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(54) **ALUMINIUM-BASED ALLOY**

LEGIERUNG AUF ALUMINIUMBASIS

ALLIAGE À BASE D'ALUMINIUM

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EP 2 006 403 B1

## Description

**[0001]** An invention covers a field of metallurgy of alloys based on aluminum, in particular to the alloy of aluminum-copper-magnesium-lithium system applied for manufacturing semi-finished products and parts thereof used as structural materials for aerospace engineering.

**[0002]** It is known that aluminum-lithium alloys possess an unique combination of mechanical properties, namely of low density, increased elasticity modulus, and sufficiently high strength characteristics. Availability of indicated properties enables to use alloys of this system as structural material for aerospace engineering, that allows to improve a number of aircraft performance features of flying vehicles, in particular, reduction of vehicle weight, fuel economy, increase of load capacity.

**[0003]** However, aluminium-lithium alloys have one disadvantage - low ductility on conditions close to maximum strength (N.I. Fridlyander, K.V. Chuistov, A.L. Berezina, N.I. Kolobnev, Aluminum-lithium alloys. Structure and Properties, Kiev: Nauk. Dumka, 1992, page 177).

Prior Art

**[0004]** Aluminum-based alloy is known having wt %:

| | |
|---|---|
| Lithium | 1.7 - 2.0 |
| Copper | 1.6 - 2.0 |
| Magnesium | 0.7 - 1.1 |
| Zirconium | 0.04 - 0.16 |
| Beryllium | 0.02 - 0.2 |
| Titanium | 0.01 - 0.07 |
| Nickel | 0.02 - 0.15 |
| Manganese | 0.01 - 0.4 |
| Aluminum | Remainder |

(Inventor’s Certificate of USSR No. 1767916, IPC C 22 C 21/16, date of publication 1997.08.20).

**[0005]** Disadvantages of the indicated alloy are its low processibility, high manufacturing labor intensiveness, and low yields by manufacturing semi-finished products and parts thereof, impossibility to obtain thin sheets, thin-walled sections and die-forgings in it.

**[0006]** Reasons causing occurrence of above mentioned disadvantages by using the known alloy include the fact, that relatively high contents of copper in the known alloy negatively influences hot brittleness and ductility by shaping, that leads to increased cracking, higher rejections on folds and non-flatness by finishing operations, namely, by flattening and stretching semi-finished products.

**[0007]** Aluminum-based alloy is known - 8093, (alloy designation is in conformance with alloy numbers and comply with definitions registered by Aluminum Assosiation, Washington, USA) having wt %:

| | |
|---|---|
| Lithium | 1.9 - 2.6 |
| Copper | 1.0 - 1.6 |
| Magnesium | 0.9 - 1.6 |
| Zirconium | 0.04 - 0.14 |
| Titanium | Up to 0.1 |
| Manganese | Up to 0.1 |
| Zinc | Up to 0.25 |
| Aluminum | Remainder |

(International designation of alloys and limits of chemical composition of wrought aluminum and aluminum alloys, Aluminum Association: 2004, pages 12, 13)

**[0008]** Disadvantages of the indicated alloy are increased cost of the alloy, its low processibility, high manufacturing labor intensiveness, and low yields by manufacturing semi-finished products and parts thereof, impossibility to obtain thin sheets, thin-walled sections and die-forgings in it.

**[0009]** Reasons causing occurrence of above mentioned disadvantages by using the known alloy include the fact, that the known alloy has increased contents of lithium, besides, increased contents of lithium lead to formation of strengthening phases slightly increasing alloy strength characteristics, but, at the same time, considerably reducing its ductility by casting and shaping, that leads to increased cracking, higher rejections on folds and non-flatness by finishing operations, namely, by flattening and stretching semi-finished products.

