Selection of an aluminum matrix composition for obtaining the heat treatable boron-aluminum alloys

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Problem of substantiating the aluminum matrix composition for obtaining the heat treatable boron-aluminum alloys in the form of ingots and sheet products. Aluminum-based materials alloyed by boron are promising radiation-resistant structural materials.

Analysis of basic systems of the heat treatable (T6) aluminum alloys was carried out. Zinc-containing systems (Al – Zn – Mg and Al – Zn – Mg – Cu) has been excluded because of likelihood of burning-out at high smelting temperatures. With the use of the calculations (Thermo-Calc software) and experimental methods (including scanning electron microscopy and micropobe analysis), justified has been an unreasonableness of obtaining the boron-aluminum alloys based on magnesium-containing systems because of an active interaction of that element with boron. An (Al, Mg)B_2 compound with particles of adverse needle-shaped form arises even at small magnesium concentrations.

Experimental study has been focused on the boron-aluminum alloys based on Al – Zr – Sc (with magnesium, manganese and titanium additives) and Al – Cu systems. Alloys have been prepared on the base of high-purity aluminum in a graphite-fireclay crucible at the temperature of 900–950 °C in a RIELTEK («РЭЛТЕК») induction furnace, which provides an intensive melt mixing required to exclude a possibility of refractory boron-containing particles deposition. The melt was poured into a graphite moulds to obtain flat ingots of 40×120×200 mm in size. Samples for structural investigations has been cut thereof. Later on the ingots have been treated by strain and thermal processing.

It was found that titanium introduction into the systems with zirconium and scandium doesn't assist in preventing their interaction with boron, which hamper the aluminum matrix hardening. The Al – Cu system meets the requirements best of all since copper doesn't interact with boron and doesn't effect on composition of the boron-containing phases. It was determined that such system allows to obtain ingots and sheet products of aluminum boron-containing alloy possessing high mechanical properties. The maximum achievable hardness on ingots and sheet products amounts to 129 *HV* and 133 *HV* correspondingly, and the tensile strength (sheets) equals to 430 MPa.

Key words: boron-aluminum, sheet products, microstructure, thermal treatment, mechanical properties, hardness of alloy.

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Introduction

Today, the Al-based boron-doped materials are considered as promising radiation-resistant structural materials for use in different fields: atomic engineering industry, at aerospace enterprises, in several lines of electrical engineering, instrument-making industry and electronics [1, 2]. The field-performance data of this class of materials should meet very high requirements. In addition to capability for absorbing thermal neutrons, corrosion resistance, thermal conductivity, boron-aluminum materials should possess high mechanical properties [3, 4].

Abroad, the volume of production with the use of the boron-filled materials measures by many tens thousands ton per year. Lately, the liquid-phase technologies of boron-aluminum production become widely (in particular, in the form of ingots meant for sheet products making thereof), since they often are essentially cheaper, technologically simpler and guarantee high mechanical properties of materials owing to the strong connection on the matrix-filler border. Some companies producing boron-aluminum use a mixing technology of powder particles of the boron-containing compounds (for example, B_4C) into liquid smelt [5]. In Russia, the wide production of boron-containing aluminum alloys is lacking until now, notwithstanding the fact that a need for them is evidently felt. Specifically, during transportation of proceeded radioactive wastes, the transit of which is currently carried out in the old-type containers made of the boron-filled steel.

Using binary Al — B alloys as an example, in the paper [6] it is shown that borides don't make unalloyed aluminum manufacturability worse during cold rolling. However, the strength of the binary boron-aluminum alloys (without additional doping) is not high. To obtain the required mechanical properties (the strengthening ones first of all), an additional doping is necessary [7].

It is known that one can gain the highest strength in aluminum alloys due to forming of the nano-sized particles, especially in the ageing process [8, 9]. The main problem of obtaining the boron-aluminum with increased strength is caused by the fact that boron is actively interacts with many elements, such as magnesium [10], titanium [11], zirconium and scandium [8, 12]. That's why the optimum concentrations of introduced elements may essentially differ from the compositions of grade alloys, which can provide the desired level of properties on their own (that is without boron).

From the above reasoning, the objective of the present paper was a substantiation of an aluminum matrix composition for obtaining the hardenable by heat-treatment boron-aluminum alloys obtained in the form of ingots and sheet products with the strength level above 300 MPa.

Analysis of basic systems of the hardenable by heat-treatment aluminum alloys

The main basic systems of the hardenable by heat-treatment aluminum alloys and reinforcing phases themselves are listed in Table 1. It should be taken into consideration that metastable phases are really present in the structure after ageing (they are indicated in parentheses). Their composition is close to those of the equilibrium phases, but the lattice is different [8, 13, 14].

