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(54) **ALUMINUM MAGNESIUM LITHIUM ALLOY WITH IMPROVED FRACTURE TOUGHNESS**

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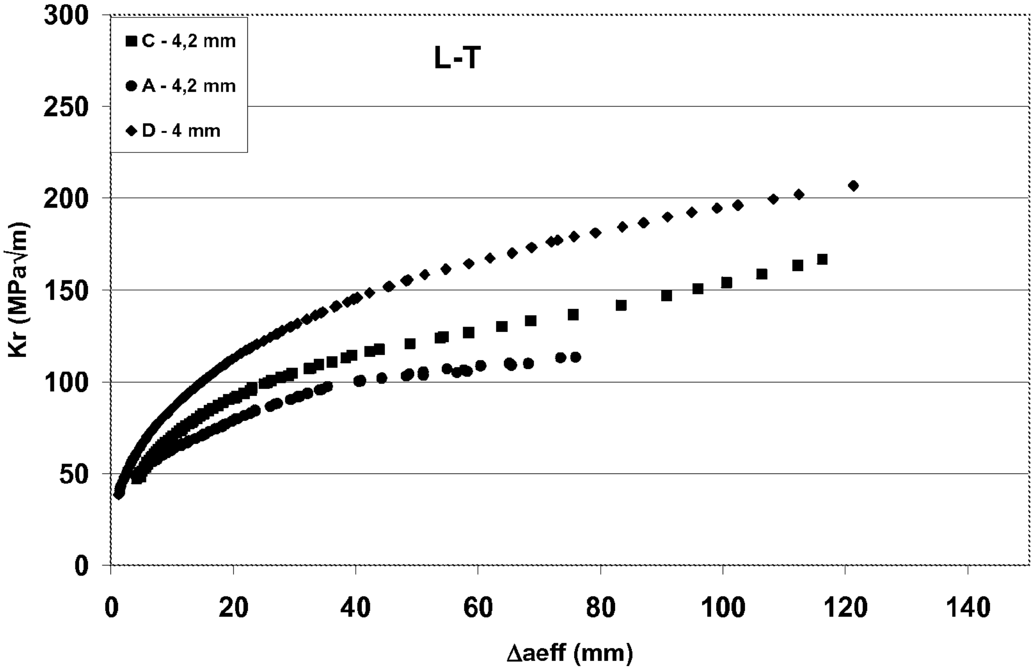
(57) **ABSTRACT**

Wrought product made of aluminum alloy composed as follows, as a percentage by weight Mg: 4.0-5.0; Li: 1.0-1.6; Zr: 0.05-0.15; Ti: 0.01-0.15; Fe: 0.02-0.2; Si: 0.02-0.2; Mn: ≦0.5; Cr≦0.5; Ag: ≦0.5; Cu≦0.5; Zn≦0.5; Sc≦0.01; other elements <0.05; the rest aluminum.

Fig.1



L-T
C - 4,2 mm
A - 4,2 mm
D - 4 mm
Kr (MPa√m)
Δaeff (mm)
0
50
100
150
200
250
300
0
20
40
60
80
100
120
140

Fig 2

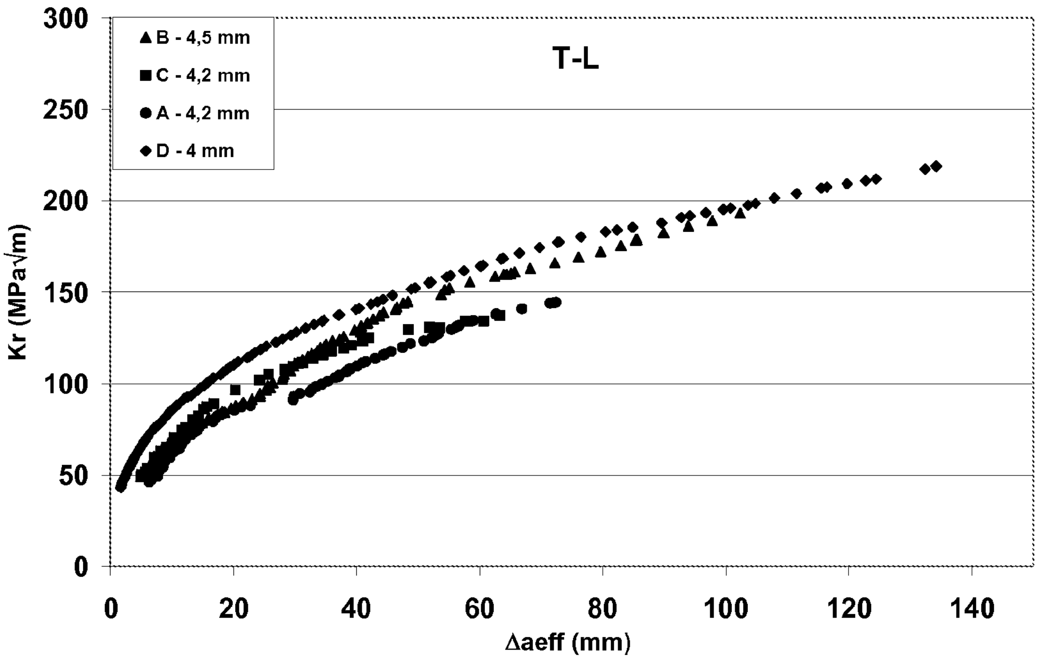
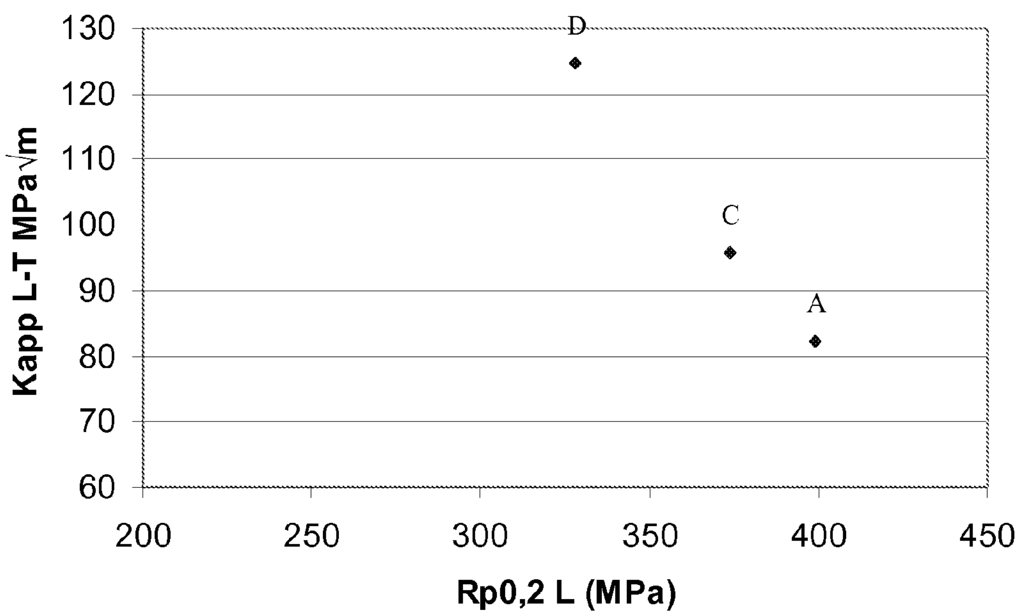