**[0010]** The closest alloy on chemical composition and function to the claimed aluminum-based alloy is the alloy having wt %:

| | |
|---|---|
| Lithium | 1.7 - 2.0 |
| Copper | 1.6 - 2.0 |
| Magnesium | 0.7 - 1.1 |
| Zirconium | 0.04 - 0.2 |
| Beryllium | 0.02 - 0.2 |
| Titanium | 0.01 - 0.1 |
| Nickel | 0.01 - 0.15 |
| Manganese | 0.001 - 0.05 |
| Gallium | 0.001 - 0.05 |
| Zinc | 0.01 - 0.3 |
| Sodium | 0.0005 - 0.001 |
| Aluminum | Remainder |

(Patent of the Russian Federation No. 2180928, IPC 7 C 22 C 21/00, C 22 C 21/16, date of publication 2002.03.27; see also EP-A-1 788 101).

**[0011]** Disadvantages of the indicated alloy taken for a prototype are its relatively low processibility, high manufacturing labor intensiveness, and low yields by manufacturing semi-finished products and parts thereof, impossibility to obtain thin sheets, thin-walled sections and die-forgings in it.

**[0012]** Reasons causing occurrence of above mentioned disadvantages by using the known alloy taken for a prototype refer to the fact, that the known alloy is characterized by increased copper contents, that negatively influences hot brittleness and ductility by shaping, that leads to increased cracking, higher rejections on folds and non-flatness by finishing operations, namely, by flattening and stretching semi-finished products, moreover, increased contents of sodium and gallium lead to considerable increase of hot brittleness of the alloy, to much more reduction of its ductile characteristics (A.V. Kurdyumov, S.V. Inkin, V.S. Chulkov, G.G. Shadrin, Metallurgical Admixtures in Aluminum Alloys, M.: Metallurgy. 1988, pages 90, 99), that considerably complicates an objective to obtain acceptable ingots and further to receive semi-finished products by various types of shaping, and also to perform quality cladding for rolled semi-finished products, as a result of formation of substantial areas of non-welded cladding on their surface.

## Invention disclosure

**[0013]** The objective, which the invention is directed to solve, consists in development of the aluminum-based alloy intended for manufacturing semi-finished products and parts in it for aerospace engineering, free from the above listed disadvantages and inherent to known engineering solutions. A technical result achieved by an embodiment of the invention comprises obtaining an alloy possessing increased ductility, that will allow to improve its processibility, to increase yields by manufacturing semi-finished products and parts thereof, to ensure possibility to produce thin sheets, thin-walled sections and die-forgings by reducing production labor intensiveness, by preservation required strength and operation characteristics of the alloy, and also semi-finished products and parts thereof demanded to structural materials for aerospace engineering.

**[0014]** The posed objective with achievement of the aforesaid technical result by invention embodiment is solved by the fact, that the known aluminum-based alloy containing lithium, copper, magnesium, zirconium, beryllium, titanium, nickel, manganese, gallium, zinc, sodium, additionally contains calcium and, at least, one element selected from a group including vanadium and scandium, with the following component ratio, wt %:

| | |
|---|---|
| Lithium | 1.6 - 1.9 |
| Copper | 1.3 - 1.5 |
| Magnesium | 0.7 - 1.1 |
| Zirconium | 0.04 - 0.2 |
| Beryllium | 0.02 - 0.2 |
| Titanium | 0.01 - 0.1 |

(continued)

| | |
|---|---|
| Nickel | 0.01 - 0.15 |
| Manganese | 0.01 - 0.2 |
| Gallium | up to 0.001 |
| Zinc | 0.01 - 0.3 |
| Sodium | up to 0.0005 |
| Calcium | 0.005 - 0.02 |

**[0015]** At least, one element selected from a group including:

| | |
|---|---|
| Vanadium | 0.005 - 0.01 |
| Scandium | 0.005 - 0.01 |
| Aluminum | Remainder |

**[0016]** The aluminum-based alloy used for manufacturing semi-finished products and parts differs from the prior art both quantitatively (reduced contents of copper, gallium, and sodium) and qualitatively (in addition it contains calcium, and, at least, one element selected from a group including vanadium and scandium).

**[0017]** We have determined that increased contents of copper results in formation of coarse irregular-shaped intermetallic compounds being copper-bearing phases formed by alloy crystallization in areas with increased copper contents inside grains and on their boundaries. These phases are represented not by separate particles, but extensive accumulations impeding shear deformations in the shaping process, which results in considerable reduction of alloy ductility.

