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Description

Technical field

The present invention relates to dispersion strengthened aluminum-base alloys, and a method of producing forged "mechanically alloyed" aluminum alloy systems having improved mechanical properties.

Background of the invention

In recent years there has been an intensive search for high strength aluminum which would satisfy the demands of advanced design in aircraft, automotive, naval and electrical industries. While high strength is a key characteristic of the materials sought, to meet the qualifications for certain advanced design applications the alloys must meet a combination of property requirements such as density, strength, ductility, toughness, fatigue and corrosion resistance, depending on the ultimate end use of the materials. The complexity of the problem goes far beyond the difficulties of developing materials with suitable combinations of properties not achieved before. Economics also plays a large role in the choice of materials. The ultimate product forms are often complex shapes, and the potential savings resulting from possible composition substitution is only a part of the picture. The new aluminum alloys would be particularly valuable if they could be shaped into desired forms using cost effective techniques such as forging while retaining their preshaped properties and/or if they could be fabricated economically into the same complex shapes now used with other materials so as to eliminate the need for retooling for fabrication of weight saving structures. Moreover, to be commercially useful, the fabricated parts must have reproducible properties. From a vantage point of commercial viability, the reproducibility will be attainable under a practical range of conditions.

The use of powder metallurgy routes to produce high strength aluminum has been proposed and has been the subject of considerable research. Powder metallurgy techniques generally offer a way to produce homogenous materials, to control chemical composition and to incorporate dispersion strengthening particles into the alloy. Also, difficult-to-handle alloying elements can at times be more easily introduced by powder metallurgy than ingot melt techniques. The preparation of dispersion strengthened powders having improved properties by a powder metallurgy technique known as mechanical alloying has been disclosed, e.g., in U.S. Patent No. 3,591,362 (incorporated herein by reference). Mechanically alloyed materials are characterized by fine grain structure which is stabilized by uniformly distributed dispersoid particles such as oxides and/or carbides. U.S. Patent Nos. 3,740,210, 3,816,080 (incorporated herein by reference) pertain particularly to the preparation of mechanically alloyed dispersion strengthened aluminum. Other aspects of mechanically alloyed aluminum-base alloys have been disclosed in U.S. Patents No. 4,292,079, 4,297,136 and 4,409,038.

For most uses a powder must be fabricated into a final product, e.g. by degassing, compaction, consolidation and shaping in one or more steps. To obtain complex parts the fabrication may take the form, e.g., of extruding, forging and machining. Usually, the less machining required to make a part the greater the economy in material use, labor and time. It will be appreciated that it is an advantage to be able to make a complex shape by forging rather than by a route which requires the shaping by manual labor on an individual basis.

It is academic that composition of an alloy often dictates the fabrication techniques that can be used to manufacture a particular product. In general, the target properties which must be attained in the type aluminum alloys of this invention before other properties will be considered are strength, density and ductility. One of the marked advantages of mechanically alloyed powders is that they can be made into materials having the same strength and ductility as materials made of similar compositions made by other routes, but with a lower level of dispersoid. This enables the production of alloys which can be fabricated more easily without resorting to age hardening additives. While the mechanical alloying route produces materials that are easier to fabricate than other aluminum alloys of comparable composition, the demands for strength and low density and the additives used to obtain higher strength and/or lower density usually decrease workability of the alloy system. (Workability takes into account at least ductility at the working temperature and the load necessary to form the material). The extent of the effect is generally related to the level of additive in the alloy. The additives not only affect the method by which the material can be fabricated, but also the fabrication techniques affect the properties of the materials.

It has now been found that low density dispersion strengthened, mechanically alloyed aluminum-lithium-magnesium alloys can be fabricated into forged parts characterized by improved strength along with adequate ductility by extruding and forging the alloys under controlled narrow conditions. It has further been found that controlling the extrusion of the materials under specific conditions makes possible a wider range of conditions under which the materials can be forged. This further enhances the commercial value of the alloys and improves the reproducibility of the forged parts. It has also been found that the temperatures at which the alloys should be forged are in a lower range than would be expected from normal handbook practice for forging aluminum alloys, e.g., as described in the Metals Handbook, 8th Ed., Vol. 5 (1970) on pp. 127—132.

Brief description of drawings

Figure 1 is a plan drawing of a "Cruciform"-type forging.

Figure 2 is a plan drawing of a "Hook"-type forging.

Summary of the invention

In its process aspects, the present invention is directed to a method for obtaining a forged product composed of a dispersion strengthened, low density aluminum-base alloy containing by weight, from 0.5 to 4% Li, 0.5 to 7% Mg, 0 to 4% Si, a small but effective amount for increased strength, up to 5% carbon, a small but effective amount for increased strength and stability up to 1% oxygen, the balance, apart from impurities, being aluminum, and having a dispersoid content of a small but effective amount for increased strength up to 10 volume % dispersoid, said alloy being derived from a powder of said alloy prepared by a mechanical alloying process, and said method for obtaining the forged product being comprised of a sequence of steps comprising: degassing and compacting said powder under vacuum to obtain a compaction billet having a density sufficiently high to obtain an extruded billet of substantially full density; extruding the resultant compaction billet at a temperature in the range of above the incipient extrusion temperature up to about 400°C (750°F) said extrusion being carried out with lubrication through a conical die to provide an extruded billet of substantially full density; and forging the resultant extruded billet said resultant billet being subjected to at least a first forging treatment at a temperature in the range of about 230°C (450°F) up to about 400°C (750°F), with the proviso that for maximizing strength the forging is carried out at the lower end of the forging temperature range when the extrusion is carried out at the higher end of the extrusion temperature range.

Degassing is carried out at a temperature higher than any temperature to be subsequently experienced by the alloy, and compaction is carried out at least to the extent that the porosity is isolated, and preferably to at least about 95% of full density and higher.

By incipient extrusion temperature is meant the lowest temperature at which a given alloy can be extruded on a given extrusion press at a given extrusion ratio. The extrusion ratio is at least 3:1 and may range, for example, to about 20:1 and higher.

By a conical die is meant a die in which the transition from the extrusion liner to the extrusion die is gradual. Advantageously the angle of the head of the die with the liner is less than about 60°, and preferably it is about 45°.

In a preferred embodiment of the present process the alloys contain about 1.5% up to about 2.5% lithium and about 2% up to about 4% magnesium, 0.5% to about 1.2% carbon and up to less than 1% oxygen, and the extrusion is carried out at a temperature in the range of about 230°C (450°F) to about 400°C (750°F). Advantageously the extrusion is carried out below about 370°C (700°F), preferably in the range of about 260°C (500°F) to about 360°C (675°F), and most preferably at about 260°C (500°F). For this alloy system, the forging operation (or in a multi-step forging operation the initial forging step) is carried out at a temperature of about 230°C (450°F) to about 400°C (750°F) when extrusion is carried out at about 260°C, and the forging operation (or initial forging step) is carried out at a narrow range at the lower end of the extrusion temperature range, e.g. at about 260°C (500°F) when extrusion is previously carried out at 370°C (700°F). In accordance with the present invention low density alloys of such system can be provided which are characterized by an 0.2% offset yield strength (YS) of at least 410 MPa (60 ksi), an elongation of at least 3%. In one aspect of the invention the Al-Li alloys have a density of less than 2.57 g/cm^3.

Detailed aspects of the invention

(A) Composition

The essential components of the matrix of the alloy systems of the present invention are aluminum, magnesium and lithium. In one embodiment the alloys contain silicon. The alloys are characterized in that they are dispersion strengthened and they are formed from mechanically alloyed powders. In one preferred embodiment they are prepared as forged articles. The dispersion strengthening agents comprise carbides and oxides and/or silicides.

Carbon and oxygen along with small amounts of magnesium and lithium are present as a small weight percentage of the alloy system in combination as insoluble dispersoids such as oxides and/or carbides. Other elements may be incorporated in the alloy so long as they do not interfere with the desired properties of the alloy for a particular end use. Also, a minor amount of impurities may be picked up from the charge materials or in preparing the alloy. Additional insoluble, stable dispersoids or dispersoid forming agents may be incorporated in the system, e.g., for strengthening of the alloy at elevated temperatures, so long as they do not otherwise adversely affect the alloy.

