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Aluminum-lithium alloys: types, properties, application, and production technologies. Overview

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ABSTRACT

The article provides a brief overview of the aluminum industry development in Kazakhstan and the possibility of obtaining high-strength structural aluminum-lithium alloys. The country's enterprises produce aluminum of technical purity and aluminum alloys of low and medium strength of 6060, 6063, 6463, 6082, AK5M2, ADS-12, AD-31, AD-35, which are available materials for the construction industry. In Kazakhstan, there is progressive development of mechanical engineering which requires stronger alloys of 300-400 MPa, and for special engineering (defense, aerospace, and other advanced industries) - strengths above 415 MPa. High-strength structural aluminum alloys are based on Al-Cu-Mg, Al-Zn-Mg-Cu, Al-Li systems. Among these systems, relatively new Al-Li alloys are of great interest, having a great potential for further improvement of characteristics. The Al-Li system alloys with record-high specific strengths, corrosion-resistant, and good welded joints are widely used in the aerospace industry, where they are used for the production of power elements and housings. The article provides an overview of the known aluminum-lithium alloys, as well as the main technological stages of their production.

Keywords: alloy, aluminum, lithium, magnesium, zirconium, strength, technology.

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Introduction

Currently, the main aluminum alloys produced in the world are alloys of the Al-Si, Al-Mn, Al-Mg, Al-Mg-Si, Al-Cu-Mg, Al-Li systems with a specific strength of 64-223 m^2/s^2. According to strength characteristics, aluminum alloys are divided into three classes: alloys of low, medium, and high specific strength (Table 1).

The high-strength alloys include alloys of the Al-Cu-Mg, Al-Zn-Mg-Cu, and Al-Li systems as can be seen from the table. The alloys of these systems have high strength compared to other alloys, however, the alloys of the Al-Cu-Mg and Al-Zn-Mg-Cu systems are not amenable to arc welding, and have a high density due to the copper and zinc included in the composition. The characteristics of high-strength alloys of the Al-Cu-Mg and Al-Zn-Mg-Cu systems do not meet the requirements of weight reduction and good weldability of the structure. These properties are a priority when creating airplanes and spacecraft. The alloys of the Al-Cu-Mg and Al-Zn-Mg-Cu systems are very susceptible to corrosion and require anodizing of the surfaces.

Among all aluminum alloys, the alloys of the Al-Li system have not only high strength characteristics but are also easily amenable to any type of welding, have high corrosion resistance, which makes them a promising new class among high-strength aluminum alloys [[1], [2], [3]]. The huge interest in aluminum-lithium alloys is caused by the fact that each percentage of lithium included in the alloy reduces the density by 3%, increases the modulus of elasticity by 6%, increases the resistance of the alloy to crack propagation [4].

Table 1 - Mechanical properties of aluminum alloys [[1], [2], [3]]

Characteristics of alloys	System	Grades	Specific strength, m^2/s^2	Arc welding	Corrosion resistance
Low strength alloys	Al-Si	AK12 AK9 AK7	64 98 83	Good	Good
	Al-Mn	AMc	80	Good	Good
Medium strength alloys	Al-Mg-Si	AD31 AD33 AD35	92 118 122	Average	Average
	Al-Mg	AMg5 AMg6	112 151	Good	Good
	Al-Zn-Mg	1915 1925	134 123	Average	Low
High-strength alloys	Al-Cu-Mg	D1 D16	147 160	Low	Low
	Al-Zn-Mg-Cu	B95	182-200	Low	Low
	Al-Li	1420 1460 2090 8090	180 215 223 171	Good	Good

But the main advantage of Al-Li alloys is that they are easy to weld, allowing the use of such types as laser, friction welding with stirring, and argon arc welding with the use of additive materials [[5], [6]]. The use of these technologies in the creation of welded structures of aerospace vehicles and other vehicles made of Al-Li alloys gives a huge weight advantage compared to riveted structures made of traditional aluminum alloys, which saves fuel consumption by reducing the weight of the product by 15-25% [7].