Table 1

Concentrations of the main alloying elements in commercial wrought alloys

№	Alloy	Cu, % (wt.)	Mg, % (wt.)	Zn, % (wt.)	Si, % (wt.)	Reinforcing phases	Typical alloys
1	Al – Cu	4.0–7.0	–	–	–	Al_2Cu (θ′,θ″)	1201
2	Al – Cu – Mg	3.0–5.0	0.5–2.0	–	–	Al_2CuMg (*S*′)	D19 (Д19)
3	Al – Mg – Si	–	0.3–1.2	–	0.3–1.2	Mg_2Si (β′, β″)	AD31 (АД31)
4	Al – Zn – Mg	–	1.0–3.0	3–6	–	$Al_2Mg_3Zn_2$ (τ′, τ″) $MgZn_2$ (η′, η″)	1915
5	Al – Mg – Si – Cu	1.0–5.0	0.3–1.2	–	0.3–1.2	$Al_5Cu_2Mg_8Si_6$ (*Q*′)	AD33 (АД33)
6	Al – Zn – Mg – Cu	0.5–3.0	1.0–3.0	5–9	–	*T* — AlCuMgZn *M* — AlCuMgZn	V95 (В95)
7	Al – Zr – Sc	0.1 – 0.4 Zr, 0.1 – 0.3 Sc				$Al_3(Zr, Sc)$ $L1_2$	1570*

*Alloy on the base of Al – Mg – Mn systems.

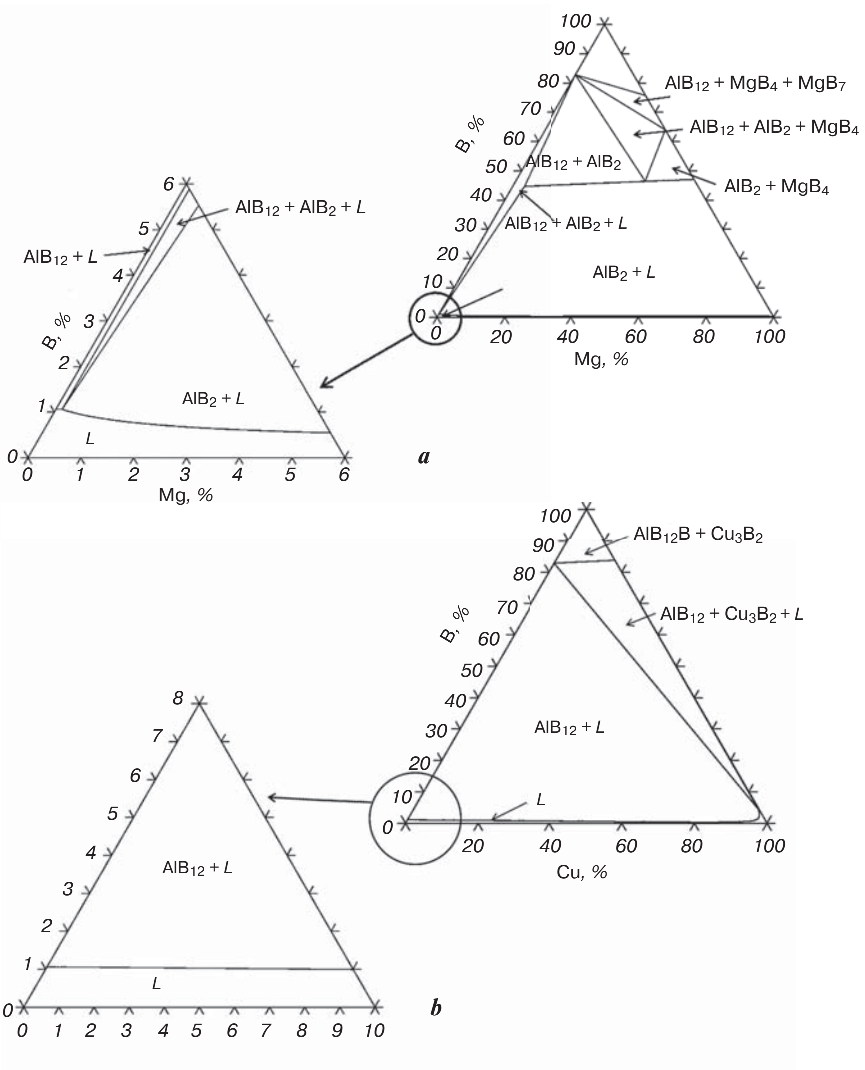

Fig. 1. Isothermal sections of ternary systems at 1100 °C (calculation by Thermo-Calc software):
a — Al – B – Mg; *b* — Al – B – Cu

Inasmuch as high temperatures of the smelt are required for the boron-aluminum alloys preparing [6], the systems containing zinc and magnesium seem to be unwanted because of significant losses during melting process. Interaction of this element with boron can also be considered as a weakness of the systems with magnesium in composition (most of the systems listed in Table 1 are of this kind). In particular, in paper [10] it is shown that achievement of necessary reinforcement in a boron-containing alloy based on Al – Mg – Si – Cu matrix required the doubled magnesium concentration in comparison with AD33 (АД33) grade alloy. Nevertheless, alloys based on this system are used in a number of developments (for example, in [15]).