Unless otherwise specified, concentration of components is given in weight %.

The lithium level in the alloys may range, for example, from about 0.5 to about 4%, advantageously in an amount of about 1 up to about 3%, and preferably from about 1.5 or 1.6 up to about 2.5%. The lithium is introduced into the alloy system as a powder (elemental or preferably prealloyed with aluminum) thereby avoiding problems which accompany the melting of lithium in ingot metallurgy methods. Magnesium may be present, for example, in an amount of about 0.5% to about 7%. Advantageously, the magnesium level may range from above 1 up to about 5%, preferably it is about 2 up to about 4 or 4.5%. Exemplary alloys contain above 1.5 up to about 2.5% lithium and about 2 to about 4.5% magnesium.

The silicon level may range, for example, from 0 up to about 4%. In the silicon-containing alloys the silicon level may range from a small but effective amount for strength up to about 4%. Advantageously the silicon-containing alloys contain about 0.2 up to about 2%, and preferably about 0.5% to about 1.5%, and typically about 0.5 to about 1%, and the invention includes the silicon-containing alloys having the compositions set forth in claims 13, 14 and 15.

Carbon is present in the system at a level ranging from a small but effective amount for increased strength e.g. about 0.05%, up to about 5%. Typically the level of carbon ranges from about 0.05 up to about 2%, advantageously from about 0.2% up to about 1% or 1.5%, preferably about 0.5 up to about 1.2%. The carbon is generally provided by a process control agent during the formation of the mechanically alloyed powders. Preferred process control agents are methanol, stearic acid, and graphite. In general the carbon present will form carbides, e.g. with one or more of the components of the system.

Oxygen is usually present in the system, and it is usually desirable at a very low level. In general, oxygen is present in a small but effective amount for increased strength and stability, e.g., about 0.05% up to 1%, and preferably, it does not exceed about 0.4 to 0.5%.

The low oxygen content is believed to be critical. When the oxygen content is above 1% the alloy is found to have poor ductility. In alloys containing above 1.5% Li, the oxygen content preferably does not exceed about 0.5%.

The dispersoid comprises oxides and carbides present in a range of a small but effective amount for increased strength up to about 10 volume % (vol. %) or even higher. Preferably the dispersoid level is as low as possible consistent with desired strength. Typically the dispersoid level is about 1.5 to 7 vol. %. Preferably it is about 2 to 6 vol. %. The dispersoids may be present, for example, as an oxide of aluminum, lithium, or magnesium or combinations thereof. The dispersoid can be formed during the mechanical alloying step and/or later consolidation and thermomechanical processing. Possibly they may be added as such to the powder charge. Other dispersoids may be added or formed in-situ so long as they are stable in the aluminum alloy matrix at the ultimate temperature of service. Examples of dispersoids that may be present are Al_2O_3, AlOOH, Li_2O, $Li_2Al_2O_4$, $LiAlO_2$, $LiAl_5O_8$, Li_5AlO_4 and MgO. The dispersoids may be carbides, e.g. Al_4C_3. Intermetallics may also be present. In the silicon-containing alloys the dispersoid may contain silicides, e.g. Mg_2Si.

In a preferred alloy system the lithium content is about 1.5 up to about 2.5%, the magnesium content is about 2 up to about 4%, the carbon content is about 0.5 to about 2%, and the oxygen content is less than about 0.5%, and the dispersoid level is about 2 or 3 to 6 volume %. For example, the alloys may be comprised of:

Al-4Mg-1.5Li-1.2C, Al-5Mg-1Li-1.1C, Al-4Mg-1.75Li-1.1C,
Al-2Mg-2Li-1.1C, Al-2Mg-2.5Li-1.1C, Al-4Mg-2.5Li-0.7C and
Al-2Mg-2.5Li-0.7C, Al-4Mg-1.5Li-.5Si-1.1C, Al-4Mg-1.5Li-1Si-1.1C,
Al-2Mg-1.5Li-.5Si-1.1C, Al-2Mg-1.5Li-1Si-1.1C, Al-2Mg-2Li-.5Si-1.1C,
Al-2Mg-2Li-1Si-1.1C, Al-2Mg-1.75Li-1Si-0.7C, Al-4Mg-1.5Li-1Si-0.7C,
Al-4Mg-1.5Li-.5Si-2C.

(B) Alloy preparation prior to fabrication

(1) Mechanical alloying to form powders

Powder compositions treated in accordance with the present invention are all prepared by a mechanical alloying technique. This technique is a high energy milling process, which is described in the aforementioned patents incorporated herein by reference. Briefly, aluminum powder is prepared by subjecting a powder charge to dry, high energy milling in the presence of a grinding media, e.g. balls, and a process control agent, under conditions sufficient to comminute the powder particles to the charge, and through a combination of comminution and welding actions caused repeatedly by the milling, to create new, dense composite particles containing fragments of the initial powder materials intimately associated and uniformly interdispersed. Milling is done in a protective atmosphere, e.g. under an argon or nitrogen blanket, thereby facilitating oxygen control since virtually the only sources of oxygen are the starting powders and the process control agent. The process control agent is a weld-controlling amount of a carbon-contributing agent and may be, for example, graphite or a volatilizable oxygen-containing hydrocarbon such as organic acids, alcohols, heptanes, aldehydes and ethers. The formation of dispersion strengthened mechanically alloyed aluminum is given in detail in U.S. Patents No. 3,740,210 and 3,816,080, mentioned above. Suitably the powder is prepared in an attritor using a ball-to-powder weight ratio of 15:1 to 60:1. As indicated above, preferably process control agents are methanol, stearic acid, and graphite. Carbon from these organic compounds and/or graphite is incorporated in the powder and contributes to the dispersoid content.

(2) Degassing and compaction

Before the dispersion strengthened mechanically alloyed powder is consolidated it must be degassed and compacted. Degassing and compacting are effected under vacuum and generally carried out at a temperature in the range of about 480°C (895°F) up to just below incipient liquefication of the alloy. As indicated above, the degassing temperature should be higher than any subsequently experienced by the alloy. Degassing is preferably carried out, for example, at a temperature in the range of from about 480°C (900°F) up to 545°C (1015°F) and more preferably above 500°C (930°F). Pressing is carried out at a temperature in the range of about 545°C (1015°F) to about 480°C (895°F).

In a preferred embodiment the degassing and compaction are carried out by vacuum hot pressing (VHP). However, other techniques may be used. For example, the degassed powder may be upset under vacuum in an extrusion press. To enable the powder to be extruded to substantially full density, compaction should be such that the porosity is isolated, thereby avoiding internal contamination of the billet by the extrusion lubricant. This is achieved by carrying out compaction to at least 85% of full density, advantageously above 95% density, and preferably the material is compacted to over 99% of full density. Preferably the powders are compacted to 99% of full density and higher, that is, to substantially full density.

The resultant compaction products formed in the degassing and compaction step or steps are then consolidated.

(C) Fabrication

(1) Consolidation

Consolidation in the present process is carried out by extrusion. The extrusion of the material not only is necessary to insure full density in the alloy, but also to break up surface oxide on the particles. The extrusion temperature is critical and within a narrow range. The lubrication practice and the conical die-type equipment used for extrusion are also important.

The extrusion temperature is chosen so that the maximum temperature achieved in the extruder is no greater than 10°C (50°F) below the solidus temperature. Typically it will be in the range of about 230°C (450°F) and about 400°C (750°F). Advantageously, it should be carried out below about 370°C (700°F) and should not exceed about 345°C (650°F). Preferably it should be lower than about 330°C (625°F). The temperature should be high enough so that the alloy can be pushed through the die at a reasonable pressure. Typically this will be above about 230°C (450°F). It has been found that a temperature of about 260°C (500°F) for extrusion is highly advantageous. By carrying out the extrusion at about 260°C (500°F), there is the added advantage of greater flexibility in conditions which may be used during the forging operation. This flexibility decreases at the higher end of the extrusion temperature range.