300
250
200
150
100
50
0
Kr (MPa√m)
B - 4,5 mm
C - 4,2 mm
A - 4,2 mm
D - 4 mm
T-L
0
20
40
60
80
100
120
140
Δaeff (mm)

Fig 3:


130
120
110
100
90
80
70
60
Kapp L-T MPa√m
D
C
A
200
250
300
350
400
450
Rp0,2 L (MPa)

ALUMINUM MAGNESIUM LITHIUM ALLOY WITH IMPROVED FRACTURE TOUGHNESS

CROSS REFERENCE TO RELATED APPLICATION

[0001] This application claims priority to French Application No. 11/01555, filed May 20, 2011, and U.S. Provisional Application No. 61/488,196, filed May 20, 2011, the content of both of which are incorporated herein by reference in their entireties.

BACKGROUND

[0002] 1. Field of the Invention

[0003] The invention relates to aluminum-magnesium-lithium alloy products, and more particularly such products, their manufacturing processes and use, designed in particular for aircraft and aerospace construction.

[0004] 2. Description of Related Art

[0005] Rolled products made of aluminum alloy are developed to produce parts of high strength designed in particular for the aircraft and aerospace industry.

[0006] Aluminum alloys containing lithium (AlLi) are of great interest in this respect, because lithium can reduce the density of aluminum by 3% and increase the modulus of elasticity by 6% for each percent of added lithium weight. For these alloys to be selected for aircraft, their performance as compared to the other usual properties must generally attain that of alloys in regular use, in particular in terms of the balance between static mechanical strength properties (tensile and compression yield stress, ultimate tensile strength) and damage tolerance properties (fracture toughness, resistance to fatigue crack propagation), these properties being in general in opposition to each other.

[0007] These alloys must also have sufficient corrosion resistance, allowing them to be formed according to the usual processes and to have low residual stresses in order to be able to be machined integrally.

[0008] Aluminum alloys containing magnesium and lithium simultaneously make it possible to obtain particularly low densities and have therefore been extensively examined GB patent 1,172,736 discloses an alloy containing 4 to 7% Mg by weight, 1.5-2.6% Li, 0.2-1% Mn and/or 0.05-0.3% Zr, the rest aluminum, useful for applications requiring high mechanical resistance, good corrosion resistance, low density and a high modulus of elasticity.

[0009] International request WO 92/03583 described an alloy useful for aeronautical structures having low density of general formula $Mg_aLi_bZn_cAg_dAl_{bal}$, in which a ranges between 0.5 and 10%, b between 0.5 and 3%, c between 0.1 and 5%, d between 0.1 and 2% and bal indicates that the rest is aluminum.

[0010] U.S. Pat. No. 5,431,876 discloses a ternary group of aluminum lithium and magnesium or copper alloys, including at least one additive such as zirconium, chromium and/or manganese.

[0011] U.S. Pat. No. 6,551,424 describes a manufacturing process for products made of aluminum-magnesium-lithium alloy of composition (as a percentage by weight) Mg: 3.0-6.0. Li: 0.4-3.0, Zn up to 2.0, Mn up to 1.0, Ag up to 0.5, Fe up to 0.3, Si up to 0.3, Cu up to 0.3, 0.02-0.5 of an element selected from the group made up of Sc, Hf, Ti, V, Nd, Zr, Cr, Y, Be, including straight and cross cold rolling.

