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PROCEEDINGS OF THE SECOND INTERNATIONAL ALUMINUM-LITHIUM CONFERENCE: ALUMINUM-LITHIUM ALLOYS II, 12th-14th April 1983, Monterey, California, edited by E.A.Starke, Jr., pages 407-418, The Metallurgical Society of AIME, Warrendale, US;J.W.BOHLER et al.: "Investigation of Al-Li based alloys at northrop"

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## Description

This invention relates to aluminum base alloys, and more particularly, it relates to improved lithium containing aluminum base alloys, products made therefrom and methods of producing the same.

5 In the aircraft industry, it has been generally recognized that one of the most effective ways to reduce the weight of an aircraft is to reduce the density of aluminum alloys used in the aircraft construction. For purposes of reducing the alloy density, lithium additions have been made. However, the addition of lithium to aluminum alloys is not without problems. For example, the addition of lithium to aluminum alloys often results in a decrease in ductility and fracture toughness. Where the use is in aircraft parts, it is imperative  
10 that the lithium containing alloy have both improved fracture toughness and strength properties.

It will be appreciated that both high strength and high fracture toughness appear to be quite difficult to obtain when viewed in light of conventional alloys such as AA (Aluminum Association) 2024-T3X and 7050-TX normally used in aircraft applications. For example, a paper by J. T. Staley entitled "Microstructure and Toughness of High-Strength Aluminum Alloys", Properties Related to Fracture Toughness, ASTM STP605,  
15 American Society for Testing and Materials, 1976, pp. 71-103, shows generally that for AA2024 sheet, toughness decreases as strength increases. Also, in the same paper, it will be observed that the same is true of AA7050 plate. More desirable alloys would permit increased strength with only minimal or no decrease in toughness or would permit processing steps wherein the toughness was controlled as the strength was increased in order to provide a more desirable combination of strength and toughness.  
20 Additionally, in more desirable alloys, the combination of strength and toughness would be attainable in an aluminum-lithium alloy having density reductions in the order of 5 to 15%. Such alloys would find widespread use in the aerospace industry where low weight and high strength and toughness translate to high fuel savings. Thus, it will be appreciated that obtaining qualities such as high strength at little or no sacrifice in toughness, or where toughness can be controlled as the strength is increased would result in a  
25 remarkably unique aluminum-lithium alloy product.

U.S. Patent 4,626,409 discloses aluminum base alloy consisting of, by wt.%, 2.3 to 2.9 Li, 0.5 to 1.0 Mg, 1.6 to 2.4 Cu, 0.05 to 0.25 Zr, 0 to 0.5 Ti, 0 to 0.5 Mn, 0 to 0.5 Ni, 0 to 0.5 Cr and 0 to 2.0 Zn and a method of producing sheet or strip therefrom. In addition, U.S. Patent 4,582,544 discloses a method of superplastically deforming an aluminum alloy having a composition similar to that of U.S. Patent 4,626,409.  
30 European Patent Application 210112 discloses an aluminum alloy product containing 1 to 3.5 wt.% Li, up to 4 wt.% Cu, up to 5 wt.% Mg, up to 3 wt.% Zn and Mn, Cr and/or Zr additions. The alloy product is recrystallized and has a grain size less than 300 micrometers. U.S. Patent 4,648,913 discloses aluminum base alloy wrought product having improved strength and fracture toughness combinations when stretched, for example, an amount greater than 3%.

35 The present invention provides as improved lithium containing aluminum base alloys which permit products having improved strength characteristics while retaining high toughness properties.

The present invention provides an improved lithium containing aluminum base alloy product which can be processed to improve strength characteristics while retaining high toughness properties or which can be processed to provide a desired strength at a controlled level of toughness.

40 Figure 1 shows a strength and fracture toughness plot of alloys in accordance with the invention.

Figure 2 shows strength plotted against aging time of an alloy in accordance with the invention.

Figure 3 illustrates different toughness yield strength relationships where shifts in the upward direction and to the right represent improved combinations of these properties.