In Fig. 1 are represented isothermal sections of Al – B – Mg and Al – B – Cu systems at 1100 °C. It is known that there is a continuous series of solid solutions between AlB_2 and MgB_2 borides in an Al – B – Mg system [16]. Therefore, an $(Al, Mg)B_2$ compound with particles of adverse needle-shaped form arises even at small magnesium concentrations, as shown in Fig. 1, *a* [6]. On the other side, copper is completely in the melt, as it appears from Fig. 1, *b*. Hence, only two basic systems remain for obtaining the heat treatable boron-aluminum alloys, namely: Al – Cu and Al – Zr – Sc (+Mg, Mn). The selection of the latter is based on the paper [4].

Experimental procedures

The main subjects of experimental investigation were the boron-aluminum alloys based on Al – Zr – Sc (+additives) and Al – Cu systems, compositions of which are represented in Table 2. According to the data of chemical analysis, actual compositions of obtained alloys differ from the nominal ones quite moderately (within the limits of relative 5%).

Alloys have been prepared basing on high-purity aluminum A99 (ГОСТ 11069–2001, the Russian State Standard) and Al – 5% B master alloy. Copper and magnesium have been introduced in pure form (Mg90 (Мг90) and M1, respectively), titanium has been introduced in the form of T80F20 (Т80Ф20) alloying tablets, the resting elements have been introduced as Al – 2% Sc, Al – 10% Zr, Al – 10% Mn master alloys. Melting has been carried out in a graphite-fireclay crucible at the temperature of 900–950 °C in a RELTEK induction furnace, which provides an intensive melt mixing, required to exclude a possibility of refractory boron-containing particles deposition. The master alloy and melting technology have been selected taking into account the results of the previously fulfilled experiments [6]. The melt was poured into a graphite mold to obtain flat ingots of 40×120×200 mm in size. Samples for structural investigations has been cut thereof. Later on the ingots have been treated by strain processing.

Table 2

Composition of experimental boron-containing alloys

№	Content of elements, %								
	Al	Cu	Mg	Mn	Si	Ti	Zr	Sc	B
1	Res.	–	–	2	–	1.5	0.25	0.1	2
2	Res.	–	4	1	–	–	–	0.3	2
3	Res.	6	–	–	–	–	–	–	2

Experimental alloys have been investigated both in cast condition and after thermal treatment, carried out with the use of a SNOL 8.2/1100 muffle electric furnace and a SNOL 58/350 low-temperature laboratory electric furnace.

Polished sections were prepared by mechanical polishing. Primary microstructure analysis of samples has been fulfilled on an Axio Observer MAT optical microscope, whereas the detailed metallographic research has been conducted on a TESCAN VEGA 3 scanning electron microscope (SEM). The TESCAN microscope, completed by an energy dispersive microanalyser device manufactured by Oxford Instruments and Aztec software, has also be used for the microprobe analysis (EMPA).

The Thermo-Calc software (with a TCAL4 data base) has been used for calculating phase composition of the systems.

The Vickers hardness has been measured on a NEMESIS 9000 hardness testing machine made by INNOVATEST. In order to determine mechanical properties (rupture strength σ_u, yield stress $\sigma_{0.2}$ and tensile strain δ), an uniaxial tension testing has been conducted on a Zwick Z250 universal machine.

Results and their examination

Composition of alloy 1 (Table 1) has been chosen relying on papers [8, 17, 18]. Heat resistance and high mechanical properties of Al – 2% Mn – 0.25% Zr – 0.10% Sc basic alloys are conditioned by the fact that the doping elements form Al_6Mn and $Al_3(Zr, Sc)$ dispersoids, possessing high thermal stability. In as-cast state this alloy has a single-phase structure. However, as it follows from the paper [4], zirconium and scandium interacts with boron. To avoid losses of these elements, titanium has been introduced, suggesting its interaction with the boron for a TiB_2 compound formation as a result. An Al – 4% Mg – 1% Mn – 2% B – 1.5% Ti – 0.3% Sc alloy containing scandium only has been complimentary examined after both introducing magnesium to guarantee an additional reinforcement of alloy due to the raise of the solid solution hardness and the scandium content increasing for providing a dispersive hardening.

