AIP Conference Proceedings

Influence of static tensile testing on the deformation behavior of Al–4% Cu alloy containing micro- and nanoparticles

Anton Khrustalyov, Sergey Vorozhtov, and Sergey Kulkov

Citation: AIP Conference Proceedings **1783**, 020088 (2016); doi: 10.1063/1.4966381
View online: http://dx.doi.org/10.1063/1.4966381
View Table of Contents: http://scitation.aip.org/content/aip/proceeding/aipcp/1783?ver=pdfcov
Published by the AIP Publishing

Influence of Static Tensile Testing on the Deformation Behavior of Al–4% Cu Alloy Containing Micro- and Nanoparticles

Anton Khrustalyov[1,a)], Sergey Vorozhtov[1,2], and Sergey Kulkov[1,2]

[1] *National Research Tomsk State University, Tomsk, 634050 Russia*
[2] *Institute of Strength Physics and Materials Science SB RAS, Tomsk, 634055 Russia*

[a)] Corresponding author: tofik0014@mail.ru

Abstract. At present, aluminum alloys reinforced with nonmetallic particles are of great interest in various fields of science and technology due to their high specific strength, hardness, wear resistance, and other properties. At the same time there is a great interest in the study of processes occurring during plastic deformation of such materials under static tensile loading. Plastic flow of metals occurs through the creation and movement of linear defects (dislocations), in which there is a phenomenon of discontinuous yielding. An introduction of particles into aluminum alloy promotes a considerable increase of stiffness and specific strength of alloys, and the study of the deformation behavior of such alloys is of great interest. The objective of this research is to analyze mechanical properties and the deformation behavior of aluminum alloy with the identification of mechanisms of plastic deformation when introducing solid nonmetallic micro- and nanoparticles into the soft aluminum matrix. An analysis of the microstructure of the obtained alloys shows that the introduction of particles (Al_2O3, TiB_2, TiC) leads to a reduction of the alloy grain size from 350 to 170 μm while residual porosity does not exceed 2%. Tensile tests performed show that the change in the type and quantity of particles also changes characteristics of discontinuous yielding, thus resulting in an increase of yield strength (from 18 to 40 MPa), reduction of ductility (from 15 to 2%), and moreover a significant increase of tensile strength (from 77 to 130 MPa), as compared to the initial Al–4 wt % Cu alloy.

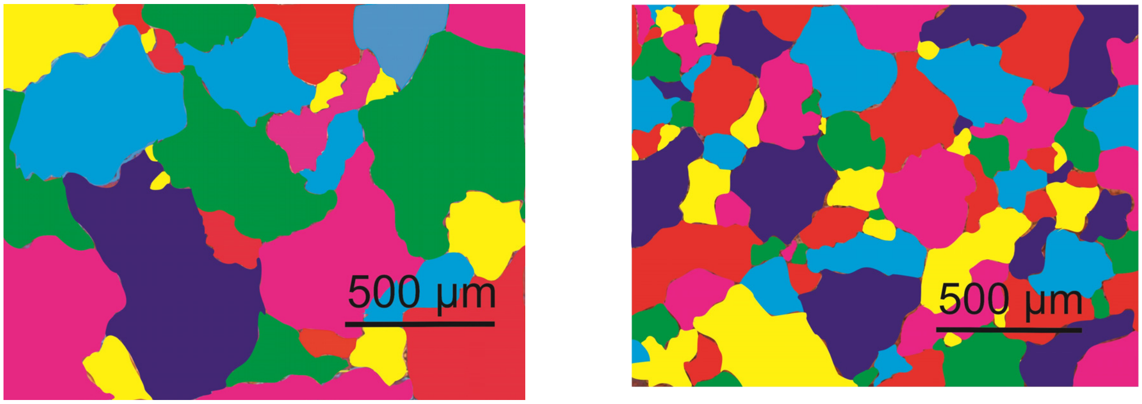
INTRODUCTION

Aluminum alloys reinforced with nonmetallic particles are of great interest in various fields of science and technology due to their high specific strength, hardness, wear resistance, and other properties. It is known, that an introduction of particles leads to a significant increase of hardness and specific strength of the alloys [1, 2].