[0012] U.S. Pat. No. 6,461,566 describes an alloy composed as follows (as a percentage by weight), Li: 1.5-1.9, Mg: 4.1-6.0, Zn 0.1-1.5, Zr 0.05-0.3, Mn 0.01-0.8 H, 0.9 10^{-5}-4.5 10-5 and at least one element selected from the group Be 0.001-0.2, Y 0.001-0.5 and Sc 0.01-0.3.

[0013] RU patent 2171308 describes an alloy composed as follows (as a percentage by weight), Li: 1.5-3.0, Mg: 4.5-7.0, Fe 0.01-0.15, Na: 0.001-0.0015, H, 1.7 10^{-5}-4.5 10^{-5} and at least one element selected from the group Zr 0.05-0.15, Be 0.005-0.1, and Sc 0.05-0.4 and at least one element selected from the group Mn 0.005-0.3, Cr 0.005-0.2, and Ti 0.005-0.2, the rest aluminum.

[0014] RU patent 2163938 describes an alloy containing (as a percentage by weight by weight) Mg: 2.0-5.8. Li: 1.3-2.3, Cu: 0.01-0.3, Mn: 0.03-0.5, Be: 0.0001-0.3, and at least one element from among Zr and Sc: 0.02-0.25 and at least one element from among Ca and Ba: 0.002-0.1, the rest aluminum.

[0015] Patent application DE 1 558 491 describes in particular an alloy containing (in weight %) Mg: 4-7, Li: 1.5-2.6, Mn: 0.2-1.0, Zr 0.05-0.3 et/ou Ti 0.05-0.15ou Cr 0.05-0.3.

[0016] These alloys did not solve certain problems and in particular their performance in terms of damage tolerance has prevented them from being used significantly in commercial aviation. It should also be noted that the manufacture of wrought products from these alloys has remained difficult and that the rejection rate is too high.

[0017] There exists a need for wrought products made of aluminum-magnesium-lithium alloy presenting improved properties as compared with those of known products, in particular in terms of the balance between static mechanical strength properties and damage tolerance properties, in particular fracture toughness and corrosion resistance while being of low density.

[0018] In addition there exists a need for a reliable and economic manufacturing process for these products.

SUMMARY

[0019] A first subject of the present invention is a wrought product made of aluminum alloy composed as follows, as a percentage by weight,

- **[0020]** Mg: 4.0-5.0
- **[0021]** Li: 1.0-1.6
- **[0022]** Zr: 0.05-0.15
- **[0023]** Ti: 0.01-0.15
- **[0024]** Fe: 0.02-0.2
- **[0025]** Si: 0.02-0.2
- **[0026]** Mn: ≦0.5
- **[0027]** Cr≦0.5
- **[0028]** Ag: ≦0.5
- **[0029]** Cu≦0.5
- **[0030]** Zn≦0.5
- **[0031]** Sc<0.01
- **[0032]** other elements <0.05, each remainder aluminum;

[0033] Another subject of the present invention is a manufacturing process for a wrought product according to the invention including, optionally successively,

- **[0034]** preparing a molten metal bath in order to obtain an aluminum alloy composed according to the invention,
- **[0035]** casting said alloy in a rough shape to form a cast product,
- **[0036]** optionally homogenizing the cast product,
- **[0037]** hot and optionally cold working,

[0038] optionally heat treating at a temperature ranging from 300 to 420° C. in one or more steps,

[0039] solution heat-treating the product so worked, and quenching,

[0040] optionally cold working the product that has been solution heat treated and quenched,

[0041] subjecting the product to artificial aging at a temperature of not more than 150° C.

[0042] Still another subject of the present invention is the use of a product of the invention to produce, for example, aircraft structural elements.

BRIEF DESCRIPTION OF THE DRAWINGS

[0043] FIG. **1**: R Curve in direction L-T (test-specimen CCT760).

[0044] FIG. **2**: R Curve in direction T-L (test-specimen CCT760).

[0045] FIG. **3**: Fracture toughness K_{app} (L-T) according to the tensile yield stress $R_{p0.2}$(L) for alloys A, C and D.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

[0046] Unless otherwise stated, all the indications concerning the chemical composition of the alloys are expressed as a percentage by weight based on the total weight of the alloy. The expression 1.4 Cu means that the copper content expressed as a percentage by weight is multiplied by 1.4. Alloys are designated in conformity with the rules of The Aluminium Association, known to those skilled in the art. The density depends on the composition and is determined by calculation rather than by a method of weight measurement. The values are calculated in compliance with the procedure of The Aluminium Association, which is described on pages 2-12 and 2-13 of "Aluminum Standards and Data". The definitions of the metallurgical tempers are indicated in European standard EN 515.

[0047] The tensile static mechanical properties, in other words the ultimate tensile strength R_m, the conventional yield stress at 0.2% of elongation $Rp_{0.2}$ and elongation at break A %, are determined by a tensile test according to standard EN ISO 6892-1, sampling and test direction being defined by standard EN 485-1.

[0048] A curve giving the effective stress intensity factor as a function of the effective crack extension, known as R curve, is given according to standard ASTM E 561. The critical stress intensity factor K_C, in other words the intensity factor which makes the crack unstable, is calculated from R curve. The stress intensity factor K_{CO} is also calculated by allotting the initial crack length at the beginning of the monotonic load, at critical load. These two values are calculated for a test-specimen of the required shape. K_{app} represents factor K_{CO} corresponding to the test-specimen which was used to carry out the test of R curve. K_{Ceff} represents factor K_C corresponding to the test-specimen which was used to carry out the test of R curve. $\Delta a_{eff(max)}$ represents the crack extension of the last valid point of R curve. The length of R curve—namely the maximum crack extension of the curve—is a parameter that is in itself important, in particular for fuselage design.

