μs.

The non-linear increase in strength with increasing of the strain rate and the significant change in the strength properties of the material after the SPD processing require a comprehensive experimental-theoretical investigation in order to assess applicability of a material for certain extreme conditions.

5. Conclusions

The performed experimental studies show that severe plastic deformation has a significant influence on the behavior of the material not only in quasistatic but also in dynamic loading regimes. A detailed study of the properties of the material in a wide range of parameters of the external action is required.

The effect of strain rate dependence of maximum stress under tension was investigated using incubation time approach. Parameters of materials were found and curves of maximum stress under tension were calculated. It was found that the SPD treatment has a great influence on strength characteristics of the material in static and dynamic regimes of loading. For the UFG aluminum alloy significant increase in strength was observed for a wide range of loads.

In addition to this, the use of the theoretical approach based on incubation time criterion makes it possible to predict behavior of the material for the regimes, that were not experimentally investigated. The proposed experimental-theoretical approach to testing of nanostructured materials for tensile strength has shown its robustness and can be recommended for complex testing of nanostructured materials, which are planned to be used under dynamic loads.

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