The above given extrusion temperature ranges which must be used for the Al-Li-Mg are those which will maximize the strength of the alloy since strength is currently the initial screening test for the forged parts made from the aluminum-base alloys. It will be appreciated that when the strength requirements are not as rigorous the teachings of this invention can be used to trade-off strength against some other property.

The extrusion in the present process is carried out in a conical-faced die as defined above, as opposed to a shear-faced die. Lubrication is applied to the die or the compaction billet or both of them. The lubricants, which aid in the extrusion operation, must be compatible with the alloy compaction billet and the extrusion press, e.g. the liner and die. The lubricant applied to the billet further protects the billet from the lubricant applied to the extrusion press.

Properly formulated lubricants for specific metals are well known in the art. Such lubricants take into account, for example, requirements to prevent corrosion and to make duration of contact of the billet with the extrusion press less critical. Examples of lubricants for the billets are kerosene, mineral oil, fat emulsion and mineral oil containing sulfurized fatty oils. Fillers such as chalk, sulfur and graphite may be added. An example of a lubricant for an extrusion press is colloidal graphite carried in oil or water, molydisulfide, boron sulfide, and boron nitride.

The extruded billets are then in condition to be forged. If necessary the billets may be machined to remove surface imperfections.

(2) Forging

In general forged aluminum alloys of the present invention will benefit from forging temperatures being as low as possible consistent with the alloy composition and equipment. Forging may be carried out as a single or multi-step operation. In multi-step forging the temperature control applies to the initial forging or blocking-type step. As in the extrusion step, it is believed that for high strength the aluminum alloys of this invention should be forged at a temperature below one where a decrease in strength will occur. In the Al-Mg-Li alloys system forging should be carried out below about 400°C (750°F), and preferably less than 370°C) (700°F), e.g. in the range of 230°C (450°F) to about 345°C (650°F), typically about 260°C (500°F). Despite the fact that forgeability may increase with temperature, the higher forging temperatures have now been found to have an adverse effect on strength. In a multi-step forging operation it has been found that it is the initial step that is critical. In subsequent forging steps of a multi-step operation after the initial forging step the temperature range for forging may be above that recommended for this process.

As noted above, while it is known in the art that conditions of forging aluminum alloys will vary with composition, it was surprising that the forging conditions—particularly the temperature—at which the alloys could be forged is related to the temperature at which the alloy is consolidated, and in particular extruded.

(3) Age hardening

A heat treatment may be carried out, if desired, on alloy systems susceptible to age hardening. In alloys having age hardenable components additional strength may be gained, but this may be with the loss of other properties, e.g. corrosion resistance. It is noted that alloys of this invention containing silicon can be age hardened without significant loss of corrosion resistance. It is a particular advantage of the present invention that low density aluminum alloys can be made with high strength, e.g. over 410 MPa (60 ksi) in the forged condition without having to resort to precipitation hardening treatments which might result in alloys which have less attractive properties other than strength.

It is noted that in conversion from °F to °C, the temperatures were rounded off, as were the conversion from ksi to MPa and inches to centimeters. Also alloy compositions are nominal. With respect to conditions, for commercial production it is not practical or realistic to impose or require conditions to the extent possible in a reasearch laboratory facility. Temperatures may stray, for example, 50°F of the target. Thus, having a wider window for processing conditions adds to the practical value of the process.

This invention is further described in, but not limited by, the examples given below. In all the examples the alloys are prepared from dispersion strengthened alloys comprising aluminum, magnesium, lithium, carbon and oxygen, prepared by a mechanical alloying technique. In Example 8, silicon is present in the alloy.

Example 1

This example illustrates the processing conditions used to prepare forged Al-Mg-Li dispersion strengthened mechanically alloyed composed of aluminum, magnesium, lithium, carbon and oxygen containing about 1.1—1.2% carbon and less than 1% oxygen.

Mechanically alloyed powders are prepared having the nominal magnesium and lithium contents given in Table I. The powders are vacuum hot pressed (VHP) to from 27.9 cm (11 in) diameter degassed compaction billets.

The compaction billets are then extruded at temperatures of about 260 and 370°C (500 and 700°F) at ram speeds of 45.7 and 25.4 cm (18 and 10 in.), depending on the extrusion temperature. All billets are sandblasted and coated with Fel-Pro C-300 (a molybdenum disulfide air drying product of Fel-Pro Inc.) prior to heat-up for extrusion, and the extrusion liner coated with resin and swathed with the lubricant LUBE-A-TUBE hot extrusion 230A (a graphite in heavy oil product of G. Whitfield Richards Co.). All the extrusions pushed successfully except for some surface tearing at 700°F. Alloy compositions and extrusion conditions, are given in Table I.

TABLE I

Alloy type	Mg	Li	Temp. °C	Temp. (°F)	Ram speed cm	Ram speed (in.)/min
A	4	1.5	260	(500)	45.7	(18)
B	4	1.75	260	(500)	45.7	(18)
C	2	2	260	(500)	45.7	(18)
D	4	1.5	370	(700)	25.4	(10)
E	4	1.75	370	(700)	25.4	(10)
F	2	2	370	(700)	25.4	(10)

Eight 8.75 cm (3.5 in.) lengths of material from each extrusion are cut for forging trials. The trial consisted of using flat dies to upset the preforms parallel to the billet axis. Forgings are performed at nominal temperatures 260°C (500°F) and 400°C (750°F) at ram speeds of 50 cm (20 in.)/min and 5 cm (2 in.)/min to final heights of 5 cm (1 in.) and 2.5 cm (0.5 in.) and strains of −0.67 and −0.83, respectively. The top and bottom forging platens are induction heated to the same temperatures as the soak temperatures and were lubricated with White and Bagley 2965 graphite base lubricant just before upsetting. Extrusion and forging data are summarized in Table II. In general the 260°C (500°F) extrusions forged better than the 370°C (700°F) extrusions, and this is believed to be due to the better extruded surface quality of the 500°F extrusions. Surface grinding prior to forging should improve forgeability. The 2Mg-2Li alloy extruded at 370°C (700°F) had the poorest forgeability. For all of the other alloys a forging condition can be found that does not cause edge cracking. In general, the alloys extruded at 260°C (500°F) have a higher hardness than material extruded at 370°C (700°F). The 4Mg-1.5Li composition extruded at 260°C (500°F) did not soften under any of the forging conditions tried. The 2Mg-2Li alloys soften after forging at about 400°C (750°F).

TABLE II

Alloy ID	Extrusion Soak T °C	Extrusion Ram Sp (m/min)	Forging Soak T °C	Forging Billet T °C	Forging Die T °C	Forging Ram Sp cm/min	Forging Final height mm	Forging appear.*	Hardness R_B
4Mg-1.5Li	260	25	As Ext						84
1			260	—	260	50	24.1	3	87
2			260	—	260	50	13.5	2	87
3			260	219	260	5	24.9	2	86
4			260	221	260	5	13.7	2	86
5			400	360	392	50	25.4	2	85
6			400	—	390	50	13.2	3	84
7			400	366	391	5	24.4	3	83
8			400	366	397	5	13.3	3	82
4Mg-1.75Li	260	45.7	As Ext						86
1			260	227	258	50	20.3	1	88
2			260	227	258	50	13.2	1	87
3			260	—	258	5	25.4	2	85
4			260	—	257	5	13.5	3	86
5			400	360	400	50	24.5	3	85
6			400	360	404	50	13.7	2	86
7			400	360	404	5	23.9	2	84
8			400	354	404	5	12.9	3	84
2Mg-2Li.	260	45.7	As Ext						85
1			260	227	256	50	24.5	3	84
2			260	—	256	50	14.7	2	85
3			260	227	258	5	25.4	3	82
4			260	—	257	5	14.2	2	85
5			400	360	404	50	23.7	3	80
6			400	—	404	50	12.9	3	81
7			400	360	400	5	24.4	3	80
8			400	366	402	5	12.7	1	80
4Mg-1.5Li	370	25.4	As Ext						83
1			260	250	257	50	24.9	2	85
2			260	238	268	50	13.5	2	86
3			260	232	302	5	25.4	2	85
4			260	232	267	5	14.3	2	87
5			400	—	402	50	24.9	3	83
6			400	360	402	50	13.5	2	82
7			400	—	402	5	26.2	2	82
8			400	354	402	5	12.7	2	82
4Mg-1.75Li	370	25	As Ext						80
1			260	—	268	50	25.6	3	83
2			260	238	268	50	14.3	1	84
3			260	232	268	5	26.0	3	84
4			260	227	267	5	13.1	1	85
5			400	370	399	50	25.2	3	82
6			400	—	394	50	13.6	2	83
7			400	370	396	5	24.9	3	82
8			400	370	394	5	14.0	1	81

TABLE II (Contd.)

