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(54) ALUMINUM-BASED ALLOY

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(57) **ABSTRACT**

The incorporation of calcium and at least one member selected from the group consisting of vanadium and scandium into an aluminum lithium alloy containing: lithium, copper, magnesium, zirconium, beryllium, titanium, nickel, manganese, gallium, zinc, and sodium provides an aluminum lithium alloy that: 1) exhibits improved ductility; 2) exhibits improved processability resulting in the capability to obtain higher yields of semi-finished products; 3) provides the ability to fabricate thin sheets, thin walled sections and forgings, all while preserving the inherent strength and operating characteristics of such alloys when applied to semi-finished products and parts thereof demanded by structural applications in these fields.

ALUMINUM-BASED ALLOY

FIELD OF THE INVENTION

[0001] The present invention relates to aluminum lithium alloys and more particularly to an aluminum-copper-magnesium-lithium alloy that overcomes the shortcomings of prior such alloys.

BACKGROUND OF THE INVENTION

[0002] It is well known that aluminum lithium alloys possess a unique combination of mechanical properties including; low density, high modulus of elasticity, and high strength. These properties contribute to the use of these alloys as structural materials in aerospace applications that result in a number of improvements in aircraft/aerospace vehicle performance including: reduction in vehicle weight, fuel economy and increased load capacity.

[0003] However, aluminum lithium alloys as a group exhibit at least one major disadvantage, low ductility under conditions at or near their maximum strength. (N. I. Friedlander, K. V. Christos. A. L. Berezina, N. I. Kolbe, Aluminum Lithium Alloys, Structure and Properties, Kiev: Nauk. Dumka, 1992, page 177).

[0004] Among the known aluminum lithium alloys are those having the following compositions in percent by weight:

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	Balance

(Inventor's Certificate of USSR No. 1767916, IPC C 22 C 21/16, published Aug. 20, 1997)

[0005] The disadvantages of these alloys are their limited processability, the high manufacturing costs associated therewith that are dictated by the labor intensiveness of such activities, low yields of satisfactory product obtained in the fabrication of semi-finished products and parts and the difficulties encountered when fabricating thin sheets, thin walled sections and forgings therefrom.

[0006] These disadvantages are due, at least in part, to the fact that the relatively high concentrations of copper in these alloys contribute to hot brittleness and negatively affect the ductility thereof. This leads to cracking, high rejection levels in folds and non-flatness in finishing operations that include flattening and stretching to form finished or semi-finished products.

[0007] Aluminum lithium alloy 8093 has the following composition based upon percent by weight:

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	Balance

[0008] The disadvantages of this alloy include, high cost, their limited processability, the high manufacturing costs associated therewith that are dictated by the labor intensiveness of such activities, low yields of satisfactory product obtained in the fabrication of semi-finished products and parts and the difficulties encountered when fabricating thin sheets, thin walled sections and forgings therefrom.

[0009] The major cause of the aforementioned disadvantages is the relatively elevated concentration of lithium in this alloy which results in the formation of strengthening phases during forming operations. The formation of these strengthening phases reduces the alloy's ductility during casting and shaping. This, in turn, results n increased cracking, higher rejections based on the presence of folds and non-flatness in finishing operations that include flattening and stretching during the fabrication of semi-finished or finished products.

[0010] A further prior art aluminum lithium alloy comprises the following elements in percent by weight:

Lithium	1.7-2.0
Copper	1.6-2.0
Magnesium	0.7-1.1
Zirconium	0.04-.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	Balance

(Russian Patent No. 2180928, IPC 7 C 22 C 21/00, C 22/21/16, published Mar. 27, 2002).

[0011] Among the disadvantages of this alloy are its limited processability, the high manufacturing costs associated therewith that are dictated by the labor intensiveness of such activities, low yields of satisfactory product obtained in the fabrication of semi-finished products and parts and the difficulties encountered when fabricating thin sheets, thin walled sections and forgings therefrom.