**[0018]** Reduction of copper contents in the alloy up to limits of 1.3 - 1.5 wt % allows practically total transfer to solid solution which results in considerable reduction of inclusion volume ratio of coarse intermetallic compounds of copper-bearing phases as determined by electron-microscopical analysis of the alloy, and, consequently, enhancement of alloy ductility. Reduction of copper contents to less than 1.3 wt % will have no enhancing influence on ductility characteristics of the alloy, but will considerably reduce its strength features.

**[0019]** Additionally, we have determined that gallium and sodium do not form phases with aluminum and accumulate on grain boundaries resulting in brittle fracture along grain boundary in processes of alloy crystallization and its shaping.

**[0020]** We have determined that with gallium and sodium contents less than 0.001 and 0.0005 wt % respectively, they practically totally dissolve in solid solution resulting in enhancement of alloy ductility.

**[0021]** Calcium in quantity of 0.005 - 0.02 wt % is an additive binding excess sodium and other residual elements of the alloy resulting in formation of a rounder shape of isolated intermetallic compounds and their coagulation resulting in more favorable conditions of shear deformation, and, consequently, in enhancement of alloy process ductility.

**[0022]** Introduction of one or more elements from a group of vanadium, scandium in indicated quantities facilitates formation of a homogeneous, fine-grained structure that promotes intensification of the role of zirconium as a modifying agent ensuring structural strengthening of semi-finished products and parts in the alloy, that allows to achieve a necessary level of alloy strength properties.

**[0023]** From the proposed aluminum-based alloy it is possible to manufacture various semi-finished products: sheets and plates, die-forgings, extrusions. From semi-finished products of the proposed alloy it is possible to obtain various parts, for example, panels for skin of aircraft fuselage structures, elements of bulkhead frame, welded fuel tanks, and other elements of aerospace engineering.

Examples of embodiments of the invention

**[0024]** Under industrial conditions a flat ingot with cross-section of 300x1,100 mm and round ingots with diameters of 190 mm and 350 mm have been cast in each alloy, which chemical composition is given in Table 1.

**[0025]** Alloy No. 1 corresponds to the alloy taken as a prototype, alloys No. 2, 3, 4 correspond to the proposed one.

**[0026]** Charge material melting, degassing and ingot casting have been done at temperature of 710 - 730°C.

Example 1

**[0027]** Later on, clad sheets have been manufactured from flat ingots in each alloy. The sheets have been manufactured based on one process flow by means of hot rolling at temperature of 430°C up to 6.5 mm of thickness with reeling to coils, and afterwards, after annealing at temperature of 400°C, by means of cols rolling.

**[0028]** It should be mentioned, that it has been achieved to roll a sheet in alloy No. 1 only up to 0.9 mm of thickness, and further rolling has been stopped due to presence of tears 30 mm deep on sheet side edges and presence of 2 ruptures in a coil.

**[0029]** Sheets in alloys No. 2, 3, 4 have been rolled without ruptures up to 0.5 mm of thickness.

**[0030]** Further finishing operations, flattening and stretching sheets in alloys No. 2, 3, 4, in comparison with alloy No. 1 and despite their lower thickness, have been done more successfully and with less rejections at release inspection on defects: folds, non-flatness, and cracks.

Table 1

| Alloy | Alloy composition No. | Component contents, wt % | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Li | Cu | Mg | Zr | Be | Ti | Ni | Mn | Ga | Zn | Na | Ca | V | Sc | Al |
| Prototype | 1 | 1.9 | 1.7 | 0.9 | 0.10 | 0.03 | 0.02 | 0.04 | 0.08 | 0.002 | 0.015 | 0.0007 | - | - | - | Remainder |
| Claimed | 2 | 1.9 | 1.5 | 1.0 | 0.11 | 0.02 | 0.02 | 0.05 | 0.06 | 0.0004 | 0.014 | 0.0003 | 0.005 | 0.007 | 0.006 | |
| | 3 | 1.8 | 1.3 | 0.9 | 0.11 | 0.03 | 0.02 | 0.04 | 0.07 | 0.0002 | 0.014 | 0.0001 | 0.02 | 0.01 | - | |
| | 4 | 1.8 | 1.4 | 0.8 | 0.10 | 0.04 | 0.02 | 0.04 | 0.07 | 0.0001 | 0.015 | 0.0002 | 0.01 | - | 0.009 | |

**[0031]** Yield by manufacturing sheets in alloys No. 2, 3, 4 has been higher by 30%, than in alloy No. 1.

**[0032]** Later on, specimens from sheets in alloys No. 1, 2, 3, 4 have been tested at static tension with determination of tensile strength ($\sigma_B$), yield strength ($\sigma_{0.2}$), elongation ($\delta$,%).