Characteristic microstructures of Al – 1.5% Ti – 2% B – 2% Mn – 0.25% Zr – 0.1% Sc and Al – 4% Mg – 1% Mn – 2% B – 1.5% Ti – 0.3% Sc alloys are shown in Fig. 2. In the microstructure distinguished are primary crystals of zirconium with manganese. In addition to the aluminum solid solution, presence of ZrB_2, TiB_2 and $Al_6(Fe, Mn)$ phases has been revealed by *X*-ray phase analysis. In spite of titanium presence in the composition, zirconium interacts with the boron. Studies of composition of aluminum matrix of the melt has showed that it practically doesn't contain other elements except Mn. Obviously, high mechanical properties and heat resistance couldn't be achieved with such a structure by means of zirconium additives.

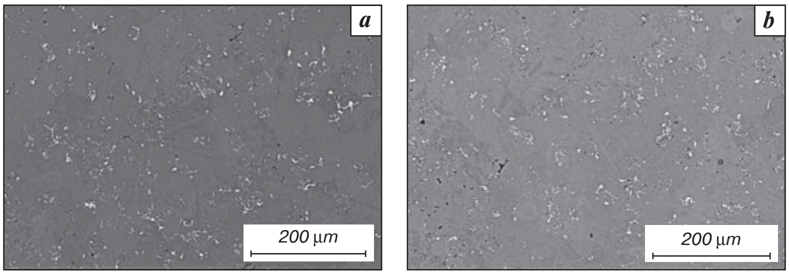

Fig. 2. Microstructure of alloys:
a — Al – 2% Mn – 2% B – 1.5% Ti – 0.25% Zr – 0.1% Sc;
b — Al – 4% Mg – 1% Mn – 2% B – 1.5% Ti – 0.3% Sc

Table 3
Quantitative phase analysis of the Al – 2% Mn – 0.25% Zr – 0.1% Sc – 1.5% Ti – 2% B alloy

Temperature, °C	Phase	Phase chemical composition, % (wt.)					
		Al	Mn	Ti	B	Zr	Sc
1000	Liquid	98.58	0.98	0	0.34	0	0.10
	MeB_2^*	12.76	20.68	29.08	32.64	4.84	0
655	Al_6Mn	74.66	25.34	0	0	0	0
	(Al)	98.97	0.93	0	0	0	0.10
	MeB_2	17.40	18.99	25.45	33.92	4.24	0

* MeB_2 is an abbreviation for borides of alloying elements.

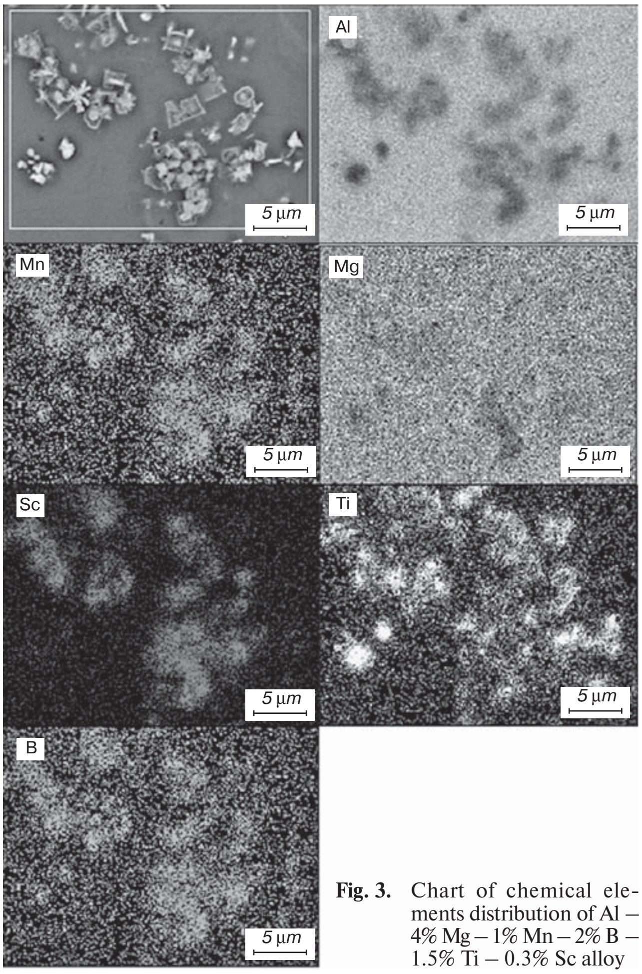

Fig. 3. Chart of chemical elements distribution of Al – 4% Mg – 1% Mn – 2% B – 1.5% Ti – 0.3% Sc alloy

It is evident from the theoretical calculation of quantitative phase analysis of the Al – 2% Mn – 0.25% Zr – 0.1% Sc – 1.5% Ti – 2% B alloy (Table 3) that all doping components interact with the boron except scandium. Only manganese and noninteracting with the boron scandium are resting in an aluminum solid solution at the temperature of 655 °C. Research results have evidenced that the boron interacts with titanium, manganese and scandium, which put obstacles in the way of the matrix reinforcement (Fig. 3).