[0049] Unless otherwise specified, the definitions of standard EN 12258 apply.

[0050] "Structural element" of a mechanical construction here refers to a mechanical part for which the static and/or dynamic mechanical properties are particularly important for the performance of the structure, and for which a structural analysis is usually prescribed or performed. These are typically elements the failure of which is likely to endanger the safety of said construction, its users or others. For an aircraft, these structural elements include the parts which make up the fuselage (such as the fuselage top skin, stringers, bulkheads, circumferential frames), the wings (such as the top or bottom wing skin, stringers or stiffeners, ribs and spars) and the tail unit, made up of horizontal and vertical stabilizers, as well as floor beams, seat tracks and doors.

[0051] According to the present invention, a selected grade of aluminum alloys which contain specific and critical amounts of magnesium, lithium, zirconium, titanium, iron and silicon makes it possible to manufacture wrought products having an improved compromise of properties, in particular between mechanical resistance and damage tolerance, while having good performance in terms of corrosion.

[0052] The magnesium content of the products according to the invention preferably lies from 4.0 to 5.0% by weight. In an advantageous embodiment of the invention, the magnesium content is at least 4.3% by weight and preferentially 4.4% by weight. A maximum content of 4.7% by weight or advantageously 4.6% by weight of magnesium is preferred.

[0053] The lithium content of the products according to the invention preferably lies from 1.0 to 1.6% by weight. The present inventors noted that a limited lithium content, in the presence of certain additional elements, makes it possible in some embodiments to very significantly improve fracture toughness and fatigue crack propagation speed, which largely compensates for the slight increase in density and the reduction in static mechanical properties.

[0054] In an advantageous embodiment, the maximum lithium content is 1.5% by weight and preferably 1.45% by weight or preferentially 1.4% by weight. A minimum lithium content of 1.1% by weight and preferably of 1.2% of weight is advantageous, in particular in order to improve resistance to intergranular corrosion.

[0055] The zirconium content of the products according to the invention preferably lies from 0.05 to 0.15% by weight and the titanium content lies from 0.01 to 0.15% by weight. The presence of these elements in conjunction with the working conditions used advantageously makes it possible in some embodiments to maintain a substantially unrecrystallized granular structure. In contrast to certain information disclosed from prior art, the present inventors noted that it is in some cases not necessary to add scandium to these alloys to obtain the desired substantially unrecrystallized granular structure and that the addition of scandium could even prove to be detrimental by making the alloy particularly fragile and difficult to cold roll down to thicknesses less than 3 mm, The scandium content is thus advantageously less than 0.01% by weight. In an advantageous embodiment of the invention, the titanium content is from 0.01 to 0.05% by weight. Manganese and/or chromium may also be added to contribute in particular to control the granular structure, their content advantageously remaining at a maximum of 0.5% by weight. In an advantageous embodiment of the invention, having in particular an improved hot ductility, the alloy contains at least one element from among Mn and Cr with, as a percentage by weight Mn: 0.05-0.5 or 0.05-0.3 and Cr: 0.05-0.3, and an element not chosen from among Mn and Cr having a content lower than 0.05% by weight. Improvement of hot ductility helps, in particular hot working, which enables reducing the rejection rate during transformation.

[0056] Copper and/or silver may also be added to improve the performances of the wrought products according to the invention, their content preferably remaining at a maximum of 0.5% by weight In an advantageous embodiment of the invention, the alloy contains at least one element from among Ag and Cu with, as a percentage by weight Cu: 0.05-0.3 and Ag: 0.05-0.3, and an element not chosen from among Ag and Cu having a content lower than 0.05% by weight. These elements can contribute, in particular, to the static mechanical properties. However, in an advantageous embodiment, to improve resistance to intergranular corrosion, Ag and/or Cu content are advantageously less than 0.05% by weight.

[0057] The wrought products according to the invention preferably contain a small quantity of iron and silicon, the content of these elements ranging from 0.02 to 0.2% by weight. The present inventors think that the presence of these elements may contribute, by forming intermetallic phases and/or by contributing to forming dispersoids in particular when manganese is present, to improving damage tolerance properties by avoiding the localization of bending. In an embodiment of the invention, the Fe content and/or the Si content are as a percentage by weight, Fe: 0.04-0.15, Si: 0.04-0.15. In an embodiment of the invention, the Fe content and/or the Si content is less than 0.15% by weight and preferably less than 0.1% by weight.

[0058] The Zn content is preferably a maximum of 0.5% by weight. In an advantageous embodiment of the invention, the Zn content is less than 0.2% by weight and preferably lower than 0.05% by weight. Deliberate Zn addition is typically not desirable because this element can contribute to deteriorate hot ductility without providing any advantageous effect on resistance to intergranular corrosion. Moreover Zn addition contributes to increase the alloy density, which is often not desirable.

[0059] Other elements have a content less than 0.05% by weight each. Certain elements can be detrimental for alloys according to the invention, in particular for reasons of alloy manufacturing such as toxicity and/or breakages during working and it is preferable to restrict them to a very low level, i.e. less than 0.05% or even less. In an advantageous embodiment, the products according to the invention have a maximum Be content of 5 ppm and preferably 2 ppm of Be and/or a maximum Na content of l Oppm and/or a maximum Ca content of 20 ppm.