**[0033]** Specimens have been cut off lengthwise, crosswise, and at angle of 45° relative to rolling direction.

**[0034]** Results of mechanical testing are presented in Table 2.

**[0035]** Table 2 shows that the proposed alloy surpasses the known alloy (the prototype) on ductility characteristics with preservation of required strength characteristics.

Example 2

**[0036]** Sections (angles with flange thickness up to 5 mm) have been manufactured from round ingots with diameter of 190 mm in each alloy.

**[0037]** Sections in different alloys have been manufactured based on one process flow by means of extruding at temperature of 400°C, with further section water quenching, and ageing at temperature of 150°C within 24 hours.

**[0038]** Yield by manufacturing sheets in alloys No. 2, 3, 4 has been higher by 15%, than in alloy No. 1.

Example 3

**[0039]** Die-forgings with wall thickness of 40 mm have been manufactured from round ingots with diameter of 350 mm in each alloy.

Table 2

| Alloy | Alloy composition No. | Sampling direction | Mechanical properties | | |
|---|---|---|---|---|---|
| | | | $\sigma_{B,\ M\Pi\alpha}$ | $\sigma_{0.2,\ M\Pi\alpha}$ | $\delta$, % |
| Prototype | 1 | Longitudinal | 432 | 347.5 | 13.5 |
| | | Transverse | 440 | 343 | 10.7 |
| | | At angle of 45° | 419 | 323 | 13.9 |
| Claimed | 2 | Longitudinal | 430 | 349 | 14.6 |
| | | Transverse | 438 | 352 | 13.8 |
| | | At angle of 45° | 424 | 328 | 14.5 |
| | 3 | Longitudinal | 431 | 351 | 14.8 |
| | | Transverse | 438 | 345 | 13.9 |
| | | At angle of 45° | 425 | 329 | 14.9 |
| | 4 | Longitudinal | 432 | 345 | 14.9 |
| | | Transverse | 439 | 339 | 14.1 |
| | | At angle of 45° | 423 | 328 | 15.1 |

**[0040]** Die-forgings in different alloys have been manufactured on one process flow by means of blanking forging at temperature of 410°C, preliminary forging at temperature of 410°C, and after etching by means of final forging at temperature of 400°C, with further quenching at temperature of 500°C during 2 hours and ageing at temperature of 150 °C during 24 hours.

**[0041]** The yield by manufacturing die-forgings in alloy No. 2, 3, 4 has been higher than alloy No. 1 by 10%.

**[0042]** Thus, the suggested alloy ensures achievement of the posed objective - improvement of alloy ductility characteristics, and, consequently, improvement of its processibility, increase of yields by manufacturing semi-finished products and parts thereof, assurance of possibility to produce thin sheets, thin-walled sections and die-forgings by reducing production labor intensiveness, and preservation of required strength and operation characteristics of the alloy and parts thereof demanded to structural materials for aerospace engineering.

## Claims

1. The aluminum-based alloy containing lithium, copper, magnesium, zirconium, beryllium, titanium, nickel, manganese, gallium, zinc, sodium, which differs by the fact, that it additionally contains calcium, and, at least, one element selected from a group including vanadium and scandium, with the following component ratio, wt %:

| | |
|---|---|
| Lithium | 1.6 - 1.9 |
| Copper | 1.3 - 1.5 |
| Magnesium | 0.7 - 1.1 |
| Zirconium | 0.04 - 0.2 |
| Beryllium | 0.02 - 0.2 |
| Titanium | 0.01 - 0.1 |
| Nickel | 0.01 - 0.15 |
| Manganese | 0.01 - 0.2 |
| Gallium | up to 0.001 |
| Zinc | 0.01 - 0.3 |
| Sodium | up to 0.0005 |
| Calcium | 0.005 - 0.02, |
| | and |

at least, one element selected from a group including:

| | |
|---|---|
| Vanadium | 0.005 - 0.01 |
| Scandium | 0.005 - 0.01 |
| Aluminum | Remainder. |

2. Semi-finished product, such as sheet, plate, die-forging or extrusion manufactured from the aluminum-based alloy according to claim 1.