Measuring hardness of the samples under consideration (Fig. 4) has showed that the basic alloy gets an increased hardness after heterogenizative annealing, though alloys with the boron additives don't become reinforced. This is connected with the boron interaction with zirconium and scandium, which leads to the lack of these elements in a quantity required to form the reinforcing phases.

Thus, introduction of small addition of boron negatively effects on capability of alloys, containing zirconium and scan-

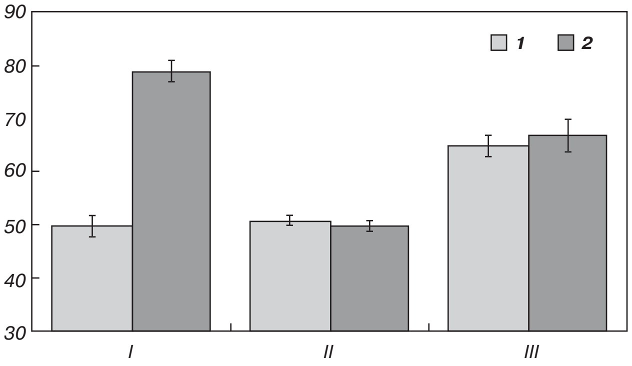

Fig. 4. Hardness of the cast (*1*) and heat-treated (*2*) ingotls of alloys with Zr and Sc additives:
I — Al – 1.5% Mg – 1% Mn – 0.25% Zr – 0.1% Sc; *II* — Al – 2% Mn – 2% B – 1.5% Ti – 0.25% Zr – 0.1% Sc; *III* — Al – 4% Mg – 1% Mn – 2% B – 0.3% Sc

Table 4
Quantitative phase analysis of the Al – 6% Cu – 2% B alloy

Temperature, °C	Phase	Mass fraction	Phase chemical composition, % (wt.)		
			Al	Cu	B
950	Liquid	96.38	93.37	6.23	0.4
	AlB_2	3.62	55.51	0	44.49
540	(Al)	93.70	94.61	5.39	–
	AlB_2	4.49	55.51	0	44.49
	Al_2Cu	1.81	47.64	52.36	–

dium, for a precipitation strengthening. In [4] there is considered a process of boron-aluminum obtaining when the boron has been introduced in the form of B_4C, with the increased zirconium and scandium content. The obtained result meets the requirements upon high mechanical properties, but redundant introduction of zirconium and scandium results in a rise in the cost of the produced material.

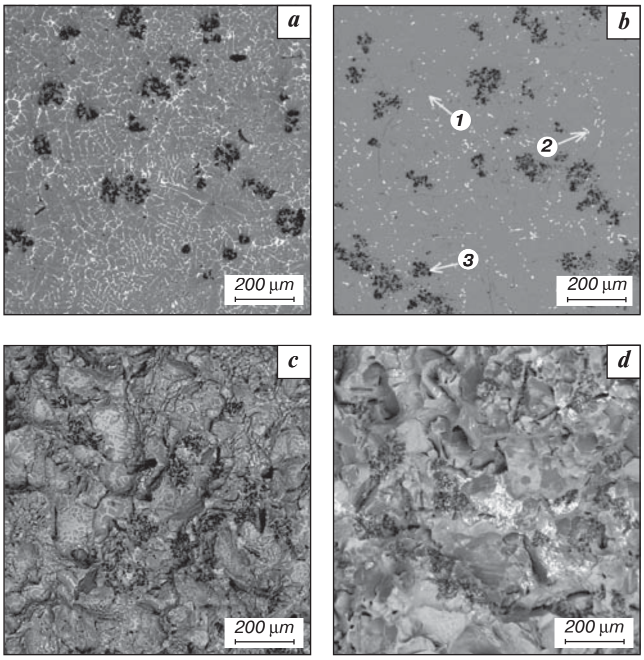

Fig. 5. Images of mictostructure (*a*, *b*) and fractograms (*c*, *d*) of Al – 6% Cu – 2% B alloy (ingots) on a scanning electron microscope: *a*, *b* — cast state; *c*, *d* — after homogenization