Aluminum-lithium alloys: history, types, and applications. Development of aluminum-lithium alloys began in 1950 and alloys of various purposes have been created to date: alloys of the Al-Li-Mg system for welded and riveted structures; high-strength alloys of the Al-Li-Cu system to replace the B95 type alloy; high crack resistance alloys of the Al-Li-Mg-Cu system to replace the alloy type D16; heat-resistant and high-strength alloys of the Al-Li-Cu-Mp-Cd system; welded high-strength alloys of the Al-Li-Cu-Sc system for operation at low temperatures. The aluminum-lithium alloys are divided into three generations. Al-Li alloys of the first generation are mainly researched and developed in USA and USSR in the period 1950-1960; Al-Li alloys of the second generation were obtained in the USA, Europe, and Russia in the period of 1970-1980; Al-Li alloys of the third generation are studied mainly in the USA. Their development began in the early 90s and continues to the present. The chemical composition and mechanical properties of the known aluminum-lithium alloys are given in Table 2 [[8], [9], [10], [11]].

The first aluminum-lithium alloy 2020 was developed in 1957 by Alcoa (USA). Alloy 2020 had high strength and high creep resistance at 150-200 ˚C and was used to manufacture the wings of the Ra-5C Vigilante BMC aircraft. In 1960, alloy 2020 was discontinued due to production problems related to its high brittleness and poor ductility [12].

The first Soviet aluminum-lithium alloy VAD23 with lithium content was developed in 1960. Alloy VAD23 has a 5% low density and a 5% high modulus of elasticity compared to alloy D16. VAD23 has high heat resistance at temperatures up to 225°C due to the content of manganese and cadmium. However, the low strength and plastic characteristics of welded joints, and the tendency to crack did not make it possible to use the alloyVAD23 in practice [[12], [13], [14], [15], [16]].

In 1965, on the basis of the Al-Li-Mg system, the first original, patented, lightest (2.4 g/m^3), weldable, corrosion-resistant alloy 1420 was developed. Alloy 1420 had high corrosion resistance, good weldability, high modulus of elasticity, sufficient strength, and low density. Alloy 1420 is 12% lighter and the modulus of elasticity is 8% higher compared to alloy D16. There are no existing analogs of alloy 1420 outside Russia [15].

In 1971, alloy 1420 was used in the riveted fuselage structure of the Yak-36 aircraft, reducing the bulk to 24%. Due to the weldability of all types of welding, alloy 1420 was used in 1980 to create the world's first welded MiG-29 aircraft (Figure 1). As a result, welded sealed tanks and the cockpit were made of alloy 1420 [17].

Alloys 1421, and 1423 with a high yield strength (up to 25%) were obtained on the basis of 1420 due to the addition of scandium. Alloy 1421 is widely used in the rocket housings of Makeev State Rocket Center JSC, which made it possible to reduce the mass by up to 15%. Alloy 1423 containing magnesium and scandium was developed in 1985-1986 and was used for the manufacture of sheet parts of complex shapes [15].

In order to replace alloys of the D16 type based on the Al-Li-Mg-Cu system, alloys 1430, 1441, and 1440 with low density (by 8%), high modulus of elasticity (by 10%) and crack resistance have been developed. Alloys 1430 and 1441 differ from alloy 1440 in high ductility (1.5-2 times) [[15], [18]].

Based on the Al-Cu-Li system, alloys 1450 and 1451 have been developed, which have high strength at elevated temperatures and high corrosion resistance. When replacing the B95 alloy with alloys 1450 and 1451, the weight of the structures is reduced by 8-10%; with an increase in stiffness by 10%. As a result of additional alloying with zirconium and scandium alloys of the Al-Cu-Li system, a weldable alloy 1460 was developed for welded cryogenic fuel tanks for space and aviation purposes [15].