Alloy ID	Extrusion Soak T °C	Extrusion Ram Sp (m/min)	Forging Soak T °C	Forging Billet T °C	Forging Die T °C	Forging Ram Sp cm/min	Forging Final height mm	Forging appear.*	Hardness ^{R}B
2Mg-2Li	370	25	As Ext						80
1			260	—	263	50	24.8	2	80
2			260	227	262	50	14.6	1	82
3			260	227	263	5	26.0	2	79
4			260	—	263	5	15.2	2	80
5			400	366	394	50	25.6	2	77
6			400	360	396	50	10.7	2	79
7			400	366	399	5	23.6	2	77
8			400	—	396	5	11.4	1	77

In the Table: 500°F=260°C; 700°F=370°C; 1 inch=2.5 cm
*1=poor 2=good 3=excellent

Example 2

This example concerns the aging response of extruded and forged alloys described in Example 1.

To streamline the aging study two forgings from each alloy of Example 1 are selected. One of each type is forged at 260°C (500°F) at 50.8 cm (20 in)/min to 2.54 cm (1 in.) final height, and the other is forged at 400°C (750°F) at 5.08 cm (2 in)/min to 1.27 cm (0.5 in.) final height. These are the two extreme forging conditions. The compositions 4Mg-1.75Li and 2Mg-2Li show hardness increases at about 125°C (255°F) after solution treating at about 480°C (900°F), and from the hardness data it can be predicted that both these alloys can be aged to achieve the desired target YS in the forged condition of about 410 to 450 MPa (60—65 ksi). The "as-extruded" alloys appear to age slower than the forged stock. It is assumed that the additional working of forging speeds the aging kinetics.

Example 3

This example illustrates forgeability of alloys in a cruciform forging test. Cruciform forging trials are performed on extruded billets of the alloy type shown in Example 1, all alloys being extruded with lubrication through a 3.875 in. dia. conical die in an 8:1 extrusion ratio.

The "cruciform"-type forging is shown in plan view in Figure 1. The center portion of the forging is a cruciform formed from two perpendicular raised ribs. The rib portion of the forging is thicker than the base portion. The forging in the tests is made in a two-step operation: (1) blocking extrusion preform on flat dies; (2) forging blocker into raised rib "cruciform", the blocking extrusion corresponding to an initial forging step in a forging operation. The 5 in.×3.675 in. dia. extruded preforms are blocked in the extrusion direction to 2.5 in. high. The blockers are "squared-up" by repeatedly pressing perpendicular to the extrusion direction forming an octahedron approximately 2.5 in. high with a 5.25 in. diagonal. The flat dies are held at about 315°C (600°F±25°F) and no lubricant is used. Extruded surface roughness produced cracking during the blocker operations. Preforms with gross surface defects had been ground prior to blocking and had less tendency to crack than did as-extruded surfaces. Blocker cracking also occurred due to high forging speeds, necessitating blocking speed to be lowered from 50.8—63.5 cm (20—25 in)/min to 12.7 cm (5 in)/min.

All cruciforms are final forged at 370°C (700°F), at a constant die temperature of 315°C (600°F), press rate of 12.7 cm (5 in)/min, utilizing full press tonnage of 1500 tons. The die was lubricated with a 1 to 3 mixture of Withrow-A-Paste (a lubricant of a graphite type product of Arthur C. Withrow Co.) and mineral oil. Cruciforms of acceptable appearance were forged of each material. Most problems in blocker cracking appear to be due to surface imperfections. Some cracking in the cruciform was related to slight cracking in the blocker. Recorded in Table III are extrusion temperature, blocker temperature, forging temperature and "as-forged" hardness for various aluminum alloys of this invention.

TABLE III

Alloy type	Ext. temp. °C	Block temp. °C	Forged temp. °C	As-forged hardness, R_B
4Mg-1.5Li	260	260	370	79
	260	370	370	79
4Mg-1.5Li	370	260	370	80
	370	370	370	77
4Mg-1.75Li	260	260	370	80
	260	370	370	81
2Mg-2Li	260	260	370	80
	260	370	370	78
4Mg-1.75Li	370	260	370	79
	370	370	370	80
2Mg-2Li	370	370	370	71

All of the 4Mg-1.5Li alloys have "as-forged" hardnesses greater than 78 R_B except for the alloy extruded, blocked and forged at 370°C (700°F) and it was ascertained that in these forgings a hardness of 78 R_B or better correlates to a YS of 410 MPa (60 ksi) or better. Accordingly, the inference can be made that alloys extruded at 370°C (700°F) and blocked at 260°C (500°F) would meet the target forged YS requirement of 410 MPa (60 ksi).

The "as-forged" hardness of compositions 4Mg-1.75Li and 2Mg-2Li can be improved by aging treatments. The 2Mg-2Li ages slower than the 4Mg-1.75Li alloy.

Example 4

This example illustrates the tensile properties of various Al-Mg-Li alloys of this invention in the extruded, blocked, forged and/or aged conditions of cruciform-type forgings tested at two different sites.

Tensile properties of various Al-Mg-Li alloys, essentially of the type described in Example 1, in the extruded, blocked, forged and/or aged conditions are given in Table IV. The blocked and forged conditions, viz. "Block Temp" and "Forge Temp", respectively, refer to the temperatures of the two steps given in Example 3 for forming the cruciform-type forging. All tests are carried out in the rib portion of the cruciform. The key to the temper of the tensile sample (TPR) is: 1=as-extruded, 2=as-blocked, 3="as-forged", 4=forged and solution treated at 480°C (900°F) for 2 hours and water quenched (WQ) then aged at 125°C (255°F) for 2 hours, and 5=solution treated as in TPR 4 but aged at 150°C (300°F) for 24 hours; Mod=Young's Modulus. Tensile properties obtained on different test equipment for a duplicate set of forged cruciform forgings on either the base (B) or rib (R) portion in various tempers and orientations are given in Table V.

Reference to Table IV shows:

The non-heat treatable Al-4Mg-1.5Li alloy extruded at 260°C (500°F), blocked at 260°C (500°F) and forged at 370°C (700°F), has a 444 MPa (64.4 ksi) YS, 518 MPa (75.2 ksi) UTS (ultimate tensile strength) and 11% El (elongation to failure). The "as-extruded", YS 477 MPa (69.3 ksi), is higher than the forged material, while the "as-extruded" ductility, 7% El, is lower. The strengths of the 260°C (500°F) blocker are less than the forged strengths. The 4Mg-1.5Li alloy extruded at 370°C (700°F), blocked at 260°C (500°F) and forged at 370°C (700°F), has a YS=424 MPa (61.5 ksi).

For all conditions tested the 4Mg-1.75Li alloy extruded at 260°C (500°F) has a YS of greater than 410 MPa (60 ksi). Solution treating and aging raises the YS to approximately 572 MPa (83 ksi) with just a slight decrease in ductility from the "as-forged" condition. The 370°C (700°F) extrusion blocked at 260°C (500°F) can also be aged (TPR=4) to 551 MPa (80 ksi) yield strength. For the same aging treatment the 370°C (700°F) extrusion blocked at 370°C (700°F) has a 537 MPa (78 ksi) YS.