[0012] These disadvantages are due, at least in part, to the fact that the relatively high concentrations of copper in these alloys contribute to hot brittleness and negatively affect the ductility thereof. This leads to cracking, high rejection levels in folds and non-flatness in finishing operations that include flattening and stretching to form finished or semi-finished products. Additionally, the relatively high levels of sodium and gallium lead to a considerable increase in the hot brittleness of the alloy with a consequent reduction in the ductility thereof. (A. V. Hurdyumov, S. V. Inkin, V. S. Chulkov, G. G. Shadrin, Metallurgical Admixtures in Aluminum Alloys, M,: Metallurgy, 1998, pp 90, 99). This complicates considerably obtaining acceptable ingots and the fabrication of various semi-finished products by shaping. This also inhibits the production of quality claddings for rolled or semi-finished products as a result of the formation of significant areas of non-welded cladding on the surface.

OBJECT OF THE INVENTION

[0013] It is therefore an object of the present invention to provide an aluminum lithium alloy for the fabrication of aircraft and aerospace vehicles that does not exhibit the disadvantages of prior art such alloys.

[0014] It is a further object of the present invention to provide an aluminum lithium alloy that: 1) exhibits improved ductility; 2) exhibits improved processability resulting in the capability to obtain higher yields of semi-finished products; 3) provides the ability to fabricate thin sheets, thin walled sections and forgings, all while preserving the inherent strength and operating characteristics of such alloys when applied to semi-finished products and parts thereof demanded by structural applications in these fields.

SUMMARY OF THE INVENTION

[0015] The foregoing objectives are obtained by the incorporation of calcium and at least one member selected from the group consisting of vanadium and scandium in an aluminum lithium alloy containing: lithium, copper, magnesium, zirconium, beryllium, titanium, nickel, manganese, gallium, zinc, and sodium. Specifically, there is provided an aluminum lithium alloy having the following composition in percent by weight:

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
at least one element selected from the group consisting of	
Vanadium	0.005-0.01
Scandium	0.005-0.01
Aluminum	Balance

DETAILED DESCRIPTION

[0016] The present invention provides an aluminum lithium alloy that: 1) exhibits improved ductility; 2) exhibits improved processability resulting in the capability to obtain higher yields of semi-finished products; 3) provides the ability to fabricate thin sheets, thin walled sections and forgings, all while preserving the inherent strength and operating characteristics of such alloys when applied to semifinished products and parts thereof demanded by structural applications in these fields.

[0017] The composition of this alloy comprises in percent by weight:

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
at least one element selected from the group consisting of	
Vanadium	0.005-0.01
Scandium	0.005-0.01
Aluminum	Balance.

[0018] The aluminum lithium alloy of the present invention differs both quantitatively (reduced levels of copper, gallium and sodium) and qualitatively (the addition of calcium and at least one member selected from the group consisting of vanadium and scandium from those of the prior art).

[0019] It has been determined that the incorporation of increased contents of copper in aluminum lithium alloys results in the formation of coarse irregularly shaped intermetallic compounds that are copper bearing phases formed by alloy crystallization in areas of increased copper content inside of grains and on their boundaries. These phases are represented not by separate particles, but rather by extensive accumulations that impair shear deformation in shaping processes resulting in a significant reduction in alloy ductility.

[0020] Scanning electron microscopic studies have determined that a reduction in the copper content of aluminum lithium alloys to within the limits of 1.3 to 1.5 weight percent result in a virtually total conversion thereof to a solid solution. This results in a significant reduction in the inclusion volume ratio of coarse intermetallic compounds of copper bearing phases, thus, enhancing the ductility of the alloy. At copper contents below about 1.3 weight percent, no further improvement in ductility is found, but strength is reduced considerably.

[0021] Additionally, it has been determined that gallium and sodium do not form phases with aluminum, but rather accumulate at grain boundaries resulting in brittle fracture along the grain boundaries in fabrication processes involving alloy crystallization and shaping.

[0022] It has been determined that with gallium and sodium contents below about 0.001 and 0.0005 weight percent respectively, these elements practically dissolve totally into solid solutions resulting in a further enhancement in alloy ductility.

[0023] Calcium in quantities of less than about 0.005-0.2 weight percent serves as a binding agent for excess sodium and other trace elements resulting in the formation of rounder shaped isolated intermetallic compounds and their coagulants resulting in more favorable conditions for shear deformation, and, consequently and enhancement in alloy ductility.

[0024] The introduction of vanadium and/or scandium in the indicated amounts facilitates formation of homogeneous, fine-grained structures that promote the role of zirconium as a modifying agent that enhances structural strength.