The study of processes of plastic deformation of such materials under static tensile loading is of great interest. Plastic flow of metals is associated with the creation and movement of linear defects (dislocations) [3] where discontinuous yielding phenomenon takes place. In the stress-strain curve, discontinuous yielding can be seen in the form of repeated inhomogeneities. Each of the jumps of discontinuous yielding represents some initial microscopic fluctuation about the general stress-strain curve. If microfluctuations do not increase with time, deformation is considered stable. If microfluctuations increase and increase to a new scale level, the instability of plastic deformation takes place, which can be seen on the regular stress-strain curve. Thus, any loss of stability of plastic deformation is a relaxation act leading to an increase of the scale level of plastic deformation, which corresponds to its general trend [4].

The main objective of this research is to study mechanical properties and the deformation behavior of aluminum alloy, and to identify the plastic deformation mechanism in the process of introduction of solid nonmetallic micro- and nanoparticles into the soft aluminum matrix.

Advanced Materials with Hierarchical Structure for New Technologies and Reliable Structures 2016
AIP Conf. Proc. 1783, 020088-1–020088-4; doi: 10.1063/1.4966381
Published by AIP Publishing. 978-0-7354-1445-7/$30.00



(a) (b)

FIGURE 1. Microstructure of the alloys and their grain size distribution: initial Al–4 wt % Cu alloy (a) and Al–4 wt % Cu alloy with 0.05 wt % of Al_2O_3 (b)

MATERIALS AND METHODS

Materials used in the research are Al–4 wt %Cu alloy as well as alloys produced on its basis using the method of die casting. Melting of the metal was carried in a Rohde Ecotop 20 muffle furnace (Germany). External treatment (mechanical, ultrasonic) of the melt was performed on the unique equipment in our own assembly (components produced in the Russian Federation) at the melt temperature 750°C with a simultaneous introduction of master alloys containing alumina nanoparticles and microparticles of titanium boride and titanium carbide into the melt according to parameters described elsewhere [5].

Alumina powder was produced using the method of electrical explosion of wire (EEW) [6]; microparticles of titanium boride and titanium carbide were produces using the method of self-propagating high-temperature synthesis (SHS) [7].

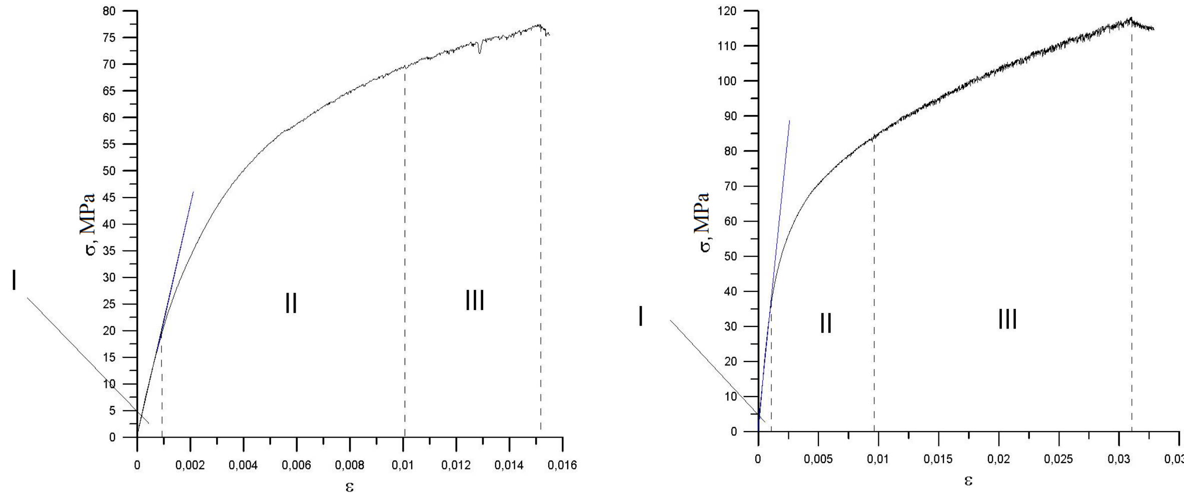
Tensile tests were performed using an Instron 3368 universal testing system at room temperature. The guaranteed frame stiffness for this machine corresponds to 250 kN load, the load accuracy is 0.5% of the indicated load. The ultimate load during testing procedures did not exceed 1.5 kN. The travelling speed of the grip comprised 0.01 mm/min. Microhardness and Young's modulus of the materials obtained were measured using a Nano Indenter G200/XP hardness tester with the maximum load 250 g.