Table 2 - Chemical composition of aluminum-lithium alloys

Alloy grade	**Content of elements in the mass.%**										
	Li	***Cu***	***Mn***	***Mg***	***Sc***	***Ag***	***Cr***	***Zr***	***Ti***	***Zn***	***Manufacturer***
1st generation. Specific strength 169-180 m^2/s^2											
2020	1.2	4.5	0.5								Alcoa 1958
1420	2.2		to 0.25	6.2				0.1			VIAM 1965
1421	2.2		0.2	6.1	0.35			0.1			VIAM 1965
1423	2.0		0.2	4.4	0.12			0.1			VIAM 1965
1424	1.8		0.25	5.1	0.08			0.1	0.2		VIAM 1965
5091	1.4			4.2							Alcoa 1958
2nd generation. Specific strength 176-223 m^2/s^2											
1440	2.3	1.9	0.08	1.1				0.2	0.1		VIAM 1980e
1430	1.7	1.6		2.7				0.11			VIAM 1980e
1441	2.0	1.9	0.4	1.1				0.16	0.07		VIAM 1980e
1450	2.0	3.2	0.08	0.1				0.2	0.15		VIAM 1980e
1460	2.3	3.3	0.1	0.1				0.12	0.15		VIAM 1980e
1461	1.8	3.5	0.5	0.6	0.8		0.05	0.12	0.05		VIAM 1980e
1464	1.8	3.2	0.4	0.7	0.09			0.11			VIAM 1980e
1469	1.7	4.5	0.5	0.5	0.28	1.5		0.2			VIAM 1980e
2090	2.6	3.0	0.0	0.3			0.05	0.1	0.1		Alcoa 1984
2091	2.3	2.5	0.1	1.9			0.1	0.1	0.1		Pechiney 1985
2094	1.4	5.2	0.2	0.8		0.6		0.12	0.1		EAA, 1984
8090	2.4	1.2		0.8				0.11			EAA, 1984
3rd generation. Specific strength 181-242 m^2/s^2											
2195	1.0	4.0		0.4		0.4		0.11			LM/Reynolds 1992
2196	1.75	2.9	0.3	0.5		0.4		0.11		0.3	LM/Reynolds 2000
2297	1.4	2.8	0.3	0.25				0.11		0.5	LM/Reynolds 1997
2397	1.4	2.8	0.3	0.2				0.11		0.1	Alcoa 1993
B-1469	1.2	3.2		0.3	0.1	0.4		0.09			VIAM 2000e
B-1461	1.8	2.8		0.5	0.1			0.08		0.6	VIAM 2000e
2098	1.05	3.5	0.35	0.53		0.4		0.11		0.3	
2198	1.0	3.2	0.5	0.5		0.4		0.11		0.3	Reynolds/McCook 2005
2099	1.8	2.7	0.3	0.3				0.09		0.7	Alcoa 2003
2199	1.6	2.6	0.3	0.2				0.09		0.6	Alcoa 2005
2050	1.0	3.6	0.3	0.4		0.4		0.11		0.2	Pechiney 2004
2296	1.6	2.4	0.2	0.6		0.4		0.11		0.2	Alcan, 2010
2060	0.7	3.9	0.3	0.8		0.2		0.11		0.4	Alcoa 2011
2055	1.1	3.7	0.3	0.4		0.4		0.11		0.5	Alcoa 2012
2065	1.2	4.2	0.4	0.5		0.3		0.11		0.2	Constellium 2012
2076	1.5	2.3	0.3	0.5		0.2		0.11		0.3	Constellium 2012

Based on the developed alloy 1420, Alcoa, Alcan, Pechiney intensive work on aluminum-lithium alloys were carried out. As a result of these works, foreign alloys 2060, 2090, 2091, 8090, Navalite and others were developed [[19], [20], [21]].