According to the present invention there is provided an aluminum base alloy suitable for forming into a  
45 wrought product having improved combinations of strength, corrosion resistance and fracture toughness, the alloy comprised of 0.2 to 5.0 wt.% Li, 0.05 to 6.0 wt.% Mg, 2.45 to less than 4.0 wt.% Cu, 0.05 to 2.0 wt.% Zn, 0.01 to 0.16 wt.% Zr, 0.5 wt.% max. Fe, 0.5 wt.% max. Si, and optional components consisting of 0 to 1.0 wt.% Mn, 0.05 to 0.2 wt.% Cr, V, Hf, Ti; the balance aluminum and incidental impurities, and having an Mg-Zn ratio of 0.1 to less than 1.0 when Mg is in the range of 0.1 to 1.0 Wt.%. The impurities are  
50 preferably limited to about 0.05 wt.% each, and the combination of impurities preferably should not exceed 0.35 wt.%. Within these limits, it is preferred that the sum total of all impurities does not exceed 0.15 wt.%.

A preferred alloy in accordance with the present invention can contain 1.5 to 3.0 wt.% Li, 2.5 to 2.95 wt.% Cu, 0.2 to 2.5 wt.% Mg, 0.2 to 2.0 wt.% Zn, 0.05 to 0.12 wt.% Zr, the balance aluminum and impurities as specified above. A typical alloy composition would contain 1.8 to 2.5 wt.% Li, 2.55 to 2.9 wt.%  
55 Cu, 0.2 to 2.0 wt.% Mg, 0.2 to 2.0 wt.% Zn, greater than 0.1 to less than 0.16 wt.% Zr, and max. 0.1 wt.% of each of Fe and Si.

A suitable alloy composition would contain 1.9 to 2.4 wt.% Li, 2.55 to 2.9 wt.% Cu, 0.1 to 0.6 wt.% Mg, 0.5 to 1.0 wt.% Zn, 0.08 to 0.12 wt.% Zr, max. 0.1 wt.% of each of Fe and Si, the remainder aluminum.

In an embodiment of the invention, an aluminum base alloy wrought product having improved combinations of strength, fracture toughness and corrosion resistance is provided. The product can be provided in a condition suitable for aging and has the ability to develop improved strength in response to aging treatments without substantially impairing fracture toughness properties or corrosion resistance. The product comprises 0.2 to 5.0 wt.% Li, 0.05 to 6.0 wt.% Mg, 2.45 to 2.95 wt.% Cu, 0.05 to 0.16 wt.% Zr, 0.2 to 2.0 wt.% Zn, 0.5 wt.% max. Fe, 0.5 wt.% max. Si, the balance aluminum and incidental impurities. The product is capable of having imparted thereto a working effect equivalent to stretching so that the product has combinations of improved strength and fracture toughness after aging. In the method of making an aluminum base alloy product having improved combinations of strength, fracture toughness and corrosion resistance, a body of a lithium containing aluminum base alloy is provided and may be worked to produce a wrought aluminum product. The wrought product may be first solution heat treated and then stretched or otherwise worked amount equivalent to stretching. The degree of working as by stretching, for example, is normally greater than that used for relief of residual internal quenching stresses.

A preferred alloy in accordance with the present invention can contain 0.2 to 5.0 wt.% Li, 2.45 to less than 4.0 wt.% Cu, 0.05 to 5.0 wt.% Mg, 0.05 to 0.16 wt.% Zr, 0.2 to 2.0 wt.% Zn, the balance aluminum and impurities as specified above. A typical alloy composition would contain 1.5 to 3.0 wt.% Li, 2.55 to 2.90 wt.% Cu, 0.2 to 2.5 wt.% Mg, 0.2 to 2.0 wt.% Zn, 0.08 to 0.12 wt.% Zr, 0 to 1.0 wt.% Mn and max. 0.1 wt.% of each of Fe and Si. In a preferred typical alloy, Mg may be in the range of 0.2 to 2.0 wt.%.

In the present invention, lithium is very important not only because it permits a significant decrease in density but also because it improves tensile and yield strengths markedly as well as improving elastic modulus. Additionally, the presence of lithium improves fatigue resistance. Most significantly though, the presence of lithium in combination with other controlled amounts of alloying elements permits aluminum alloy products which can be worked to provide unique combinations of strength and fracture toughness while maintaining meaningful reductions in density.