[0060] The wrought products according to the invention are preferentially extruded products such as sections, rolled products such as sheets or plates and/or forged products

[0061] A suitable manufacturing process of the products according to the invention includes the successive steps of preparing a molten metal bath in order to obtain an aluminum alloy composed according to the invention, casting said alloy in rough shape, optionally homogenizing the product so cast, hot and optionally cold working, solution heat-treating the product so worked, and quenching, optionally cold working the product that has undergone solution heat-treatment and has been quenched, and artificial aging at a temperature of less than 150° C.

[0062] In the first step, a molten metal bath is produced in order to obtain an aluminum alloy composed according to the invention.

[0063] The molten metal bath is then cast typically in rough shape, typically a rolling slab, extrusion billet, or forging stock.

[0064] The rough shape is then optionally homogenized in order to reach a temperature ranging from 450° C. to 550° and preferably from 480° C. to 520° C. for a length of time ranging from 5 to 60 hours. The homogenization treatment can be carried out in one or more steps. However the present inventors did not note any significant advantage provided by homogenization and in a preferred embodiment of the invention, one proceeds directly to hot working following simple reheating without carrying out any homogenization.

[0065] Hot working, typically by extrusion, rolling and/or forging, is carried out preferably with an input temperature greater than 400° C. and advantageously greater than 430° C. or even 450° C.

[0066] In the case of the manufacture of sheets by rolling, it may be necessary to perform a cold rolling step for products of which the thickness is less than 3 mm. It may prove useful to carry out one or more intermediate heat treatment operations before or during cold rolling. These intermediate heat treatment operations are typically carried out at a temperature ranging from 300 to 420° C. in one or more steps.

[0067] The present inventors noted that even by carrying out these intermediate heat treatment operations, they had not been able to industrially cold roll reference alloy sheets down to a thickness of 2 mm, whereas this step proved to be possible with alloy sheets according to the invention. The sheets according to the invention have a preferred thickness of at least 0.5 mm and preferably of at least 0.8 mm or 1 mm.

[0068] After hot and optionally cold working, the product undergoes solution heat-treatment and is quenched. Before undergoing solution heat-treatment, it may be advantageous to carry out heat treatment at a temperature ranging from 300 to 420° C. in one or more steps, in order to improve control of the substantially unrecrystallized granular structure. Solution heat-treatment is preferably carried out, according to the composition of the product, at a temperature ranging from 370 to 500° C. Quenching can be carried out, for example, in water and/or in air. It is advantageous to carry out air quenching because the intergranular corrosion properties are improved.

[0069] The product that undergoes solution heat-treatment and is then quenched can optionally be cold worked once more. Flattening or straightening operations are typically performed at this step but it is also possible to carry out more thorough working so as to still further improve the mechanical properties.

[0070] The metallurgical temper obtained for the rolled products is advantageously a T6 or T6X or T8 or T8X temper and for extruded products advantageously a T5 or T5X temper in the case of press quenching or a T6 or T6X or T8 or T8Xtemper.

[0071] The product finally undergoes artificial aging at a temperature of less than 150° C. Advantageously, artificial aging is carried out in three steps: a first step at a temperature ranging from 70 to 100° C., a second step at a temperature ranging from 100 to 140° C. and a third step at a temperature ranging from 90 to 110° C., the duration of these steps being typically from 5 to 50 h.

[0072] The combination of the chosen composition, in particular the zirconium and titanium content, and the transformation parameters, in particular the hot working temperature and if necessary the heat treatment before solution heat-treatment, advantageously makes it possible to obtain a substantially unrecrystallized granular structure. "Substantially unrecrystallized granular structure" is taken to mean an unrecrystallized granular structure content at mid-thickness greater than 70% and preferably greater than 85%.

[0073] Rolled products according to the invention have particularly advantageous characteristics. The rolled products preferably have a thickness ranging from 0.5 mm to 15 mm, but products of thickness greater than 15 mm, up to 50 mm or even 100 mm or more may have advantageous properties.

[0074] The rolled products obtained by the process according to the invention have, for a thickness ranging from 0.5 to 15 mm, at mid-thickness at least one static mechanical strength property among properties (i) to (iii) and at least one damage tolerance property among properties (iv) to (vi)

[0075] (i) a tensile yield stress $R_{p0.2}$(L)≧280 MPa and preferably $R_{p0.2}$(L)≧310 MPa,

[0076] (ii) a tensile yield stress $R_{p0.2}$(LT)≧260 MPa and preferably $R_{p0.2}$(LT)≧290 MPa,

[0077] (iii) a tensile yield stress)$R_{p0.2}$(45°)≧200 MPa and preferably)$R_{p0.2}$(45°)≧240 MPa,

[0078] (iv) a fracture toughness for test-specimens of width W=760 mm K_{app} (L-T)≧90 MPa√m for a thickness less than 3 mm and K_{app} (L-T)≧110 MPa√m for a thickness of at least 3 mm,

[0079] (v) a fracture toughness for test-specimens of width W=760 mm K_{app} (T-L)≧100 MPa√m for a thickness less than 3 mm and K_{app} (T-L)≧120 MPa√m for a thickness of at least 3 mm,

[0080] (vi) a crack extension of the last valid point of R curve for test-specimens of width W=760 mm $\Delta a_{eff(max)}$ (T-L)≧80 mm for a thickness of less than 3 mm and $\Delta a_{eff(max)}$ (T-L)≧110 mm for a thickness of at least 3 mm.