Aluminum-lithium alloys are used in the manufacture of wings and horizontal stabilizer of the American military aircraft A-5 "Vigilante", in the lower wing skin of the Airbus A380, the internal structure of the Airbus A350 wing, Bombardier CSeries fuselage (where alloys make up 24% of the fuselage) [22], in the cargo floor of the Boeing 777X [23] and in the blades the fan of the Pratt & Whitney PurePower turbofan aircraft engine [24]. Welded hulls of the well-known Proton and Angara launch vehicles (Russia) are made of aluminum-lithium alloys.

In space technology, tanks for fuel and oxidizer of the first and second stages of the Falcon 9 launch vehicle are made of aluminum-lithium alloys using friction welding with mixing (Figure 2) [25]. The Falcon 9 is a two-stage liquid-fuel rocket with a diameter of 3.66 m. The tanks of both stages are made of sheets and plates of Al-Li 2198.

Figure 1 - MiG-29 FTR

The thrust panels of the Space Shuttle launch vehicle tank were also made of Al-Li alloys 2090, 2195, which made it possible to reduce the weight of the product by 3000 kg than when using alloy 2219 (Figure 3) [11].

Figure 2 - Falcon 9 fuel tank made of aluminum-lithium alloy 2198

The use of Al-Li alloys for future cryogenic tanks was studied by the European Space Association (ESA) [[26], [27]]. Al–Li alloys are used in the Centaur upper stage in the Atlas V rocket (Figure 4) [28] and the Orion spacecraft (Figure 5) [[29], [30]]. Orion has a crew module and a maintenance module. Both modules use aluminum-lithium alloys 2195 for the main bearing spars and alloy 2050 for other components, including frames, ribs and window sections.

Figure 3 - External fuel tanks and thrust panels of the Space Shuttle tank made of aluminum-lithium alloys 2090 and 2195

Figure 4 - Centaur upper stage in the Atlas V rocket

The key technology for manufacturing Al-Li alloy components and structures for spacecraft, especially tanks and tank domes, is friction mixing welding. Friction welding with mixing was used to connect the components of the Orion crew module Al-Li, including the final 11.3 m long weld connecting the forward cone assembly and the crew tunnel with the aft assembly [[31], [32]]. Friction welding with mixing has also been used to manufacture spin domes of fuel tanks made of Al-Li alloy 2195 [33] and it is planned to use this technology to connect parts of the main tank made of alloy 2219 for the Ariane 5 launcher [34].

Figure 5 - Al-Li alloys used in the American Orion spacecraft

Aluminum-lithium alloys are also beginning to be used in shipbuilding and the automotive industry.

Technology for the production of aluminum-lithium alloys. Aluminum-lithium alloys used in aerospace, defense technology and other high-tech industries have high mechanical properties ($\sigma_{in} \geq$ 415 MPa) and are subject to international export control agreements for dual-use goods and technologies [[35], [36], [37], [38]]. The countries producing such materials do not publish the technologies used, and the finished materials are sold to third countries only under intergovernmental agreements, similar to arms sales. In open sources, only the grades of the alloy, its chemical composition, mechanical properties, and in some cases possible prices are given. International export control agreements do not restrict the rights of third countries to develop and manufacture dual-use materials.

Despite the fact that there are no direct descriptions of the production technology of dual-use aluminum-lithium alloys in the literature, their main principal stages can be described in a general way, based on standard operations for the production of traditional aluminum alloys [39].

The simplest and most commonly used aluminum-lithium alloy is alloy 1420 (Table 2). Alloy 1420 belongs to the Al-M–Li system. A feature of this alloy is its very strong oxidizability during melting and casting, due to the presence of lithium. It is believed that the introduction of lithium and refractory zirconium into the melt requires the development of special technological techniques. The technological stages of obtaining aluminum-lithium alloy 1420, most likely consist of the following stages:

1. *Preparation of the charge.* At the beginning of the operation, the components of the charge are calculated by % weight. Alloying components are used in the form of pure metal or aluminum ligature Al-Li, Al-Zr, and Al-Mg. The technology of introducing alloying components is not described in the literature, they need to be determined experimentally [[40], [41], [42]].