It must be recognized that to obtain a high level of corrosion resistance in addition to the unique combinations of strength and fracture toughness as well as reductions in density requires careful selection of all the alloying elements. For example, for every 1 wt.% Li added, the density of the alloy is decreased about 2.4%. Thus, if density is the only consideration, then the amount of Li would be maximized. However, if it is desired to increase toughness at a given strength level, then Cu should be added. However, for every 1 wt.% Cu added to the alloy, the density is increased by 0.87% and resistance to corrosion and stress corrosion cracking is reduced. Likewise, for every 1 wt.% Mn added, the density is increased about 0.85%. Thus, care must be taken to avoid losing the benefits of lithium by the addition of alloying elements such as Cu and Mn, for example. Accordingly, while lithium is the most important element for saving weight, the other elements are important in order to provide the proper levels of strength, fracture toughness, corrosion and stress corrosion cracking resistance.

With respect to copper, particularly in the ranges set forth hereinabove for use in accordance with the present invention its presence enhances the properties of the alloy produce by reducing the loss in fracture toughness at higher strength levels. That is, as compared to lithium, for example, in the present invention copper has the capability of providing higher combinations of toughness and strength. Thus, in the present invention when selecting an alloy, it is important in making the selection to balance both the toughness and strength desired, since both elements work together to provide toughness and strength uniquely in accordance with the present invention. It is important that the ranges referred to hereinabove, be adhered to, particularly with respect to the limits of copper, since excessive amounts, for example, can lead to the undesirable formation of intermetallics which can interfere with fracture toughness. Typically, copper should be less than 3.0 wt.%; however, in a less preferred embodiment, copper can be increased to less than 4.0 wt.% and preferably less than 3.5 wt.%. The combination of lithium and copper should not exceed 5.5 wt.% with lithium being at least 1.5 wt.% with greater amounts of lithium being preferred.

Thus, in accordance with this invention, it has been discovered that adhering to the ranges set forth above for copper, fracture toughness, strength, corrosion and stress corrosion cracking can be maximized.

Magnesium is added or provided in this class of aluminium alloys mainly for purposes of increasing strength although it does decrease density slightly and is advantageous from that standpoint. It is important to adhere to the limits set forth for magnesium because excess magnesium, for example, can also lead to interference with fracture toughness, particularly through the formation of undesirable phases at grain boundaries.

Zirconium is the preferred material for grain structure control; however, other grain structure control materials can include Cr, V, Hf, Mn, Ti, typically in the range of 0.05 to 0.2 wt.% with Hf and Mn up to typically 0.6 wt.%. The level of Zr used depends on whether a recrystallized or unrecrystallized structure is desired. The use of zinc results in increased levels of strength, particularly in combination with magnesium.

However, excessive amounts of zinc can impair toughness through the formation of intermetallic phases.

Zinc is important because, in this combination with magnesium, it results in an improved level of strength which is accompanied by high levels of corrosion resistance when compared to alloys which are zinc free. Particularly effective amounts of Zn are in the range of 0.1 to 1.0 wt.% when the magnesium is in the range of 0.05 to 0.5 wt.%, as presently understood. It is important to keep the Mg and Zn in a ratio in the range of about 0.1 to less than 1.0 when Mg is in the range of 0.1 to 1 wt.% with a preferred ratio being in the range of 0.2 to 0.9 and a typical ratio being in the range of about 0.3 to 0.8. The ratio of Mg to Zn can range from 1 to 6 when the wt.% of Mg is 1 to 4.0 and Zn is controlled to 0.2 to 2.0 wt.%, preferably in the range of 0.2 to 0.9 wt.%.

Working with the Mg/Zn ratio of less than one is important in that it aids in the worked product being less anisotropic or being more isotropic in nature, i.e., properties more uniform in all directions. That is, working with the Mg/Zn ratio in the range of 0.2 to 0.8 can result in the end product having greatly reduced hot worked texture, resulting from rolling, for example, to provide improved properties, for example in the 45° direction.

Toughness or fracture toughness as used herein refers to the resistance of a body, e.g. extrusions, forgings, sheet or plate, to the unstable growth of cracks or other flaws.

The Mg/Zn ratio less than one is important for another reason. That is, keeping the Mg/Zn ratio less than one, e.g., 0.5, results not only in greatly improved strength and fracture toughness but in greatly improved corrosion resistance. For example, when the Mg and Zn content is 0.5 wt.% each, the resistance to corrosion is greatly lowered. However, when the Mg content is about 0.3 wt.% and the Zn is 0.5 wt.%, the alloys have a high level of resistance to corrosion.

