Materials Physics and Mechanics 28 (2016) 6-10 Received: June 26, 2015

EFFECT OF TEMPERATURE ON THE MECHANICAL PROPERTIES OF MULTI-COMPONENT Al-Mg-Si ALLOYS DURING NANOINDENTATION TEST

E.V. Sadyrin[1*], B.I. Mitrin[1], S.M. Aizikovich[1], T.I. Zubar[2]

[1]Research and Education Center "Materials", Don State Technical University,

Gagarin Sq. 1, Rostov-on-Don, 344010, Russia

[2]A.V. Luikov Heat and Mass Transfer Institute of the National Academy of Sciences of Belarus,

P. Brovki str. 15, Minsk, 220072, Belarus

*e-mail: evgeniy.sadyrin@gmail.com

Abstract. This paper presents the research results of the effect of the difference in the sample and indenter temperature on the calculated characteristics of the mechanical properties of multi-component Al-Mg-Si alloys during nanoindentation test carried out on the AVT-1 alloy sample. The surface topography of the sample was studied using atomic force microscope and profilometer, after that 3 series of indentation experiments with different heating schemes were conducted, results are presented in the form of tables and illustrated with graphs, showing dependence of calculated characteristics of the material mechanical properties, determined using the nanoindentation platform software, from temperature.

1. Introduction

Modern high-tech industries such as biotechnology, nanoelectronics, energetics and mechanical engineering are placing increasing demands on the physical and mechanical properties of materials [1]. Nanoindentation holds leading position in the research of physical and mechanical properties of traditional and advanced materials in the micro- and nanoscale , representing today a broad class of techniques and methods of micro- and nanomechanical testing of materials, and related modes of contact atomic force microscopy. In a short time, they gave birth to a myriad of ideas and approaches to improve the creation of traditional and original materials, structures, coatings [2]. New physically justified models of the indentation process are currently developed [3-5] as well as the methods for extraction of real characteristics out of raw data for modern materials such as nanocomposites, polymers, ceramics, thin films, biomaterials, and others. Improved designs of nanoindentation platforms and expanding of their functionality create prerequisites for the study of temperature-dependent mechanical properties of metals and alloys with such devices [6-8 and others].

The aim of this study was nanoindentation of Al-Mg-Si alloys. The AVT-1 alloy sample was considered, which was subjected to conventional hardening heat treatment: quenching in water at 515-525 °C and aging treatment at 160 °C with 12-18 hours of exposure. In the aging process of such alloys (aircraft-grade aluminum) Mg and Si atoms form thermally stable compounds of magnesium silicide Mg_2Si (reinforcing phases [9]).

Due to its high corrosion resistance, large enough strength, high fatigue strength and toughness, the alloys of this system are widely used in the manufacture of propeller blades of helicopters, components for aviation, car frame and chassis, orthopedic implants and other constructions [10-12].

indenter and the sample were carried out separately. For each pair of temperature values of the indenter and the sample between 8 and 12 indentations were performed at different spaced apart regions of the sample (situated not far from each other), with the average value of characteristics determined during indentation test was assumed as a result.

Series 1 - the temperature of the indenter was maintained constant at 60 °C, while the temperature of the sample was increased from experiment to experiment. The results of this series of experiments are presented in Table 1.

Series 2 – both the sample and the indenter were heated to the same temperature, which was increased from one experiment to another. The results of this series of experiments are presented in Table 2.

Series 3 - sample temperature was maintained constant at 60 °C, while the temperature of the indenter was increased from experiment to experiment. Results of this series of experiments are presented in Table 3.

Table 1. Results of series 1 of experiments.

№	Indenter temperature, °C	Sample temperature, °C	Results	
			Modulus of elasticity E, GPa	Hardness H, GPa
1	60	40	152.43 ± 6.10	1.94 ± 0.051
2	60	60	120.43 ± 5.59	1.95 ± 0.110
3	60	80	95.45 ± 5.13	2.15 ± 0.068
4	60	100	75.15 ± 3.63	2.59 ± 0.16
5	60	115	68.06 ± 2.02	3.23 ± 0.131

Table 2. Results of series 2 of experiments.

№	Indenter temperature, °C	Sample temperature, °C	Results	
			Modulus of elasticity E, GPa	Hardness H, GPa
1	40	40	121.38 ± 6.35	1.98 ± 0.2
2	60	60	120.43 ± 5.59	1.95 ± 0.110
3	80	80	130.63 ± 9.93	2.09 ± 0.2
4	100	100	149.23 ± 12.59	1.96 ± 0.22
5	115	115	150.43 ± 26.58	2.11 ± 0.084

Table 3. Results of series 3 of experiments.

№	Indenter temperature, °C	Sample temperature, °C	Results	
			Modulus of elasticity E, GPa	Hardness H, GPa
1	40	60	96.39 ± 5.34	2.28 ± 0.166
2	60	60	128.48 ± 3.42	2.035 ± 0.119
3	80	60	179.26 ± 11.79	1.9 ± 0.007
4	100	60	171.69 ± 3.74	1.7 ±0.101
5	115	60	150.34 ± 8.57	1.34 ± 0.117

Figures 3 and 4 show graphs of modulus of elasticity and hardness dependence from temperature in three series of experiments.