2. *Melting.* The charge is melted in an induction vacuum furnace in an argon or helium medium at a temperature of about 660-700°C for 10-120 minutes. It is allowed to increase the temperature to 780 ± 15˚C for uniform distribution of refractory zirconium over the melt volume. Heating over 800˚C is not desirable due to the strong oxidizability of lithium and loss of magnesium. There are no data on melting pressure. However, it can be assumed that the residual pre-vacuum pressure will be sufficient [[43], [44], [45]].

3. *Degassing.* The melt is kept in a vacuum chamber at a residual pressure of 266-1333 Pa (2-10 mmHg) and at a temperature of 750-800°C for 5-20 minutes. Using such treatment of the melt with a chlorine-containing flux, the hydrogen content decreases to 0.10 cm^3/100 g [45].

4. *Casting.* The finished melt is poured and cooled in steel or graphite molds in an argon or helium medium [45].

5. *The chemical composition* of the cast sample should be within the following limits: Mg – 5-6%, Li – 1.9-2.3%, Zr – 0.09-0.15%, Si – 0.1-0.3%, res. Al.

6. *Homogenization annealing* of the sample varies at the following intervals: 450± 10 ˚C for 1.5-6 hours. The vacuum in the chamber should not be lower than 0.1MPa (1 atm) [[46], [47]].

7. *Sample tempering* varies at the following intervals: 450˚C-490˚C for 20 - 120 minutes and cooled in air or water [[46], [47], [48], [49], [50], [51]].

8. *Sample aging* is carried out under the following conditions [[47], [48], [49], [50]]:

- 120-180°C- 5-16 h
- 120 ˚ C-12 h, + 180 ˚C – 12 h

9. *Sample deformation* varies at the following intervals: deformation of 15-30% at a rate of $1s^{-1}$ for 0.5-1 hour at 20-550°C and a pressure of 6 MPa [[46], [51], [52]].

10. *Sample recrystallization is* carried out at 510˚C for 30 minutes [51].

11. *Determination of sample properties.*

The above-proposed stages of 1420 alloy production can be implemented at Kazakhstan plants to produce aluminum alloys and products.

Aluminum industry in Kazakhstan. Kazakhstan has a good raw material base for the production of aluminum and its alloys. The only alumina producer in the country is the Pavlodar Aluminum Plant, which uses alumina as a raw material for the production of primary metallic aluminum. Pavlodar Aluminum Plant is part of the association of Aluminum of Kazakhstan JSC. The plant was put into operation in 1964 and until today its production capacity has reached 1.5 million tons of alumina per year.

The main consumers of commercial alumina of Aluminum of Kazakhstan JSC are enterprises of the Russian Federation, Tajikistan, China and the Kazakh enterprise Kazakhstan Electrolysis Plant JSC.

The Kazakhstan Electrolysis Plant was founded in 2007 in the southeast of Pavlodar and is also the only producer of primary aluminum in the country. To date, the Kazakhstan Electrolysis Plant produces technical purity aluminum (Al>99.0%) and high purity aluminum (Al>99.95%). The capacity of the enterprise is 250 thousand tons of aluminum per year.

According to the Ministry of Industry and Infrastructure Development of the Republic of Kazakhstan, the country is working on the implementation of a project for the construction of a new electrolysis plant in the city of Pavlodar, which is scheduled to be launched in 2025. After its launch, the processing of alumina in Kazakhstan will be increased to one million tons per year, followed by the production of primary aluminum up to 500 thousand tons per year. The finished products are planned to be delivered to the countries of the European Union and Asia, as well as to the domestic market of the country.

At the moment, the Kazakhstan Electrolysis Plant sends about 90% of finished products to foreign markets and supplies the remaining 10% to Kazakhstani enterprises such as Aluminum of Kazakhstan, Giessenhaus, Alprof, Casting, Tsvetlit, Gold Aluminum. These enterprises, using primary aluminum, produce the following types of aluminum alloys and products from them:

1. The German-Russian enterprise Giessenhaus LLP, which is located in the Pavlodar region, produces 36-40 thousand tons of alloyed high-strength aluminum alloy per year. The alloyed aluminum produced consists of aluminum, silicon, magnesium, titanium, and manganese (the specific production technology of the German parent company LVG GmbH is closed). The finished alloyed aluminum alloy is sent to Vector-Pavlodar LLP, where cast car wheels are produced.