While the inventors do not wish to be held to any theory of invention, it is believed that the resistance to exfoliation and the resistance to crack propagation under an applied stress increases as Zn is added. It is believed that this behavior is due to the fact that Zn stimulates the desaturation of Cu from the matrix solid solution by enhancing the precipitation of Cu-rich precipitates. This effect is believed to change the solution potential to higher electronegative values. It is also believed that Zn forms Mg-Zn bearing phases at the grain boundaries that interact with propagating cracks and blunt the crack tip or deflect the advancing crack and thereby improves the resistance to crack propagation under an applied load.

Improved combinations of strength and toughness is a shift in the normal inverse relationship between strength and toughness towards higher toughness values at given levels of strength or towards higher strength values at given levels of toughness. For example, in Fig. 3, going from point A to point D represents the loss in toughness usually associated with increasing the strength of an alloy. In contrast, going from point A to point B results in an increase in strength at the same toughness level. Thus, point B is an improved combination of strength and toughness. Also, going from point A to point C results in an increase in strength while toughness is decreased, but the combination of strength and toughness is improved relative to point A. However, relative to point D, at point C, toughness is improved and strength remains about the same, and the combination of strength and toughness is considered to be improved. Also, taking point B relative to point D, toughness is improved and strength has decreased yet the combination of strength and toughness are again considered to be improved.

As well as providing the alloy product with controlled amounts of alloying elements as described hereinabove, it is preferred that the alloy be prepared according to specific method steps in order to provide the most desirable characteristics of both strength and fracture toughness. Thus, the alloy as described herein can be provided as an ingot or billet for fabrication into a suitable wrought product by casting techniques currently employed in the art for cast products, with continuous casting being preferred.

Further, the alloy may be roll cast or slab cast to thicknesses from 6.3 to 50 or 75 mm (0.25 to 2 or 3 inches) or more depending on the end product desired. It should be noted that the alloy may also be provided in billet form consolidated from fine particulate such as powdered aluminum alloy having the compositions in the ranges set forth hereinabove. The powder or particulate material can be produced by processes such as atomization, mechanical alloying and melt spinning. The ingot or billet may be preliminarily worked or shaped to provide suitable stock for subsequent working operations. Prior to the principal working operation, the alloy stock is preferably subjected to homogenization, and preferably at metal temperatures in the range of 482 to 566 °C (900 to 1050 °F) for a period of time of at least one hour to dissolve soluble elements such as Li, Cu, Zn and Mg and to homogenize the internal structure of the metal. A preferred time period is about 20 hours or more in the homogenization temperature range.

Normally, the heat up and homogenizing treatment does not have to extend for more than 40 hours; however, longer times are not normally detrimental. A time of 20 to 40 hours at the homogenization temperature has been found quite suitable. In addition to dissolving constituent to promote workability, this homogenization treatment is important in that it is believed to precipitate the Mn and Zr-bearing dispersoids

which help to control final grain structure.

After the homogenizing treatment, the metal can be rolled or extruded or otherwise subjected to working operations to produce stock such as sheet, plate or extrusions or other stock suitable for shaping into the end product. To produce a sheet or plate-type product, a body of the alloy is preferably hot rolled to a thickness ranging from 2.5 to 6.3 mm (0.1 to 0.25 inch) for sheet and 6.3 to 150 mm (0.25 to 6.0 inches) for plate. For hot rolling purposes, the temperature should be in the range of 538 °C (1000 °F) down to 399 °C (750 °F). Preferably, the metal temperature initially is in the range of 454 to 524 °C (850 to 975 °F).

When the intended use of a plate product is for wing spars where thicker sections are used, normally operations other than hot rolling are unnecessary. Where the intended use is wing or body panels requiring a thinner gauge, further reductions as by cold rolling can be provided. Such reductions can be to a sheet thickness ranging, for example, from 0.25 to 6.33 mm (0.010 to 0.249 inch) and usually from 0.76 to 2.5 mm (0.030 to 0.10 inch).

After working a body of the alloy to the desired thickness, the sheet or plate or other worked article is subjected to a solution heat treatment to dissolve soluble elements. The solution heat treatment is preferably accomplished at a temperature in the range of 482 to 566 °C (900 to 1050 °F) and preferably produces an unrecrystallized grain structure.