The 2Mg-2Li alloy extruded at either 260°C (500°F) or 370°C (700°F) produce forgings that have lower as-forged strength than the alloys containing 4% magnesium. Aging at (TPR=5) increases the YS to 530 MPa (77 ksi) and 502 MPa (73 ksi), respectively, for the 260°C (500°F) and 370°C (700°F) extrusions blocked at 370°C (700°F).

The tests demonstrate the importance of extrusion temperature in processing mechanically alloyed Al-Mg-Li alloys to maximize strength in the final forging. Blocker temperature has a secondary effect on forged strength with the lower blocker temperature leading to high strengths. Final forging temperature appears to be of less importance as long as the material has been extruded and blocked at relatively low temperatures.

A comparison of data for "as-forged" longitudinal samples in Tables IV and V shows the consistency of results in different testing equipment.

TABLE IV

Ext. temp. °C	Blocker temp. °C	Block forge °C	TPR	Orient.	Tensile properties YS MPa	UTS MPa	El. %	RA %	Mod 10^3 MPa
					Al-4Mg-1.5Li				
260	—	—	1	L	478	516	7	12.5	69.6
260	—	—	1	T	468	543	0	1	96.5
260	260	—	2	L	425	508	3.5	8.5	77.2
260	260	370	3	L	444	518	11	22	69.6
260	370	—	2	L	413	498	7.5	12	74.5
260	370	370	3	L	405	495	—	19	76.5
					Al-4Mg-1.5Li				
370	—	—	1	L	454	504	6	11	79.3
370	—	—	1	T	427	505	2	4.5	77.2
370	260	—	2	L	398	519	3.5	9.5	70.3
370	260	370	3	L	424	514	—	9.5	69.0
370	370	—	2	L	380	492	7.5	12.5	69.6
370	370	370	3	L	383	487	—	17.0	72.4
					Al-4Mg-1.75Li				
260	—	—	1	L	523	662	0.5	1.0	78.6
260	—	—	1	T	454	547	0	0.5	77.2
260	260	—	2	L	431	553	0	1.5	73.8
260	260	370	3	L	438	513	—	9.0	76.5
260	260	370	4	L	570	603	—	8.25	72.4
260	370	—	2	L	401	509	2.0	7.0	69.0
260	370	370	3	L	425	521	4.5	4.0	80.0
260	370	370	4	L	569	607	3.5	11	72.4
					Al-2Mg-2Li				
260	—	—	1	L	507	628	0.5	2.5	80.0
260	—	—	1	T	415	490	0	1.0	80.7
260	260	—	2	L	371	466	0	1.5	71.7
260	260	370	3	L	390	480	4.5	11.0	67.7
260	260	370	5	L	—	—	—	—	—
260	370	—	1	L	371	466	0	1.5	71.7
260	370	370	3	L	390	480	4.5	11.0	67.7
260	370	370	5	L	533	583	2	4.3	73.1
					Al-4Mg-1.75Li				
370	—	—	1	L	441	484	2.0	4.0	76.6
370	—	—	1	T	427	503	1.0	0.5	77.9
370	260	—	2	L	385	499	2.0	9.5	71.7
370	260	370	3	L	402	498	6.5	11.0	73.9
370	260	370	4	L	552	591	3.5	10	71.7
370	370	370	3	L	366	504	6.5	10.5	74.5
370	370	370	3	L	387	492	6.5	10.0	77.2
370	370	370	4	L	538	587	3.5	9	71.1
370	370	370	4	L	521	582	7.0	10.1	77.2
					Al-2Mg-2Li				
370	—	—	1	L	453	527	1	4.5	80.0
370	—	—	1	T	391	473	1	0.5	77.9
370	260	—	2	L	333	443	2	7.0	63.4
370	260	370	3	—	—	—	—	—	—
370	260	370	3	—	—	—	—	—	—
370	370	—	2	L	336	444	2	4.5	63.4
370	370	370	3	L	332	439	9	15	77.9
370	370	370	5	L	504	552	3.5	4.0	76.5

TABLE V

Alloy (extrusion & blocker conditions)	Test orient.	Temper*	YS MPa	UTS MPa	% El
Al-4Mg-1.5Li (260°C Extrusion) (260°C Blocker)	T R	F	447	518	6.7
	T R	ST+A	453	518	8.1
	T B	ST+A	461	524	9.5
	T B	ST	448	530	8.1
	L R	ST+A	478	535	12.3
	L R	ST+A	475	538	10.9
	L R	F	478	538	8.1
	L R	F	486	536	8.1
	T B	ST+A	447	511	10.2
Al-4Mg-1.5Li (260°C Extrusion) (370°C Blocker)	T R	F	419	502	9.5
	T R	ST+A	447	511	9.5
	T B	ST+A	422	502	12.3
	T B	ST	433	505	12.3
	L R	ST+A	430	502	15.1
	L R	ST+A	416	502	12.3
	L R	F	414	499	10.9
	L R	F	414	494	10.9
	T B	ST+A	419	499	10.2
Al-4Mg-1.5Li (370°C Extrusion) (260°C Blocker)	T R	F	416	517	8.1
	T R	ST+A	422	513	6.7
	T B	ST+A	422	513	8.1
	T B	ST	416	507	8.1
	L R	ST+A	436	516	10.9
	L R	ST+A	437	519	12.3
	L R	F	439	519	6.7
	L R	F	436	516	8.1
	T B	ST+A	419	505	6.7
Al-4Mg-1.5Li (370°C Extrusion) (370°C Blocker)	T R	F	406	502	9.5
	T R	ST+A	433	519	12.3
	T B	ST+A	422	511	9.5
	T B	ST	419	505	8.1
	L R	ST+A	428	516	11.6
	L R	ST+A	414	507	9.5
	L R	F	409	505	8.1
	L R	F	406	507	10.9
	T B	ST+A	414	507	12.3
Al-4Mg-1.75Li (260°C Extrusion) (260°C Blocker)	T R	F	425	518	6.7
	T R	ST+A	599	626	5.3
	T B	ST+A	612	634	6.7
	T B	ST	479	536	6.7
	L R	ST+A	625	646	6.7
	L R	ST+A	627	648	5.3
	L R	F	464	521	3.9
	L R	F	472	546	3.9
	T B	ST+A	599	615	5.3
Al-4Mg-1.75Li (260°C Extrusion) (370°C Blocker)	T R	F	450	521	5.3
	T R	ST+A	609	643	3.9
	T B	ST+A	599	632	3.9
	T B	ST	453	524	8.1
	L R	ST+A	615	640	6.7
	L R	ST+A	608	630	5.3
	L R	F	436	527	6.7
	L R	F	436	478	3.2
	T B	ST+A	589	612	2.5

TABLE V (Cont'd)

Alloy (extrusion & blocker conditions	Test orient.	Temper*	YS MPa	UTS MPa	% El
Al-4Mg-1.75Li	T R	F	414	502	8.1
(370°C Extrusion)	T R	ST+A	576	609	3.9
(260°C Blocker)	T B	ST+A	588	619	5.3
	T B	ST	439	524	10.9
	L R	ST+A	588	615	5.3
	L R	ST+A	588	615	3.9
	L R	F	425	502	8.1
Al-4Mg-1.75Li	T R	F	416	502	3.9
(370°C Extrusion)	T R	ST+A	574	615	6.7
(370°C Blocker)	T B	ST+A	564	598	3.9
	T B	ST	422	511	10.9
	L R	ST+A	574	607	6.0
	L R	ST+A	571	599	6.7
	L R	F	406	511	9.5
	L R	F	406	513	9.5
	T B	ST+A	579	602	3.9
Al-2Mg-2Li	T R	F	411	511	5.3
(260°C Extrusion)	T R	ST+A	564	612	3.9
(260°C Blocker)	T B	ST+A	—	529	—
	T B	ST	401	470	2.5
	L R	ST+A	583	626	3.9
	L R	ST+A	566	615	2.5
	L R	F	414	502	3.2
	L R	F	400	502	2.5
	T B	ST+A	571	612	2.5
Al-2Mg-2Li	T R	F	400	488	3.9
(260°C Extrusion)	T R	ST+A	555	596	1.8
(370°C Blocker)	T B	ST+A	—	560	—
	T B	ST	400	480	3.9
	L R	ST+A	569	602	6.7
	L R	ST+A	552	595	2.5
	L R	F	373	464	3.8
	L R	F	370	475	2.5
	T B	ST+A	552	579	2.5
Al-2Mg-2Li	T R	F	348	450	8.1
(370°C Extrusion)	T R	ST+A	518	555	6.7
(370°C Blocker)	T B	ST+A	513	560	5.3
	T B	ST	356	448	8.1
	L R	ST+A	527	560	3.2
	L R	ST+A	505	546	5.3
	L R	F	345	447	10.9
	L R	F	342	442	6.7
	T B	ST+A	516	546	3.9