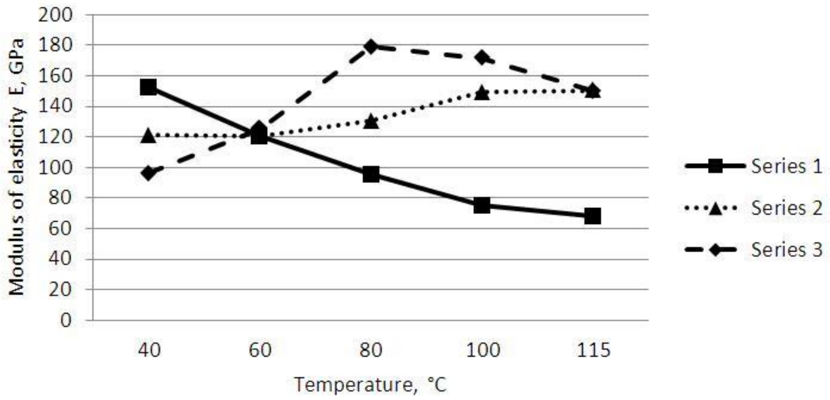

Fig. 3. Modulus of elasticity of AVT-1 alloy dependence from temperature acquired in three series of experiments.

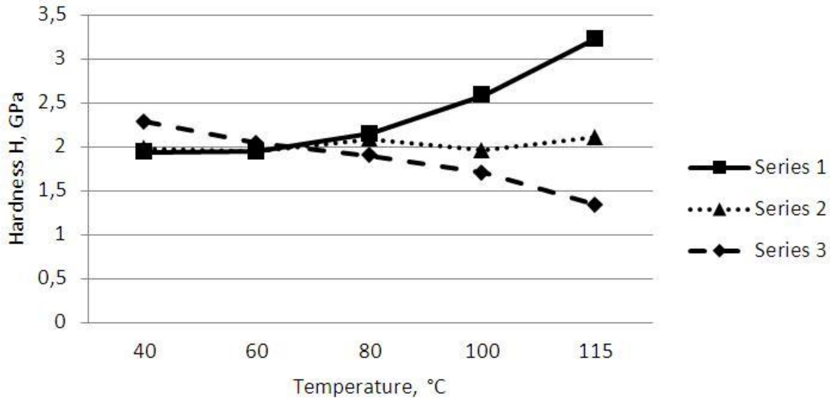

Fig. 4. Hardness of AVT-1 alloy dependence from temperature acquired in three series of experiments.

3. Conclusions

Investigation of the effect of temperature on the calculated mechanical properties of multi-component Al-Mg-Si alloys during nanoindentation test was conducted during the three series of experiments using different heating schemes with subsequent data interpretation by the standard software of the device according to the Oliver – Pharr method.

It is shown that the temperature difference and the heat flow between the indenter and the sample has a significant impact on the calculated mechanical characteristics of material, determined by the standard software of the device. Therefore, using the standard methods for determining the mechanical properties of materials requires one to perform simultaneous and uniform heating of both the indenter and the sample during nanoindentation test. Today rather small amount of devices for nanoindentation have ability to satisfy these requirements.

The study results demonstrate the dependence of the calculated hardness and modulus of elasticity of the AVT-1 alloy from temperature even at small difference in temperature of the indenter and the sample (heating to 115 ºC) determined using the standard software of the device. It is shown that one must take into account the difference in temperature of the indenter and the sample during nanoindentation test for an adequate interpretation of the experimental results.

Acknowledgements

This work was partially supported by the Ministry of Education and Science of Russia and Russian Foundation for Basic Research (grants nos. 14-07-00343-a, 16-07-00958-a, 15-38-20790-mol_a_ved, 15-57-04084-Bel_mol_a).

References

[1] V.I. Moschenok // *Avtomobilniy transport* **22** (2008) 151. (In Russian).
[2] Y.I. Golovin, *Nanoindentation and its capabilities* (Mashinostroenie, Moscow, 2009). (In Russian).
[3] A.J. Muir Wood, T.W. Clyne // *Acta Materialia* **54(20)** (2006) 5607.
[4] S.M. Aizikovich, V.M. Alexandrov, J.J. Kalker, L.I. Krenev, I.S. Trubchik // *International Journal of Solids and Structures* **39(10)** (2002) 2745.
[5] L.I. Krenev, S.M. Aizikovich, B.I. Mitrin // *Vestnik of Don State Technical University* **14(1)** (2014) 34. (In Russian).
[6] A. Richter, C.-L. Chen, R. Smith, E. McGee, R.C. Thomson, S.D. Kenny // *Materials Science and Engineering A* **494(1-2)** (2008) 367.
[7] A.A. Volinsky, N.R. Moody, W.W. Gerberich // *Journal of Materials Research* **19(9)** (2004) 2650.
[8] S. Nsoesie, R. Liu, K. Jiang, M. Liang // *International Journal of Material and Mechanical Engineering* **2(3)** (2013) 48.
[9] V.I. Nikitin, *High-temperature strength, ductility and corrosion of aircraft-grade aluminum* (Metallurgia, Moscow, 1978). (In Russian).
[10] Y.M. Lakhtin, *Metallurgy and heat treatment of metals* (Metallurgia, Moscow, 1983). (In Russian).
[11] A.P. Dolin, G.F. Shongin, *Open switchgear with rigid busbar* (Energoatomizdat, Moscow, 1988). (In Russian).
[12] K.K. Alaneme, T.M. Adewale, P.A. Olubambi // *Journal of Materials Research and Technology* **3(1)** (2014) 9.
[13] http://nano.donstu.ru/