2. Aluminum of Kazakhstan LLP (Hoffmann Aluminum) produces aluminum alloys of 6060, 6063, 6463, 6082 grades (Almaty). The company produces 16,200 tons of aluminum alloys per year. The plant has a full production cycle: from loading the charge into the furnace to the production of finished products of any complexity. The plant's capacities are not fully loaded.

3. Casting LLP (Almaty) produces casting and deformable aluminum alloys of AK5M2 and ADS-12 grades. Enterprise capacity Casting LLP makes 12 thousand tons of aluminum alloys per year.

4. Alprof LLP (Almaty) produces various types of semi-finished products and products made of aluminum alloys of AD 31, AD 35, 6060, 6063 grades.

5. Gold Aluminum (Shymkent) manufactures various profiles from structural aluminum alloy 6063. The plant produces 750 tons of aluminum profiles per year.

6. Tsvetlit LLP (Shymkent) produces aluminum wire rods and aluminum alloys. The productive capacity of the enterprise is 24 thousand tons of wire rods and 12 tons of alloys.

The aluminum alloys produced at these enterprises have low and medium strength characteristics and are intended for the production of aluminum reinforcement for construction. The products of these plants are intended for internal use; these alloys are not in demand in other countries and do not have export potential.

Kazakhstan exports the following types of aluminum products, namely heat-resistant, a corrosion-resistant high-strength aluminum alloy of Giessenhaus LLP; primary aluminum of technical and high purity of the enterprise of Kazakhstan Electrolysis Plant JSC, and alumina of Aluminum Kazakhstan JSC. The products of these enterprises are in demand not only in the CIS countries, but in Germany, Austria, and Poland.

Table 3 shows the comparative prices of alumina, aluminum, and alloys of construction fittings produced in Kazakhstan, as well as alloy 1420.

Table 3 - Prices of alumina, aluminum and alloys

Material	Price, KZT/kg
Alumina	143-156
Aluminum	450-615
Alloys for construction fittings	626-1000
Alloy 1420	1827

As can be seen, alloy 1420 is 2-3 times more expensive than alloys of the type silumin, duralumin, avial, and others produced in Kazakhstan. Aluminum-lithium alloys, including alloy 1420, are in high demand on the international market. The development of the 1420 alloy production technology and its implementation at the factories of Kazakhstan is an urgent and cost-effective task since this material is of high processing and high technology.

The composition of alloy 1420 includes zirconium, magnesium, and lithium. These alloying elements are currently freely available on the international market in the form of pure metal or ligature. In the future, it would be possible to use zirconium and lithium of their own production. On this issue, the situation is as follows:

1. The Obukhov Mining and Processing Plant (North Kazakhstan region) produces zirconium concentrate. Expoengineering LLP processes titanium-zirconium ore at the Shokash deposit in the Aktobe region.

2. Primary magnesium in ingots is produced by Ust-Kamenogorsk Titanium and Magnesium Plant JSC (Ust-Kamenogorsk) At the moment, 100% of finished products are exported to countries such as the USA, Russia, China, and others.

3. According to the representative of "NC KAZAKH INVEST" - Aitkulov B., it is planned to build mining and processing plants near lithium deposits in the East Kazakhstan region, Aktobe, Kostanay, and West Kazakhstan regions. The cost of the project in the East Kazakhstan region is estimated at USD102 mln., and the production capacity will reach 4 thousand tons of lithium carbonate per year. According to geological research, lithium reserves in Kazakhstan amount to about 80 thousand tons. Kazakhstan has every opportunity to implement a full cycle of lithium production in the coming years and, consequently, alloys with its use.