[0081] The rolled products according to the invention typically have an improved isotropy of mechanical properties, in particular fracture toughness. The rolled products according to the invention therefore advantageously have, for test-specimens of width W=760 mm, a difference between K_{app} (L-T) and K_{app} (T-L) less than 20% and/or a difference between $\Delta a_{eff(max)}$ (T-L) and $\Delta a_{eff(max)}$ (L-T) less than 20% and preferably less than 15%.

[0082] Moreover rolled products according to the invention such as those that have been air-quenched have a weight loss less than 20 mg/cm^2 and preferably less than 15 mg/cm^2 after the intergranular corrosion test NAMLT ("Nitric Acid Mass Loss Test" ASTM-G67).

[0083] The wrought products according to the invention are advantageously used to produce structural elements for aircraft, in particular airplanes. Preferred aircraft structural elements are in particular a fuselage skin obtained advantageously with sheets of thickness 0.5 to 12 mm according to the invention, a fuselage framework a stringer obtained advantageously with sections according to the invention or a rib.

[0084] These aspects, as well as others of the invention are explained in greater detail using the following illustrative and non-restrictive examples.

EXAMPLE 1

[0085] In this example, several Al—Mg—Li alloy plates, the composition of which is given in table 1, were cast. Alloy D has a composition according to the invention; alloys A to C are reference alloys.

TABLE 1

Composition as a percentage by weight and density of the Al—Mg—Li alloys used

Alloy	Ag	Li	Si	Fe	Cu	Ti	Mn	Mg	Zn	Zr	Na (ppm)	Sc
A	0.1	1.8	0.04	0.04	0.17	0.02	0.13	4.6	0.46	0.07	9	0.08
B	0.1	1.7	0.04	0.04	0.07	0.02	0.13	4.9	0.48	0.13	8	
C	0.1	1.7	0.04	0.04	0.17	0.02	0.15	4.8	0.44	0.12	11	
D	0.1	1.4	0.05	0.04	0.18	0.02	0.15	4.5		0.12	4	

[0086] The plates were heated and hot-rolled to a thickness of approximately 4 mm. Cold-rolling tests to thickness 2 mm were carried out after heat treatment made up of two successive steps of one hour at 340° C. followed by 1 hour at 400° C. Only the alloy sheets according to the invention could be cold-rolled successfully to the final thickness, reference alloy sheets having broken at thickness 2.6 mm After hot and possibly cold rolling, the sheets underwent solution heat-treatment at 480° C. for 20 min, this treatment being preceded by heat treatment made up of two successive steps of one hour at 340° C. followed by 1 hour at 400° C. After solution heat-treatment, the sheets were air-quenched and flattened. Artificial aging was carried out for 10 hours at 85° C. followed by 16 hours at 120° C. followed by 10 hours at 100° C.

[0087] The granular structure of all the samples was substantially unrecrystallized, the rate of recrystallization at mid-thickness being less than 10%.

[0088] Samples were tested to determine their static mechanical properties (tensile yield stress $R_{p0.2}$, ultimate tensile strength R_m, and elongation at break (A).

[0089] The results obtained are given in table 2 below.

TABLE 2

Mechanical properties of sheets obtained.

		Direction L			Direction TL			Direction 45°		
Alloy	Th. (mm)	Rm (MPa)	R0.2 (MPa)	A %	Rm (MPa)	R0.2 (MPa)	A %	Rm (MPa)	R0.2 (MPa)	A %
A	4.5	507	399	4.9	502	355	12.5	436	293	21.8
B	4.5	488	370	6.0	513	354	12.4	423	274	24.7
C	4.2	487	374	5.6	506	349	11.7	444	286	21.0
D	4.2	436	328	8.5	443	304	16.1	394	256	23.1
D	2.1	439	344	5.4	455	327	15.2	379	256	25.8

[0090] The fracture toughness of the sheets was characterized by the test of R curves as per standard ASTM E561. The tests were carried out with a full thickness test-specimen CCT (W=760 mm, 2a0=253 mm). All the results are shown in table 3 and table 14 and are illustrated by the graphs in FIG. **1** and FIG. **2**.

TABLE 3

Summary data of R curve

			Kr (MPa√m) at Δa_{eff} (mm)							
Alloy	Th. (mm)	Dir.	10	20	30	40	50	60	70	80
A	4.5	L-T	63	79	91	101	105	107	111	
C	4.2		70	91	105	115	122	129	135	142
D	4.2		86	113	131	145	157	166	175	183
D	2.1		79	101	113	120	128	132	137	141
A	4.5	T-L	62	86	95	110	123	135	143	
B	4.5		68	87	110	129	147	157	164	174
C	4.2		70	94	110	122	131	134		
D	4.2		86	110	128	141	153	164	175	183
D	2.1		84	106	122	133	142	150	157	161

TABLE 4

Fracture toughness test results

Alloy	Th. (mm)	D	K_{app} MPa√m	Kc_{eff} MPa√m	Δa_{eff}max Mm
A	4.5	L-T	82	102	76
C	4.2		96	132	116
D	4.2		125	177	121
D	2.1		99	122	113
A	4.5	T-L	102	142	72
B	4.5		119	179	102
C	4.2		102	131	63

TABLE 4-continued

Fracture toughness test results

Alloy	Th. (mm)	D	K_{app} MPa√m	Kc_{eff} MPa√m	Δa_{eff}max Mm
D	4.2		125	177	134
D	2.1		112	147	103

[0091] FIG. **3** shows the improvement in the compromise between yield stress and fracture toughness.