3. Part manufactured from a semi-finished product according to claim 2, such as a panel for the skin of an aircraft fuselage structure, an element of a bulkhead frame, a welded fuel tank or any other element of aerospace engineering.

4. Method of manufacturing an aluminum-based alloy according to claim 1, including charge material melting, degassing and ingot casting performed at a temperature of 710- 730°C.

5. Method according to claim 4, comprising manufacturing a sheet from flat ingots, the sheets being manufactured based on a process flow by means of hot rolling at temperature of 430°C up to 6.5 mm of thickness with reeling of coils, and afterwards, after annealing at temperature of 400°C, by means of cols rolling.

6. Method according to claim 5 including manufacturing die-forgings with wall thickness of 40 mm from round ingots with diameter of 350 mm.

7. Method according to claim 5, comprising manufacturing the die-forging on a process flow by means of blanking forging at temperature of 410°C, preliminary forging at temperature of 410°C, and after edging by means of final forging at temperature of 400°C, with further quenching at temperature of 500°C during two hours and ageing at temperature of 150°C during 24 hours.

## Patentansprüche

1. Aluminiumbasierte Legierung, enthaltend Lithium, Kupfer, Magnesium, Zirkon, Beryllium, Titan, Nickel, Mangan, Gallium, Zink, Natrium, **dadurch gekennzeichnet, dass** sie zusätzlich Calcium und wenigstens ein Element enthält, das aus einer Gruppe ausgewählt ist, die Vanadium und Scandium enthält, mit dem folgenden Komponentenverhältnis in Gew.-%:

| | |
|---|---|
| Lithium | 1,6 - 1,9 |
| Kupfer | 1,3 - 1,5 |
| Magnesium | 0,7 - 1,1 |
| Zirkon | 0,04 - 0,2 |
| Beryllium | 0,02 - 0,2 |
| Titan | 0,01 - 0,1 |
| Nickel | 0,01 - 0,15 |
| Mangan | 0,01 - 0,2 |
| Gallium | bis 0,001 |
| Zink | 0,01 - 0,3 |
| Natrium | bis 0,0005 |
| Calcium | 0,005 - 0,02, |

und wenigstens ein Element, das aus einer Gruppe ausgewählt ist, die enthält:

| | |
|---|---|
| Vanadium | 0,005 - 0,01 |
| Scandium | 0,005 - 0,01 |
| Aluminium | Rest. |

**2.** Halbfertigerzeugnis wie Folie bzw. Blech, Platte, Gesenkschmiedestück oder Extrudier- bzw. Strangpressteil, das aus der aluminiumbasierten Legierung nach Anspruch 1 hergestellt ist.

**3.** Teil, das aus einem Halbfertigerzeugnis nach Anspruch 2 hergestellt ist, wie ein Paneel für die Verkleidung einer Flugzeugrumpfstruktur, ein Element eines Schott- bzw. Trennwandrahmens, ein geschweißter Treibstofftank oder jedes andere Element aus dem Flugzeugingenieurwesen.

**4.** Verfahren zum Herstellen einer aluminiumbasierten Legierung nach Anspruch 1, das beinhaltet, das Schmelzen des Einsatzstoffs, das Entgasen, und das Gießen von Barren bzw. Gussblöcken bei einer Temperatur von 710-730 °C durchzuführen.

**5.** Verfahren nach Anspruch 4, das beinhaltet, ein Blech aus flachen Gussblöcken herzustellen, wobei die Bleche auf Grundlage eines Prozessablaufs mittels Heißwalzen bei einer Temperatur von 430 °C bis zu einer Dicke von 6,5 mm mit einem Aufspulen von Spulen bzw. Coils, und, danach, nach dem Anlassen bzw. Fixieren bei einer Temperatur von 400 °C, mittels Aufwickeln von Spulen hergestellt werden.