Conclusions

There is an increasing demand in the world for high-strength aluminum-based alloys with strength characteristics ≥ 415 MPa for promising engineering tasks. The development of technologies for the production of the high-strength alloy to develop exports of domestic finished products to other countries is relevant. This would allow Kazakhstan to take a worthy place among manufacturers and suppliers of competitive aluminum-lithium alloys.

Conflict of interest

On behalf of all the authors, the correspondent author declares that there is no conflict of interest.

Gratitude

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ТҮЙІНДЕМЕ

Мақалада Қазақстанның алюминий өнеркәсібінің даму жағдайына және беріктігі жоғары конструкциялық алюминий-литий қорытпаларын алу мүмкіндігіне қысқаша шолу келтіріледі. Еліміздің кәсіпорындарында техникалық таза алюминий мен құрылыс индустриясы үшін жалпыға қолжетімді материалдар болып табылатын беріктігі төмен және орташа болатын 6060, 6063, 6463, 6082, АК5М2, АДС-12, АД-31, АД-35 маркалы алюминий қорытпаларын өндіреді. Қазақстанда машина жасаудың үдемелі дамуы жүріп жатыр, ол үшін беріктігі 300-400 МПа, ал арнайы машина жасау (қорғаныс, аэроғарыш және басқа да озық салалар) үшін беріктігі 415 МПа - дан жоғары неғұрлым берік қорытпалар қажет болады. Жоғары беріктігі бар алюминий қорытпалары Al-Cu-Mg, Al-Zn-Mg-Cu, Al-Li жүйелеріне негізделген. Осы жүйелердің ішінде салыстырмалы түрде жаңа Al-Li қорытпалары үлкен қызығушылық тудырады, олардың сипаттамаларын одан әрі жақсартуға үлкен әлеуеті бар. Al-Li жүйесінің қорытпалары рекордтық жоғары беріктігі, коррозияға төзімділігі, дәнекерленген қосылыстардың жақсы көрсеткіштері бойынша аэроғарыш саласында кеңінен қолданылады, онда олар қуат элементтері мен корпустардың өндірісінде қолданылады. Жұмыста белгілі алюминий-литий қорытпаларының сипаттамаларына, сондай-ақ оларды өндірудің негізгі технологиялық кезеңдеріне шолу жасалады.

Түйін сөздер: қорытпа, алюминий, литий, магний, цирконий, беріктік, технология.

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Алюминиево-литиевые сплавы: виды, свойства, применение и технологии получения. Обзор

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АННОТАЦИЯ

В статье приводится краткий обзор по состоянию развития алюминиевой промышленности Казахстана и возможности получения высокопрочных конструкционных алюминиево-литиевых сплавов. В предприятиях страны производят алюминий технической чистоты и алюминиевые сплавы низкой и средней прочности 6060, 6063, 6463, 6082, АК5М2, АДС-12, АД-31, АД-35, которые являются общедоступными материалами для строительной индустрии. В Казахстане идет поступательное развитие машиностроения, для которого требуются более прочные сплавы с прочностями 300-400 МПа, а для специального машиностроения (оборонная, аэрокосмическая и другие передовые отрасли) - с прочностями выше 415 МПа. Высокопрочные конструкционные алюминиевые сплавы основаны на системах Al-Cu-Mg, Al-Zn-Mg-Cu, Al-Li. Среди этих систем большой интерес представляют относительно новые сплавы Al-Li, имеющие, по-видимому, большой потенциал дальнейшего улучшения характеристик. Сплавы системы Al-Li с рекордно высокими удельными прочностями, стойкими к коррозии, хорошими показателями сварных соединений находят широкое применение в аэрокосмической промышленности, где используются для производства силовых элементов и корпусов. В работе дается обзор характеристик известных алюминиево-литиевых сплавов, а также основные технологические этапы их производства.

Ключевые слова: сплав, алюминий, литий, магний, цирконий, прочность, технология.

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