RESULTS AND DISCUSSION

Figure 1 shows the microstructure of Al–4 wt % Cu alloy (Fig. 1a) and an alloy containing alumina nanoparticles (Fig. 1b).

The analysis of the obtained images of the microstructure indicates that the introduction of particles leads to a reduction of the alloy grain size while the residual porosity does not exceed 2%. The introduction of alumina particles makes it possible to reduce the grain size from 336 to 213 µm; of titanium carbide particles, to 283 µm; of titanium boride particles, to 174 µm. Thus, the introduction of nonmetallic particles leads to a more than 40% reduction of the alloy grain size. The obtained data indicate that particles and ultrasonic treatment make a significant contribution to the refinement of the ingot structure, which in turn makes it possible to improve mechanical properties of the alloys [2].

Strain-stress diagrams of Al–4 wt % Cu aluminum alloy and the alloy on its basis containing alumina nanoparticles are given in Fig. 2. The loading curves have a typical form for aluminum alloys, and the "serrated" character of the loading curves indicates a discontinuity of plastic deformation. A change of the particle type and quantity affects characteristics of discontinuous yielding, which is expressed in a change of the range and amplitude of stress fluctuation. The comparative analysis shows that discontinuous yielding is clearly manifested under deformation when $\varepsilon = 0.004$ and increases with increasing load. All obtained σ–ε diagrams are characterized by a smooth decrease of the strain-hardening coefficient without a distinct yield point. The introduction of particles (Al_2O_3, TiC, TiB_2) increases the yield strength, reduces ductility, and significantly increases ultimate tensile strength as compared to the initial alloy.



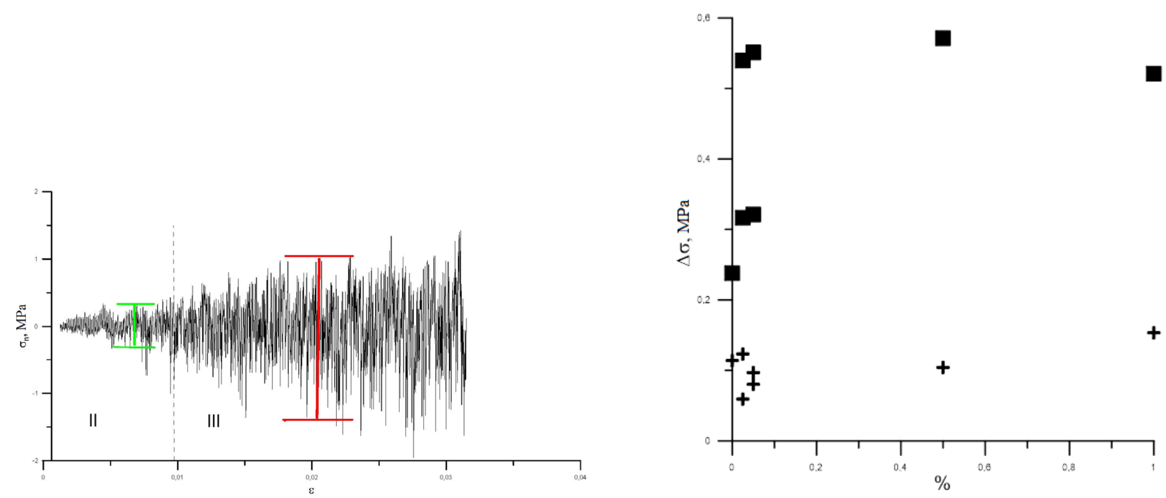
(a) (b)