[0025] The aluminum lithium alloys of the present invention permit the manufacture and fabrication of a wide variety of semi-finished products including: sheet and plate, forgings and extrusions. From these semi-finished products it is therefore possible to fabricate finished fuselage skin panels for aircraft, bulkhead elements, welded fuel tank assemblies and a wide variety of other aircraft and aerospace vehicle parts and assemblies.

EXAMPLES

Example 1

[0026] Alloys having a chemical composition within the range described for the prior art sodium and gallium containing alloys described above and those of the present invention were cast into rectangular ingots 300×1 and 100 mm in length and round ingots in diameters of 190 mm and 350 mm. All casting operations were performed in the temperature range of from 710 to 730° C. The prior art material is identified hereinafter as sample 1 while those specimens produced from the alloys of the present invention are identified as samples 2-4.

[0027] Cladding sheets were fabricated from flat ingots in each of the alloys. These sheets were produced by hot rolling to 6.5 mm at a temperature 430° C., coiling and annealing at a temperature of 400° C. by means of cold rolling.

[0028] Sample 1 could only be rolled to a thickness of 90 mm because of the presence of tears 30 mm deep on the edges of the coil and 2 breakages of the coil. Sheets of samples 2-4 were reduced to a thickness of 0.5 mm with no cracking or separation.

[0029] The sheets of samples 2-4 were then finished in flattening and stretching operations with minimal rejection because of folds, non-flatness or cracks. Yields of sheets from samples 2-4 were 30% higher than those experienced with sheets of sample 1 which were produced from the minimum thickness rolled sheets previously obtained.

[0030] Specimens cut at a 45° angle lengthwise and subjected to mechanical testing to determine, mechanical strength, yield strength and elongation showed the results indicated in attached Table 1. As shown in this Table, the properties of the alloy, tensile strength (σ), yield strength ($\sigma_{0.2}$) and percent elongation (δ%) of the present invention equal or surpass those of the prior art alloy.

TABLE 1

		Mechanical Properties		
Sample No.	Sampling Direction	σ_B, MP_a	$\sigma_{0.2}$, MP_a	δ, %
1	Longitudinal	432	347.5	13.5
	Transverse	440	343	10.7
	At 45° Angle	419	323	13.9
2	Longitudinal	430	349	14.6
	Transverse	438	352	13.8
	At 45° Angle	424	328	14.5
3	Longitudinal	431	351	14.8
	Transverse	438	345	13.9
	At 45° Angle	425	329	14.9
4	Longitudinal	432	345	14.9
	Transverse	439	339	14.1
	At 45° Angle	423	328	15.1

Example 2

[0031] Extruded sections up to 5 mm thick with flanges have been extruded from ingots 190 mm in diameter in each of the alloys. These sections were manufactured by extruding at a temperature of 400° C., cold water quenching and aging for 24 hours at a temperature of 150° C. The yields obtained from samples 2-4 were demonstrated to be 15% higher than those obtained from sample 1.

Example 3

[0032] Forgings with wall thicknesses of 40 mm were fabricated from round ingots with a diameter of 350 mm in each of the alloys. Samples were prepared by blanking the forging at a temperature of 410° C., preliminarily forging at this same temperature, final forging at a temperature of 400° C., quenching at a temperature of 500° C. for two hours and aging at a temperature of 150° C. for 24 hours. The forgings thus produced indicated that fabrication yields for samples 2-4 were 10% higher than those for sample 1.

[0033] There has thus been described an aluminum lithium alloy that an aluminum lithium alloy that: 1) exhibits improved ductility; 2) exhibits improved processability resulting in the capability to obtain higher yields of semi-finished products; 3) provides the ability to fabricate thin sheets, thin walled sections and forgings, all while preserving the inherent strength and operating characteristics of such alloys when applied to semi-finished products and parts thereof demanded by structural applications in these fields.

[0034] As the invention has been described, it will be apparent to those skilled in the art that the same may be varied in many ways without departing from the spirit and scope of the invention. Any and all such modifications are intended to be included within the scope of the appended claims.

What is claimed is:

1) An aluminum alloy having the following composition:

Element	Percent by Weight
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
at least one element selected from the group consisting of	
Vanadium	0.005-0.01
Scandium	0.005-0.01
Aluminum	Balance.

2) The alloy of claim **1** comprising from 0.005 to 0.01 percent by weight vanadium.

3) The alloy of claim **1** comprising from 0.005 to 0.01 weight percent scandium.

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