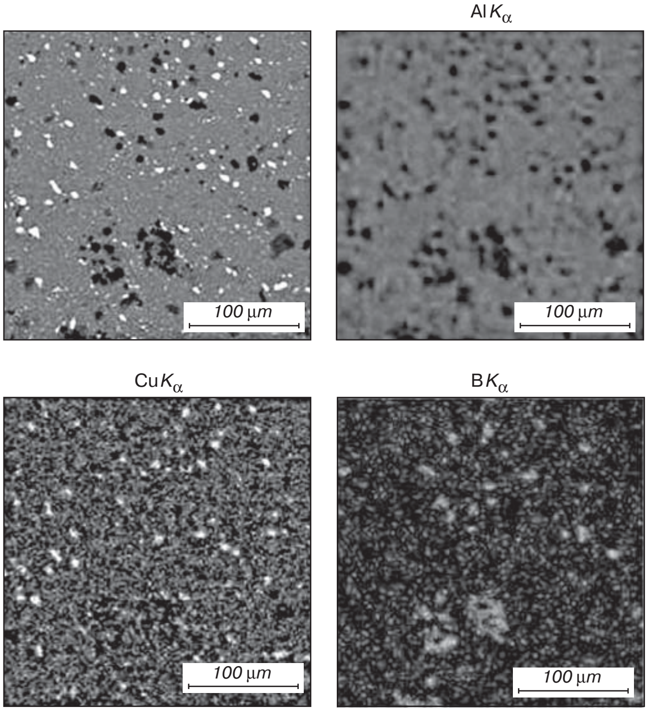

Fig. 6. Chart of chemical elements distribution of the Al – 6% Cu – 2% B alloy (homogenized ingot)

Hence, the Al – Cu system rests the only one to be considered. It is evident from the calculations of the quantitative phase analysis of the Al – 6% Cu – 2% B alloy (Table 4) that three phases are observed in the microstructure, but for all that copper doesn't interacts with boron and is contained in a solid aluminum solution (or smelt) and in an Al_2Cu compound.

Study on the Al – 6% Cu – 2% B alloy microstructure shows a uniform distribution of AlB_{12} boride particles, crystals of which don't exceed 30 μm (Fig. 5, *a*). The needle-shaped impurities of AlB_2 are observed in small proportion (as in a source master alloy [6]). In the structure, there are revealed light Al_2Cu streaks of eutectic origin, which are well observable in fractograms (Fig. 5, *c*, *d*).

Annealing at 540 °C doesn't affect the morphology and composition of borides. The main part of Al_2Cu from a non-equilibrium eutectic has been dissolved in (Al); the remaining impurities have been shaped into a globular form (Fig. 5, *b*).

Explorations of the microstructure confirm the Al – 6% Cu – 2% B alloy (Table 5). Three areas correspond to the following phases: No. 1 — an aluminum solid solution, containing about 4% of copper; No. 2 — Al_2Cu phase of eutectic origin; No. 3 — AlB_{12} boride (Fig. 5, *b*). The *X*-ray data corroborate the fact that copper doesn't react with boron (Fig. 6).

Strengthening level has been estimated on the ingots after applying various heat treatment conditions. As one can see in Fig. 7, *a*, the maximum value of hardness is observed at the ageing temperature of 180–210 °C. With the temperature increase, a weakening (or overageing) takes place. Studying on the strengthening level on the sheet products (Fig. 7, *b*) has confirmed the results obtained on the ingots.

Table 5

Data of the quantitative EMPA analysis of the Al – 6% Cu – 2% B alloy

Phase	Content of elements, %		
	B	Al	Cu
(Al)	Not observed	95.66	4.34
Al_2Cu	Not observed	65.03	34.63
AlB_{12}	83.00	15.24	Not observed

Table 6

Mechanical properties of the Al – 6% Cu – 2% B alloy sheet products

Ageing temperature	$\sigma_{0.2}$, MPa	σ_u, MPa	δ, %
T4 (hardening and natural ageing), °C	241±6	368±5	10.2
120	255±8	357±9	7.8
150	287±6	401±11	8.9
180	307±2	430±14	9.5
210	270±4	379±8	8.4
240	206±3	289±13	6.4