FIGURE 2. Stress-strain diagram: (a) Al–4 wt % Cu; (b) Al–4 wt % Cu + 0.1 wt % Al_2O_3

In order to find boundaries of the stages of strain hardening [8], the stress-strain diagram was divided into three regions using Honeycomb's concepts [9]. The first part represents an elastic region while the second and the third parts are characterized by plastic deformation regions. The root mean square deviation of stresses $\Delta\sigma_n$ is one of the basic parameters of discontinuous yielding. The following expression was used to determine it at two stages of plastic deformation:

$$\Delta\sigma_n = \sigma - \sigma_{tr},$$

where σ is the stress according to the loading diagram and σ_{tr} is the stress corresponding to the neutral line of the trend regarding material stress jumps. The obtained data make it possible to represent a serrated curve of discontinuous yielding in the form of stress fluctuations (Fig. 3a). The average amplitude of stress jumps $\Delta\sigma_n$ increases when the stress fluctuation system passes from the second part of the stress-strain curve to the third one. The dependence of the root mean square Δσ on the number of particles (Al_2O_3, TiB_2, TiC) introduced into the Al–4 wt % Cu alloy is shown in Fig. 3b.



(a) (b)

FIGURE 3. Relation at two stages of strain hardening: $\Delta\sigma_n$–ε (a); Δσ versus the number of particles introduced into the alloy (b)

It can be seen that an increase of the particle content in the alloy at the second part of the stress-strain curve lead to no significant increase in the stress deviation $\Delta\sigma_n$. However, further deformation and the transition to the second stage of strain hardening (corresponds to the third part of the stress-strain curve) is characterized by a significant increase of material microfluctuations. Apparently, this effect is associated with the fact that there was an inhomogeneous distribution of particles and insufficient deagglomeration in the process of material synthesis, which resulted in inhomogeneous deformation of the alloys. An additional optimization of the alloy production process can provide more homogeneous and stable deformation making it possible to improve mechanical characteristics and ensure the structural safety in critical situations.

SUMMARY

It was found that the introduction of nonmetallic particles leads to a more than 40% reduction of an alloy grain size.

It was also shown that the introduction of particles increases yield strength, reduces ductility, and increases significantly ultimate tensile strength. In this case, the stress-strain curves have a typical form with a distinct difference of discontinuous yielding.

Moreover, the analysis of the stress-strain curves revealed that the inhomogeneous distribution of particles and insufficient deagglomeration leads to the unstable material deformation at the second stage of strain hardening. A better process optimization may improve the deformation behavior of such alloys.

ACKNOWLEDGMENTS

The work was financially supported by the Ministry of Education and Science of the Russian Federation within the framework of the Federal Target Program, Agreement No. 14.578.21.0025 (Unique identifier RFMEFI57814X 0025).

REFERENCES

1. I. G. Brodova, M. A. Uimin, et al., Lett. Mater. **3**, 91–94 (2013).
2. S. A. Vorozhtsov, A. P. Khrustalyov, et al., Russ. Phys. J. **57**(11), 1485–1490 (2015).
3. E. D. Schmitter, Phys. Lett. A **368**(3), 320–323 (2007).
4. M. M. Krishtal, Phys. Mesomech. **7**(5–6), 27 (2004).
5. S. A. Vorozhtsov, D. G. Eskin, A. B. Vorozhtsov, V. V. Promakhov, A. P. Khrustalyov, J. Tamayo, and A. A. Averin, Metall. Mater. Trans. A **46**(7), 2870–2875 (2015).
6. S. Tarasov, A. Kolubaev, S. Belyaev, M. Lerner, and F. Tepper, Nanotech. Russ. **4**(11), 741–757 (2009).
7. J. Subrahmanyam and M. Vijayakumar, J. Mater. Sci. **27**(23), 6249–6273 (1992).
8. V. I. Danilov, et al., J. Appl. Mech. Tech. Phys. **47**(2), 298–305 (2006).
9. R. W. K. Honicomb, *The Plastic Deformation of Metals* (1984).