[0092] In particular, the improvement in K_{app} (L-T) is greater than 25% whereas the reduction in yield stress is less than 15% compared to alloy C sheet. The length of the R-curve is also significantly improved, and so $\Delta a_{eff(max)}$ (T-L) is improved by more than 30%.

[0093] The crack propagation speed was determined as per standard E647 on CCT test-specimens of width 160 mm.

Tableau 5 - Crack propagation speed (σ_{max} = 80 MPa or σ_{max} = 120 MPa (**), R = 0.1-full thickness)									
	Th..		da/dN (mm/cycles) at ΔK (MPa√m)						
Alloy	(mm)	Dir.	10	15	20	25	30	35	40
D	4.2	L-T	$1.24 \cdot 10^{-04}$	$1.17 \cdot 10^{-04}$	$2.27 \cdot 10^{-04}$	$3.85 \cdot 10^{-04}$	$0.63 \cdot 10^{-03}$	$0.95 \cdot 10^{-03}$	$1.48 \cdot 10^{-03}$
D	2.1		$1.20 \cdot 10^{-04}$	$1.59 \cdot 10^{-04}$	$2.82 \cdot 10^{-04}$	$4.95 \cdot 10^{-04}$	$0.90 \cdot 10^{-03}$		
A	4.5	T-L	$1.30 \cdot 10^{-04}$	$2.58 \cdot 10^{-04}$	$7.81 \cdot 10^{-04}$	$35.3 \cdot 10^{-04}$	$14.4 \cdot 10^{-03}$		
B	4.5**		$1.37 \cdot 10^{-04}$	$1.89 \cdot 10^{-04}$	$2.73 \cdot 10^{-04}$	$5.63 \cdot 10^{-04}$	$0.98 \cdot 10^{-03}$	$2.20 \cdot 10^{-03}$	$5.30 \cdot 10^{-03}$
C	4.2**			$2.84 \cdot 10^{-04}$	$5.10 \cdot 10^{-04}$	$9.61 \cdot 10^{-04}$	$1.99 \cdot 10^{-03}$	$9.60 \cdot 10^{-03}$	
D	4.2		$1.35 \cdot 10^{-04}$	$2.00 \cdot 10^{-04}$	$3.52 \cdot 10^{-04}$	$5.14 \cdot 10^{-04}$	$0.92 \cdot 10^{-03}$	$1.95 \cdot 10^{-03}$	
D	2.1		$1.01 \cdot 10^{-04}$	$1.53 \cdot 10^{-04}$	$2.96 \cdot 10^{-04}$	$5.56 \cdot 10^{-04}$	$0.90 \cdot 10^{-03}$		

[0094] The results of the intergranular corrosion test NAMLT ("Nitric Acid Farmhouse Loss Test" ASTM-G67) for various sheets are summed up in Table 6. Certain sheets underwent solution heat-treatment and were quenched with water in the laboratory.

TABLE 6

NAMLT intergranular corrosion test					
		Weight loss (mg/cm^2)			
	Th.	Water-quenched		Air-quenched	
Alloy	(mm)	Surface	t/10e	Surface	t/10
A	4.5	24		13	
B	4.5	26		16	
C	4.2	26		18	
D	4.2	26.5	24	16	17
D	2.1			12	

[0095] Air-quenched alloy sheets according to the invention have low sensitivity to intergranular corrosion for a thickness of 4 mm and are not sensitive to intergranular corrosion for a thickness of 2 mm.

EXAMPLE 2

[0096] In this example, small ingots were cast to evaluate hot ductility and intergranular corrosion properties of different alloys. The size of the ingot after machining was in mm 255×180×28.

[0097] The composition of the alloys is provided in Table 7.

TABLE 7

Composition as a percentage by weight and density of the Al—Mg—Li alloys used											
Alloy	Ag	Li	Si	Fe	Cu	Ti	Mn	Mg	Zn	Zr	Cr	Sc
E	—	1.4	0.03	0.03	—	0.02	0.40	4.5	—	0.11	0.18	—
F	—	1.4	0.03	0.03	—	0.02	0.16	4.4	—	0.12	0.19	—
G	—	1.4	0.03	0.03	—	0.02	0.17	4.4	—	0.11	—	—
H	—	1.1	0.03	0.03	—	0.02	0.16	4.5	—	0.12	—	—
I	—	1.4	0.03	0.03	—	0.02	0.17	4.5	0.6	0.12	—	—

[0098] Hot ductility was evaluated on tests samples machined from the small ingots after homogenization of 12 h at 505° C. The hot ductility test was carried out with a servo hydraulic instrument provided by Servotest Testing Systems Ltd on specific test samples having a thickness of 20 mm and at a deformation rate of 1 s^{-1}. The test consists in the compression of a sample containing two holes. Due to the compression,

[0099] the material between the two holes expands at a controlled deformation rate. The test conditions are described in the journal article from d'A. Deschamps et al. published in the journal Materials Science and Engineering A319-321 (2001) 583-586. The normalized measurement of the reduction in area of the fractured zone (ΔA/A0) enables to evaluate hot ductility at the temperature under consideration. Results obtained at 450° C. and 475° C. are provided in Table 8.

TABLE 8

Hot ductility ($\Delta A/A_0$) (%)			
Hot ductility ($\Delta A/A_0$) (%)	Deformation temperature (° C.)		
Alloy	450	475	Average
E	17	19	18
F	13	19	16
G	12	13	12
H	11	20	15
I	8	12	10

[0100] Alloys E and F which contain Mn and Cr have an advantageous hot ductility whereas hot ductility of reference alloy I which contains 0.6 wt. % Zn is the lowest among tested alloys.