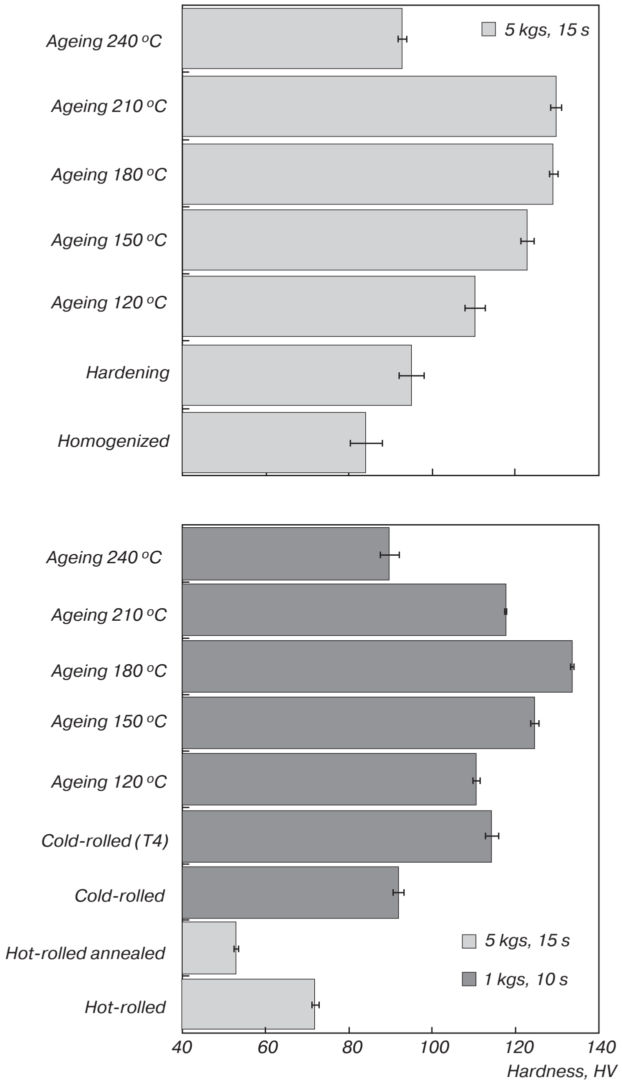

Fig. 7. Ingots (*a*) and sheet products (*b*) of Al – 6% Cu – 2% B alloy hardness dependence of a heat-treatment mode

Testing on uniaxial tension has showed high strength properties (Table 6), achievable by forming the nanoscale phases as a result of heat treatment.

Conclusions

1. Systems of the heat treatable aluminum alloys have been analyzed with reference to obtaining the boron-aluminum alloys on their base. There were indicated the weaknesses of traditional systems containing magnesium and zinc as well as of those containing zirconium and scandium.

2. It has been found experimentally that introducing zirconium and scandium additives to the boron-aluminum alloys is inexpediently for these elements form primary crystals, which practically completely remove them from composition of the solid aluminum solution.

3. It was shown that the most promising matrix which can be used as a base for obtaining the boron-aluminum alloys is an Al – Cu *system, since copper doesn't interact with boron and that permits to achieve the same hardening as that of the grade alloys of a 2219 type.*

4. Using a model Al – 6% Cu – 2% B *alloy as an example, it was shown that the alloying system under review allow to reach a combination of high manufacturability during sheet steel production and high mechanical properties, including that after the heatings at 210 °C.*

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References

1. Eichler J., Lesniak C. Boron nitride (BN) and BN composites for high-temperature applications. Journal of the European Ceramic Society. 2008, No. 28. pp. 1105–1109.

2. Peng Zhang, Yuli Li, Wenxian Wang, Zhanping Gao, Baodong Wang. The design, fabrication and properties of B_4C/Al neutron absorbers. Journal of Nuclear Materials. 2013. No. 437. pp. 350–358.

3. Mohantya R. M., Balasubramaniana K., Seshadrib S. K.. Boron carbide-reinforced alumnium 1100 matrix composites: Fabrication and properties. Materials Science and Engineering A. 2008. Vol. 498. pp. 42–52.

4. Lai J., Zhang Z., Chen X.-G. The thermal stability of mechanical properties of Al – B_4C composites alloyed with Sc and Zr at elevated temperatures. Materials Science and Engineering A. 2012. Vol. 532. pp. 462–470.

5. Skibo Michael D., Schuster David M., Bruski Richard S. Apparatus for continuously preparing castable metal matrix composite material. Patent USA, No. 5531425. F27D27/00, B22D11/11, B01F7/16, C22C32/00, F27D3/00, C22C1/10, B22D1/00, C22C1/00. Patent holder : Alcan Aluminum Corporation. Asserted 07.02.1994. Published 02.07.1996.

6. Samoshina M. E., Belov N. A., Alabin A. N., Chervyakova K. Yu. Struktura i mekhanicheskiye svoystva listovogo prokata iz splava Al – 3% B, poluchennogo zhidkofaznym metodom (Structure and mechanical properties of alloy Al – 3% B flats, obtained by liquid-phase method). T*svetnye metally = Non-Ferrous Metals*. 2015. No. 10. pp. 19–24.

7. Ömer Savaş, Ramazan Kayikci. Production and wear properties of metal matrix composites reinforced with boride particles. Materials & Design. 2013. Vol. 51 (October). pp. 641–647.

8. Belov N. A. *Fazovyy sostav promyshlennykh i perspektivnykh alyuminievykh splavov* (Phase composition of industrial and prospective aluminium alloys). Moscow : Publishing House of "MISiS", 2010. 511 p.

9. Mondolfo L. F. *Struktura i svoystva alyuminievykh splavov* (Aluminium Alloys: Structure and Properties). Translated from English. Moscow : Metallurgiya, 1979. 640 p.