*Tempers: F=As-Forged—370°C (700°F)
ST=Solution Treated—495°C (925°F)/1hr/WQ
A=Aged—125°C (255°F)/10hr/AC

Example 5

This example illustrates the tensile properties of the dispersion strengthened alloys of this invention in "Hook"-type forging samples. All materials were prepared as extruded billets essentially as shown in Example 1.

The "Hook" forging die set used in the tests consists of a high deformation 1st blocker die, a 2nd blocker die which raises the ribs of the forging and a finish die which produces minimal deformation but achieves final tolerances in the part. For this test to avoid the time and expense of using the finish die, evaluation of the forgings was made after the 2nd blocker, i.e. at an intermediate forging step.

Figure 2 shows a plan drawing of the finished "Hook"-type forging. Tensile specimens were heat treated in sets of two, representing the longitudinal (L) and the short transverse (ST) orientations.

Table VI shows properties in two directions for forgings in two conditions: F (as-forged) and T4 (solution treated and naturally aged) for an alloy system containing 4Mg-1.5Li. The data show no significant difference in results between the F and T4 conditions. The best properties exhibited in Table VI are for the alloy of test 1, i.e. in the as-forged condition processed at 260°C (500°F) extrusion and first blocker temperatures. The data confirm that strength is primarily controlled by extrusion temperature and secondarily by blocker temperature.

TABLE VI

Ext. temp. (°C)	1st Blocker temp. (°C)	2nd Blocker temp. (°C)	Orient.	Temper	YS MPa	UTS MPa	El %	RA %
260	260	320	L	F	462	525	13	25
260	260	320	ST	F	430	495	11	15
260	260	320	L	T4	458	524	14	23
260	260	320	ST	T4	428	495	7	11
260	357	320	L	F	453	511	14	26
260	357	320	ST	F	406	490	10	20
260	357	320	L	T4	443	512	13	23
260	357	320	ST	T4	415	495	11	21
370	260	320	L	F	411	502	12	18
370	260	320	ST	F	407	495	9	12
370	260	320	L	T4	410	501	13	20
370	260	320	ST	T4	413	493	7	14
370	357	320	L	F	413	483	14	23
370	357	320	ST	F	376	471	11	18
370	357	320	L	T4	390	484	14	22
370	357	320	ST	T4	369	463	12	21

Similar tests carried out on alloys containing 4Mg-1.75Li and 2Mg-2Li in blocked forgings showed that the Li level affected both the strength and age hardening aspects of the alloys markedly.

A comparison with results on "cruciform" forgings shows that there is essentially the same trend in the alloy properties resulting from the processing conditions.

Example 6

This example illustrates the effect of normal forging practice on the tensile properties of a forged sample of an alloy of the type Al-4Mg-1.5Li. An extruded billet is prepared from a vacuum hot pressed compaction billet as described in Example 1. The compaction billet was extruded from 27.9 cm (11 in.) to 9.53 cm (3-3/4 in.) diameter rod at temperatures of 650—700°F through a shear-faced die at an extrusion ram speed of 0.1 in/sec. and a breakthrough pressure of 1100—1600 tons. The extrusion liner was lubricated but not the billets. A "Hook" forging was made at a temperature of 420°C (788°F) in the first blocker and 488°C (838°F) in the second blocker. Tensile tests on various locations on the specimen showed it to have in the as-forged condition the average properties: YS of 368 MPA (52.7 ksi), UTS of 470 MPa (68.3 ksi), El of 14.5% and RA of 19.7%. In the solution treated condition of 1 hour at 480°C (900°F)/glycol quench condition the average properties are: YS of 352 MPa (51.5 ksi), UTS of 466 MPa (67.6 ksi), El of 14% and the RA of 19.9%. The method of this example is not effective for achieving the maximum strength potential of the alloy.

Example 7

This example illustrates the effect of normal forging practice on the tensile properties of a cruciform forging. An extruded billet of an alloy of the 4Mg-1.5Li-type is prepared as described in Example 6. The first blocker temperature of the cruciform forging is carried out at 370°C (700°F). A lubricant, a Withrow A Paste-mineral oil mixture, is used in the finish forging which is carried out at various temperatures. Finish forging temperatures and tensile properties of the finish cruciform forgings in the longitudinal and transverse directions are shown in TABLE VII. The method of this example is not effective for achieving maximum strength potential of the alloy.

TABLE VII

Direction	Forging temp. (°C)	YS MPa	UTS MPa	El (%)	RA (%)
Longitudinal	315	363	470	12	15
	315	353	457	12	20
	345	362	467	11	16
	345	357	465	11	18
	370	361	460	12	17
	370	359	454	11	19
	400	358	458	11	16
	400	356	460	13	16
	425	354	458	13	17
	425	352	453	11	16
Short transverse	315	344	433	5	6
	315	354	450	5	3
	315	347	398	2	5
	315	366	432	2	7
	370	344	449	11	13
	400	344	441	6	10
	425	344	453	11	11

Example 8 .

This example illustrates dispersion strengthend low density alloys of this invention composed of aluminum, lithium, magnesium, silicon, carbon and oxygen, and containing about 1.1 to 1.2% carbon and less than 1% oxygen.

Mechanically alloyed powders are prepared having the nominal magnesium, lithium and silicon contents given in Table VIII. The powders are vacuum hot pressed to compaction billets and extruded essentially as described in Example 1, except that all extruded billets are prepared at 260°C (500°F) and at ram speeds of 25.4 cm (10 in)/min. Extruded billets are forged at 260°C (500°F) to form "Hook"-type forgings essentially as described in Example 5. An age hardening treatment is applied to the forged product consisting of a solution treatment at a temperature of about 520°C (970°F), water quenching, and aging at about 145° to 175°C (300° to 340°F) for up to 18 hours.

The silicon-containing alloys of this invention in the forged, age hardened condition have high strength, with advantageous preservation of corrosion resistant properties in the alloy. It is believed that the increased strength is due to the precipitation of a silicide such as Mg_2Si and/or lithium silicide.

TABLE VIII

Alloy type	Mg	Li	Si
G	4	1.5	.5
H	4	1.5	1.0
I	2	1.5	.5
J	2	1.5	1.0
K	2	2	.5
L	2	2	1.0

Claims

1. A method for obtaining a forged product composed of a dispersion strengthened, low density aluminum-base alloy, said alloy containing, by weight, from 0.5 to 4% lithium, 0.5 to 7% magnesium, 0 to 4% silicon, a small but effective amount for increased strength up to 5% carbon, a small but effective amount for increased stability and strength up to 1% oxygen, the balance, apart from impurities, being aluminum, said alloy having a dispersoid content of a small but effective amount for increased strength and stability up to 10% by volume and being derived from a powder of said alloy prepared by a mechanical alloying process, said method being comprised of a sequence of steps comprising: degassing and compacting said powder under vacuum to obtain a compaction billet having a density sufficiently high to obtain an extruded billet of substantially full density; extruding the resultant compaction billet at a

temperature in the range of above the incipient extrusion temperature up to about 400°C (750°F), said extrusion being carried out with lubrication through a conical die to provide an extruded billet of substantially full density; and forging the resultant extruded billet said resultant billet being subjected to at least a first forging treatment at a temperature in the range of about 230°C (450°F) up to about 400°C (750°F), with the proviso that for maximizing strength the forging is carried out at the lower end of the forging temperature range when the extrusion is carried out at the higher end of the extrusion temperature range.