**6.** Verfahren nach Anspruch 5, das beinhaltet, Gesenkschmiedestücke mit Wandstärken von 40 mm aus runden Gussblöcken mit einem Durchmesser von 350 mm herzustellen.

**7.** Verfahren nach Anspruch 5, das beinhaltet, das Gesenkschmiedestück in einem Prozessablauf mittels Stanzen des Schmiedestücks bei einer Temperatur von 410 °C, Vorschmieden bei einer Temperatur von 410 °C, und, nach dem Kanten bzw. Stauchen, durch Endschmieden bei einer Temperatur von 400 °C herzustellen, ferner mit einem Abschrecken bzw. Abkühlen bei einer Temperatur von 500 °C während zwei Stunden und einem Altern bzw. Warmaushärten bei einer Temperatur von 150 °C während 24 Stunden.

## Revendications

**1.** Alliage à base d'aluminium contenant du lithium, du cuivre, du magnésium, du zirconium, du béryllium, du titane, du nickel, du manganèse, du gallium, du zinc, du sodium, qui diffère par le fait qu'il contient en plus du calcium, et, au moins, un élément choisi parmi un groupe constitué du vanadium et du scandium, les teneurs en composants, exprimées en % en poids, étant les suivantes :

| | |
|---|---|
| lithium | 1,6 à 1,9 |

(suite)

| | |
|---|---|
| cuivre | 1,3 à 1,5 |
| magnésium | 0,7 à 1,1 |
| zirconium | 0,04 à 0,2 |
| béryllium | 0,02 à 0,2 |
| titane | 0,01 à 0,1 |
| nickel | 0,01 à 0,15 |
| manganèse | 0,01 à 0,2 |
| gallium | jusqu'à 0,001 |
| zinc | 0,01 à 0,3 |
| sodium | jusqu'à 0,0005 |
| calcium | 0,005 à 0,02 |

et au moins un élément choisi parmi un groupe constitué de :

| | |
|---|---|
| vanadium | 0,005 à 0,01 |
| scandium | 0,005 à 0,01 |
| aluminium | le reste |

**2.** Produit semi-fini, tel qu'une tôle, une plaque, une pièce forgée par matriçage ou un profilé fabriqué à partir de l'alliage à base d'aluminium selon la revendication 1.

**3.** Pièce fabriquée à partir d'un produit semi-fini selon la revendication 2, telle qu'un panneau pour le revêtement d'une structure de fuselage d'avion, un élément d'un cadre de cloison, un réservoir de carburant soudé ou tout autre élément utilisé dans l'aérospatiale.

**4.** Procédé de fabrication d'un alliage à base d'aluminium selon la revendication 1, incluant la fusion d'un matériau de charge, le dégazage et la coulée en lingotière effectuée à une température de 710 à 730 °C.

**5.** Procédé selon la revendication 4, comportant la fabrication d'une tôle à partir de lingots plats, les tôles étant fabriquées sur la base d'un déroulement de processus au moyen d'un laminage à chaud à une température de 430 °C jusqu'à 6,5 mm d'épaisseur avec rembobiner de bobines, et ensuite, après un recuit à une température de 400 °C, au moyen d'un enroulement de bobines.

**6.** Procédé selon la revendication 5 incluant la fabrication de pièces forgées par matriçage ayant une épaisseur de paroi de 40 mm, à partir de lingots ronds ayant un diamètre de 350 mm.

**7.** Procédé selon la revendication 5, comportant la fabrication de la pièce forgée par matriçage pendant un déroulement de processus au moyen d'un découpage de la piece forgée à une température de 410 °C, d'un forgeage préliminaire à une température de 410 °C, et après refoulement au moyen d'un forgeage final à une température de 400 °C, avec une trempe supplémentaire à une température de 500 °C pendant deux heures et un vieillissement à une température de 150 °C pendant 24 heures.

## REFERENCES CITED IN THE DESCRIPTION



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- SU 1767916 **[0004]**
- RU 2180928 **[0010]**
- EP 1788101 A **[0010]**


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