10. Kurbatkina E. I., Belov N. A., Alabin A. N., Sidun I. A. Osobennosti plavki i litiya bor-soderzhashchikh alumomatrichnykh kompositov na osnove splavov 6xxx serii (Peculiarities of melting and casting of boron-containing aluminum-matrix composites based on 6xxx alloys). *Tsvetnye metally = Non-Ferrous Metals*. 2015. No. 1. pp. 85–90.

11. Chen Xiao-Guang, Dube Ghyslain, Steward Nigel. Neutron absorption effectiveness for boron content aluminum materials. Patent US, No. 20080050270. G21F 1/08, C22B 21/00, C22C 21/00, C22C 32/00. Assertes 21.04.2005. Published 12.06.2007.

12. Alabin A. N., Belov N. A., Tabachkova N. Yu., Akopyan T. K. Heat resistant alloys of Al – Zr – Sc system for electrical applications: analysis and optimization of phase composition. Non-ferrous Metals. 2015. No. 2. pp. 36–40.

13. Chen B. A., Pan L., Wang R. H., Liu G., Cheng P. M., Xiao L., Sun J. Effect of solution treatment on precipitation behaviors and age hardening response of Al–Cu alloys with Sc addition. Materials Science and Engineering A. 2011. Vol. 530. pp. 607–617.

14. Marquis E.A., Seidman D.N. Nanoscale structural evolution of Al_3Sc precipitates in Al (Sc) alloys. Acta Materialia. 2001. Vol. 49. pp. 1909–1919.

15. Yasuhiro Aruga, Katsura Kajihara, Yasuaki Sugizaki. Aluminum base alloy containing boron and manufacturing method thereof. Patent US. No. 7125515. B22D 30/00, C22F 1/04. Asserted 15.04.2003. Published 24.10.2006.

16. Belov N. A., Samoshina M. E., Alabin A. N., Chervyakova K. Yu. Vliyanie medi i magniya na strukturu i fazovyi sostav slitkov boraluminiya (Copper and magnesium effect on structure and phase composition of boron-aluminum ingots). *Metally = Metals*. 2016. No. 1. pp. 86–92.

17. Belov N. A., Alabin A. N. Termostoykiy splav na osnove aluminiya i sposob polucheniya iz nego deformirovannykh polufabrikatov (Aluminum base heat-resistant alloy and strained half-finished product manufacturing method thereof). Patent RF, No. 2446222. IPC C22C 21/14, C22F 1/057. Patent holder : National University of Science and Technology “MISiS”. Asserted 29.10.2010. Published 27.03.2012.

18. Alabin A. N., Belov V. D., Belov N. A., Mishurov S. S. Termostoykiy liteynyi aluminievyi splav (Heat-resistant casting aluminum alloy). Patent RF, No. 2478131. IPC B82B 3/00, C22C 21/06. Patent holder : National University of Science and Technology “MISiS”. Asserted 29.10.2010. Published 27.03.2012.

Oxide semi-conductors usagein beta-voltaic elements

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Making beta-voltaic cells (nuclear batteries) is nowadays a promising line for developing a new generation of semiconductors. Improving characteristics of these cells requires development and use of new semiconducting materials and technologies of their manufacturing which should provide an effective ionizing radiation energy transformation, continuous operation life and manufacturability. It is proposed a polycrystalline semiconducting materials usage in order to provide stable characteristics of nuclear batteries during their service life. The distinctive feature of these materials in comparison with the high-ordered monocrystals is their less sensitivity to radiation-induced defects in the lattice, arising under the influence of ionizing radiation. Discussed are the prospects of polycrystalline semiconducting oxides usage for increasing efficiency of energy transformation in beta-voltaic cells under the prolonged exploitation conditions. It is shown that ^{63}Ni may be simultaneously used as a radiation source and as a part of semiconductor converter based on the Schottky barrier junction or a rectifying heterostructure. It is suggested that the heterostructure with the required properties can be obtained when forming the TiO_2 – NiO successive layers on titanic substrate. An experimental sample of such structure has been obtained and an electronic microscopical analysis of the interface element composition has been implemented. Applicability of the proposed approaches to making the ^{63}Ni-based beta-voltaic cells is shown.

Key words: beta-voltaic element, oxide semi-conductors, ^{63}Ni, rectifying contacts, energy converter, nuclear battery.

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Introduction

Interest to elaboration of miniature sources of electric power based on nuclear batteries using beta-emitting radionuclids has recently grown [1–5]. Batteries of the given type consist of elements, which include an isotopic source of beta rays and a semiconductor converter of radiation to electric energy. The ^{63}Ni radioisotope-based radiation sources exhibit the most promise for elaborated beta-voltaic elements. The ^{63}Ni usage prospect is stipulated by a long half-value period (100.1 years), high specific power intensity ($5.7 \cdot 10^{-3}$ W/g, with the maximal