2. A method according to claim 1, wherein the degassing and compacting steps are carried out by vacuum hot pressing the powder.

3. A method according to claim 1 or claim 2, wherein degassing and compacting are carried out at a temperature of 480°C (900°F) to 545°C (1015°F).

4. A method according to any preceding claim, wherein the extrusion is carried out at a temperature of at least 230°C (450°F).

5. A method according to claim 4, wherein extrusion is carried out at a temperature of about 260°C (500°F) and said forging is carried out at a temperature in the range of about 260°C (500°F) up to about 370°C (700°F).

6. A method according to claim 4, wherein extrusion is carried out at a temperature of about 370°C (700°F) and said forging step is carried out at a temperature of about 260°C (500°F).

7. A method according to any preceding claim, wherein extrusion of the compaction billet is carried out at an extrusion ratio of at least 3:1.

8. A method according to any preceding claim, wherein said forged alloy is subjected to an aging treatment.

9. A method according to any preceding claim, wherein said dispersion strengthened alloy contains, by weight, 1.5 to 2.5% lithium, 2 to 4% magnesium and 0.5 to 2% carbon and less than 1% oxygen, and the dispersoid content is from 3 to 6% by volume and said alloy in the forged condition has a yield strength of at least about 410 MPa (60 ksi) and elongation of at least 3%.

10. A method according to any preceding claim, wherein the dispersion strengthened alloy contains silicon.

11. A method according to claim 1 wherein said dispersion strengthened alloy has a magnesium content of 2 to 4.5%, a lithium content of 1 to 3%, a carbon content not exceeding 1.2% and an oxygen content not exceeding 1%.

12. A method according to claim 11 wherein said dispersion strengthened alloy has a carbon content of 0.5 to 1.2% and an oxygen content of 0.05 to 0.5%.

13. A dispersion strengthened, mechanically alloyed aluminum-base alloy consisting of 0.5 to 4% lithium, 0.5 to 7% magnesium, 0.2 to 4% silicon, a small but effective amount for increased strength up to 5% carbon, a small but effective amount for increased stability and strength up to 1% oxygen, the balance, apart from impurities, being aluminum, and having a dispersoid content of a small but effective amount for increased stability and strength up to 10% by volume.

14. An alloy according to claim 13, wherein the silicon content does not exceed 2%.

15. An alloy according to claim 12, wherein the silicon content is from 0.5 to 1.5%.

16. An alloy according to any one of claims 13 to 15, wherein the carbon content does not exceed 2%.

Patentansprüche

1. Verfahren zur Herstellung eines geschmiedeten Produktes, bestehend aus einer dispersionsgehärteten Legierung auf Aluminiumbasis mit geringer Dichte, wobei diese Legierung bezogen auf das Gewicht enthält: 0,5 bis 4% Lithium, 0,5 bis 7% Magnesium, 0 bis 4% Silizium, eine geringe, jedoch in bezug auf erhöhte Festigkeit wirksame Menge Kohlenstoff bis zu 5%, eine geringe, jedoch in bezug auf erhöhte Stabilität und Festigkeit wirksame Menge Sauerstoff bis zu 1%, wobei der Rest, abgesehen von Verunreinigungen, Aluminium ist, wobei diese Legierung eine geringe, jedoch in bezug auf erhöhte Festigkeit und Stabilität wirksame Menge Dispersoid bis zu 10 Vol.% enthält und mit Hilfe eines mechanischen Legierungsvorganges aus einem Pulver dieser Legierung hergestellt wird, wobei dieses Verfahren eine Folge von Schritten umfaßt: Entgasen und Pressen dieses Pulvers unter Vakuum zur Herstellung einer verdichteten Tablette mit einer Dichte, die ausreichend hoch ist für die Herstellung einer stranggepreßten Tablette mit im wesentlichen voller Dichte; Strangpressen der entstehenden verdichteten Tablette bei einer Temperatur im Bereich über der anfänglichen Strangpreßtemperatur bis zu ungefähr 400°C (750°F), wobei das Strangpressen mit Schmierung durch ein konisches Werkzeug erfolgt, wobei man eine stranggepreßte Tablette mit im wesentlichen voller Dichte erhält; und Schmieden der entstehenden stranggepreßten Tablette, wobei diese Tablette mindestens einer ersten Schmiedebehandlung bei einer Temperatur im Bereich von ungefähr 230°C (450°F) bis zu ungefähr 400°C (750°F) unterworfen wird, unter der Bedingung, daß zum Maximieren der Festigkeit das Schmieden am unteren Ende des Schmiedetemperaturbereiches erfolgt, wenn das Strangpressen am oberen Ende des Strangpreßtemperaturbereiches erfolgt.

2. Verfahren nach Anspruch 1, dadurch gekennzeichnet, daß das Entgasen und Pressen durch Vakuum-Warmpressen des Pulvers erfolgt.

3. Verfahren nach Anspruch 1 oder 2, dadurch gekennzeichnet, daß das Entgasen und Pressen bei einer Temperatur von 480°C (900°F) bis 545°C (1015°F) erfolgt.

4. Verfahren nach einem der vorhergehenden Ansprüche, dadurch gekennzeichnet, daß das Strangpressen bei einer Temperatur von mindestens 230°C (450°F) erfolgt.

5. Verfahren nach Anspruch 4, dadurch gekennzeichnet, daß das Strangpressen bei einer Temperatur von ungefähr 260°C (500°F) und das Schmieden bei einer Temperatur im Bereich von ungefähr 260°C (500°F) bis ungefähr 370°C (700°F) erfolgt.

6. Verfahren nach Anspruch 4, dadurch gekennzeichnet, daß das Strangpressen bei einer Temperatur von ungefähr 370°C (700°F) und das Schmieden bei einer Temperatur von ungefähr 260°C (500°F) erfolgt.

7. Verfahren nach einem der vorhergehenden Ansprüche, dadurch gekennzeichnet, daß das Strangpressen der verdichteten Tablette mit einem Formänderungsverhältnis von mindestens 3:1 erfolgt.

8. Verfahren nach einem der vorhergehenden Ansprüche, dadurch gekennzeichnet, daß die geschmiedete Legierung einer Vergütungsbehandlung unterzogen wird.

9. Verfahren nach einem der vorhergehenden Ansprüche, dadurch gekennzeichnet, daß die dispersionsgehärtete Legierung 1,5 bis 2,5% Lithium, 2 bis 4% Magnesium und 0,5 bis 2% Kohlenstoff und weniger als 1% Sauerstoff bezogen auf das Gewicht enthält, und der Dispersoidgehalt 3 bis 6 Vol.% beträgt, und diese Legierung im geschmiedeten Zustand eine Streckgrenze von mindestens ungefähr 410 MPa (60 ksi) und eine Dehnung von mindestens 3% hat.

10. Verfahren nach einem der vorhergehenden Ansprüche, dadurch gekennzeichnet, daß die dispersionsgehärtete Legierung Silizium enthält.

11. Verfahren nach Anspruch 1, dadurch gekennzeichnet, daß die dispersionsgehärtete Legierung einen Magnesiumgehalt von 2 bis 4,5%, einen Lithiumgehalt von 1 bis 3%, einen Kohlenstoffgehalt von nicht mehr als 1,2% und einen Sauerstoffgehalt von nicht mehr als 1% hat.

12. Verfahren nach Anspruch 11, dadurch gekennzeichnet, daß die dispersionsgehärtete Legierung einen Kohlenstoffgehalt von 0,5 bis 1,2% und einen Sauerstoffgehalt von 0,05 bis 0,5% hat.