[0101] The small ingots were hot rolled to a thickness of 4 mm. The sheets so obtained were solution heat treated at 480° C., this treatment being preceded by a heat treatment made up of two successive steps of one hour at 345° C. followed by 1 hour at 400° C. After solution heat treatment, the sheets were air quenched and flattened by controlled stretching with a 2%

permanent set. Artificial aging was carried out for 10 hours at 85° C. followed by 16 hours at 120° C. followed by 10 hours at 100° C.

[0102] The results of the intergranular corrosion test NAMLT ("Nitric Acid Farmhouse Loss Test" ASTM-G67) are presented in Table 9.

TABLE 9

NAMLT intergranular corrosion test measured at the surface

Alloy	Weight loss (mg/cm^2)
E	11
F	11
G	8
H	16
I	8

[0103] Alloy G, which in particular is different from alloy D through a lower copper content, exhibits a very low weight loss. Alloy I which contains Zn is not different from alloy G for resistance to intergranular corrosion. Alloy H, which has a lithium content lower than that of the other tested alloys, exhibits a higher weight loss.

1. A wrought product comprising an aluminum alloy of a composition, as a percentage by weight,

Mg: 4.0-5.0
Li: 1.0-1.6
Zr: 0.05-0.15
Ti: 0.01-0.15
Fe: 0.02-0.2
Si: 0.02-0.2
Mn: ≦0.5
Cr ≦0.5
Ag: ≦0.5
Cu ≦0.5
Zn ≦0.5
Sc <0.01
other elements <0.05, each
remainder aluminum;

2. A wrought product according to claim **1**, comprising at least one element selected from the group consisting of Mn and Cr with the following contents if chosen, as a percentage by weight

Mn: 0.05-0.5
Cr: 0.05-0.3, and
an element not chosen from among Mn and Cr having a content less than 0.05% by weight.

3. The wrought product according to claim **1**, comprising at least one element selected from the group consisting of Cu and Ag with the following contents if chosen, as a percentage by weight

Cu: 0.05-0.3
Ag: 0.05-0.3, and
an element not chosen from among Cu and Ag having a content less than 0.05% by weight.

4. The wrought product according to claim **1**,wherein the Li content is, as a percentage by weight

Li: 1.1-1.5.and optionally Li: 1.2-1.4.

5. The wrought product according to claim **1**, wherein the Mg content is, as a percentage by weight

Mg: 4.4-4.7.

6. The wrought product according to claim **1**, comprising a maximum Be content of 5 ppm and/or a maximum Na content of 10 ppm and/or a maximum Ca content of 20 ppm.

7. The wrought product according to claim **1**, comprising a Zn content less than 0.2% by weight and optionally less than 0.05% by weight.

8. The wrought product according to claim **1**, wherein said Fe content and/or said Si content are, as a percentage by weight

Fe: 0.04-0.15
Si: 0.04-0.15.

9. The wrought product according to claim **1**, wherein said product has been worked and the working is carried out by rolling.

10. The wrought product according to claim **9**, comprising a thickness ranging from 0.5 to 15 mm, at mid-thickness having at least one static mechanical strength property among properties (i) to (iii) and at least one damage tolerance property among properties (iv) to (vi)

(i) a tensile yield stress $R_{p0.2}$(L)≧280 MPa and optionally $R_{p0.2}$(L)≧310 MPa,
(ii) a tensile yield stress $R_{p0.2}$(LT)≧260 MPa and optionally $R_{p0.2}$(LT)≧290 MPa,
(iii) a tensile yield stress $R_{p0.2}$(45°)≧200 MPa and optionally $R_{p0.2}$(45°)≧240 MPa,
(iv) a fracture toughness for test-specimens of width W=760 mm K_{app} (L-T)≧90 MPa√m for a thickness less than 3 mm and K_{app} (L-T)≧110 MPa√m for a thickness of at least 3 mm,
(v) a fracture toughness for test-specimens of width W=760 mm K_{app} (T-L)≧100 MPa√m for a thickness less than 3 mm and K_{app} (T-L)≧120 MPa√m for a thickness of at least 3 mm,
(vi) a crack extension of the last valid point of R curve for test-specimens of width W=760 mm $\Delta a_{eff(max)}$ (T-L) ≧80 mm for a thickness of less than 3 mm and $\Delta a_{eff(max)}$ (T-L)≧110 mm for a thickness of at least 3 mm.

11. The manufacturing process for a wrought product according to claim **1**, comprising:

preparing a molten metal bath in order to obtain an aluminum alloy,
casting said alloy in a rough shape to form a cast product,
optionally homogenizing of the cast product,
hot and optionally cold working said product,
optionally heat treating the product at a temperature ranging from 300 to 420° C. in at least one step,
solution heat-treating the product so worked, and quenching,
optionally cold working the product that has been solution heat treated and quenched,
conducting artificial aging at a temperature of not more than 150° C.

12. The process according to claim **11**, wherein said quenching is carried out in air.

13. The product according to claim **1**, capable of being used to produce an aircraft structural element, optionally a fuselage skin, a fuselage framework, a stringer or a rib.

14. The process of claim **11**, which is conducted in the order given.

15. The process of claim **11**, wherein working is conducted by rolling.

* * * * *