13. Dispersionsgehärtete, mechanisch legierte Legierung auf Aluminiumbasis, bestehend aus 0,5 bis 4% Lithium, 0,5 bis 7% Magnesium, 0,2 bis 4% Silizium, einer geringen, jedoch in bezug auf erhöhte Stabilität und Festigkeit wirksame Menge Sauerstoff bis zu 1%, wobei der Rest, abgesehen von Verunreinigungen, Aluminium ist, und mit einem Gehalt einer geringen, jedoch in bezug auf erhöhte Stabilität und Festigkeit wirksamen Dispersoidmenge bis zu 10 Vol.%.

14. Legierung nach Anspruch 13, dadurch gekennzeichnet, daß der Siliziumgehalt 2% nicht übersteigt.

15. Legierung nach Anspruch 12, dadurch gekennzeichnet, daß der Siliziumgehalt 0,5 bis 1,5% beträgt.

16. Legierung nach einem der Ansprüche 13 bis 15, dadurch gekennzeichnet, daß der Kohlenstoffgehalt 2% nicht übersteigt.

Revendications

1. Procédé d'obtention d'un produit forgé à base d'alliage d'aluminium de faible densité composé d'une dispersion renforçante comprenant, en poids, de 0,5 à 4% de lithium, 0,5 à 7% de magnésium, 0 à 4% de silicium, une quantité petite mais efficace pouvant atteindre 5% de carbone pour améliorer la résistance, une quantité petite mais efficace pouvant atteindre 1% d'oxygène pour améliorer la résistance et la stabilité, le complément étant, outre les impuretés, l'aluminium, et ledit alliage ayant une teneur en dispersoïde petite mais efficace pour augmenter la résistance et la stabilité, pouvant atteindre 10% en volume de dispersoïde, ledit alliage étant obtenu à partir d'une poudre dudit alliage préparé par un procédé d'alliage mécanique, et ledit procédé comprend une séquence d'étapes telles que: dégazage et compactage de ladite poudre sous vide pour obtenir un lingot compacté ayant une densité suffisamment élevée pour obtenir un lingot extrudé de densité sensiblement égale à la densité finale; extrusion du lingot compacté résultant à une température comprise dans l'intervalle compris entre une température supérieure à celle de début d'extrusion jusqu'à environ 400°C (750°F), ladite extrusion étant réalisée avec lubrification en utilisant une filière conique pour donner un lingot extrudé de densité sensiblement égale à la densité finale; et forgeage du lingot extrudé résultant, le lingot résultant étant soumis à au moins un premier traitement de forgeage à une température comprise entre environ 230°C (450°F) et environ 400°C (750°F), à la condition que pour optimiser la résistance, le forgeage est réalisé à la limite inférieure de l'intervalle de températures de forgeage alors que l'extrusion est réalisée à la limite supérieure de l'intervalle de températures d'extrusion.

2. Procédé selon la revendication 1, dans lequel les étapes de dégazage et de compactage sont réalisées sous vide par compression à chaud de la poudre.

3. Procédé selon la revendication 1 ou la revendication 2, dans lequel le dégazage et le compactage sont réalisés à une température de 480°C (900°F) à 545°C (1015°F).

4. Procédé selon l'une quelconque des revendications précédentes, dans lequel l'extrusion est réalisée à une température d'au moins 230°C (450°F).

5. Procédé selon la revendication 4, dans lequel l'extrusion est réalisée à une température d'environ 260°C (500°F) et ledit forgeage est réalisé à une température comprise entre environ 260°C (500°F) et environ 370°C (700°F).

6. Procédé selon la revendication 4, dans lequel l'extrusion est réalisée à une température d'environ 370°C (700°F) et ladite étape de forgeage est réalisée à une température d'environ 260°C (500°F).

7. Procédé selon l'une quelconque des revendications précédentes, dans lequel l'extrusion du lingot compacté est réalisée à un rapport d'extrusion d'au moins 3:1.

8. Procédé selon l'une quelconque des revendications précédentes, dans lequel ledit alliage forgé est soumis à un traitement de durcissement.

9. Procédé selon l'une quelconque des revendications précédentes, dans lequel ledit alliage renforcé par une dispersion contient, en poids, 1,5 à 2,5% de lithium, 2 à 4% de magnésium et 0,5 à 2% de carbone, et moins de 1% d'oxygène, et la teneur en dispersoïde est comprise entre 3 et 6% en volume et ledit alliage, à l'état forgé, a une limite élastique d'au moins environ 410 MPa (60 ksi) et un allongement d'au moins 3%.

10. Procédé selon l'une quelconque des revendications précédentes, dans lequel l'alliage renforcé par une dispersion contient du silicium.

11. Procédé selon la revendication 1, dans lequel ledit alliage renforcé par une dispersion a une teneur en magnésium de 2 à 4,5%, une teneur en lithium de 1 à 3%, une teneur en carbone ne dépassant pas 1,2% et une teneur en oxygène ne dépassant pas 1%.

12. Procédé selon la revendication 11, dans lequel ledit alliage renforcé par dispersion a une teneur en carbone de 0,5 à 1,2% et une teneur en oxygène de 0,05 à 0,5%.

13. Alliage à base d'aluminium, mécaniquement allié, renforcé par une dispersion, constitué de 0,5 à 4% de lithium, 0,5 à 7% de magnésium, 0,2 à 4% de silicium, d'une quantité petite mais efficace jusqu'à 5% de carbone pour augmenter la résistance, d'une quantité petite mais efficace jusqu'à 1% d'oxygène pour augmenter la stabilité et la résistance, le complément, outre les impuretés, étant l'aluminium, et ayant une teneur en dispersoïde petite mais efficace pour augmenter la stabilité et la résistance jusqu'à 10% en volume.

14. Alliage selon la revendication 13, dans lequel la teneur en silicium ne dépasse pas 2%.

15. Alliage selon la revendication 12, dans lequel la teneur en silicium est comprise entre 0,5 et 1,5%.

16. Alliage selon l'une quelconque des revendications 13 à 15, dans lequel la teneur en carbone ne dépasse pas 2%.

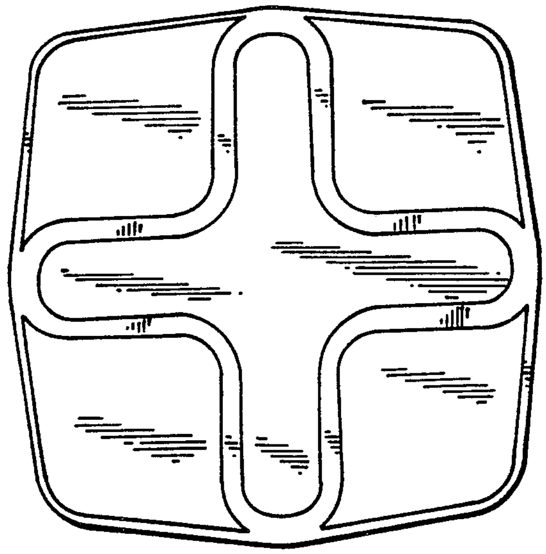

FIG. 1

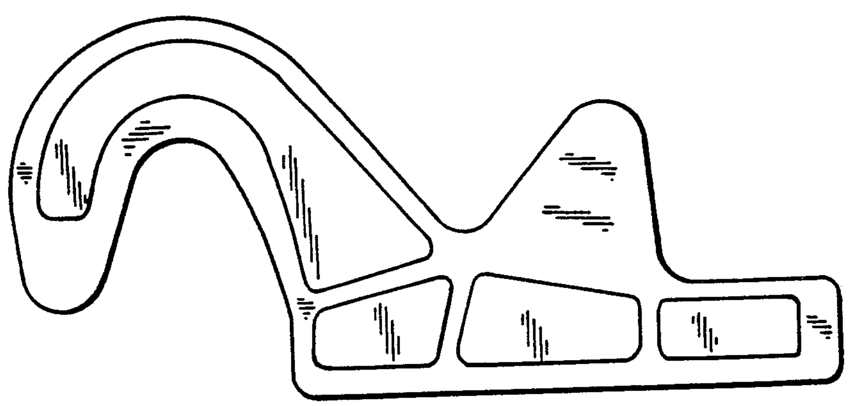

FIG. 2