Solution heat treatment can be performed in batches or continuously, and the time for treatment can vary from hours for batch operations down to as little as a few seconds for continuous operations. Basically, solutionizing of the alloy into a single phase field can occur fairly rapidly, for instance in as little as 30 to 60 seconds, once the metal has reached a solution temperature of about 538 to 566 °C (1000 to 1050 °F). However, heating the metal to that temperature can involve substantial amounts of time depending on the type of operation involved. In batch treating a sheet product in a production plant, the sheet is treated in a furnace load and an amount of time can be required to bring the entire load to solution temperature, and accordingly, solution heat treating can consume one or more hours, for instance one or two hours or more in batch solution treating. In continuous treating, the sheet is passed continuously as a single web through an elongated furnace which greatly increases the heat-up rate. The continuous approach is favored in practicing the invention, especially for sheet products, since a relatively rapid heat up and short dwell time at solution temperature is obtained. Accordingly, the inventors contemplate solution heat treating in as little as about 1.0 minute. As a further aid to achieving a short heat-up time, a furnace temperature or a furnace zone temperature significantly above the desired metal temperature provides a greater temperature head useful in reducing heat-up times.

To further provide for the desired strength and fracture toughness, as well as corrosion resistance, necessary to the final product and to the operations in forming that product, the product should be quenched to prevent or minimize uncontrolled precipitation of strengthening phases referred to herein later.

After the alloy product of the present invention has been solution heat treated and quenched, it may be artificially aged to provide the combination of fracture toughness and strength which are so highly desired in aircraft members. This can be accomplished by subjecting the sheet or plate or shaped product to a temperature in the range of 65 to 204 °C (150 to 400 °F) for a sufficient period of time to further increase the yield strength. Some compositions of the product are capable of being artificially aged to a yield strength as high as 655 MPa (95 ksi). However, the useful strengths are in the range of 345 to 586 MPa (50 to 85 ksi) and corresponding fracture toughnesses for plate products are in the range of 28 to 83 MPa  $\sqrt{m}$  (25 to 75 ksi  $\sqrt{in}$ ). Preferably, artificial aging is accomplished by subjecting the alloy product to a temperature in the range of 135 to 190 °C (275 to 375 °F) for a period of at least 30 minutes. A suitable aging practice contemplate a treatment of about 8 to 24 hours at a temperature of about 163 °C (325 °F). Further, it will be noted that the alloy product in accordance with the present invention may be subjected to any of the typical underaging treatments well known in the art, including natural aging and multi-step agings. Also, while reference has been made herein to single aging steps, multiple aging steps, such as two or three aging steps, are contemplated and stretching or its equivalent working may be used prior to or even after part of such multiple aging steps.

After solution heat treatment and quenching as noted herein, the improved sheet, plate or extrusion and other wrought products can have a range of yield strength from about 172.5 to 345 MPa (25 to 50 ksi) and a level of fracture toughness in the range of about 55 to 165 MPa  $\sqrt{m}$  (50 to 150 ksi  $\sqrt{in}$ ). However, with the use of artificial aging to improve strength, fracture toughness can drop considerably. To minimize the loss in fracture toughness associated in the past with improvement in strength, it has been discovered that the solution heat treated and quenched alloy product, particularly sheet, plate or extrusion, must be stretched, preferably at room temperature, an amount greater than 1%, e.g. about 2 to 6% or greater, of its original length or otherwise worked or deformed to impart to the product a working effect equivalent to stretching

greater than 1% of its original length. The working effect referred to is meant to include rolling and forging as well as other working operations. It has been discovered that the strength of sheet or plate, for example, of the subject alloy can be increased substantially by stretching prior to artificial aging, and such stretching causes little or no decrease in fracture toughness. It will be appreciated that in comparable high strength alloys, stretching can produce a significant drop in fracture toughness. Stretching AA7050 reduces both toughness and strength, as shown by the reference by J.T. Staley, mentioned previously. For AA2024, stretching 2% increases the combination of toughness and strength over that obtained without stretching; however, further stretching does not provide any substantial increases in toughness. Therefore, when considering the toughness-strength relationship, it is of little benefit to stretch AA2024 more than 2%, and it is detrimental to stretch AA7050. In contrast, when stretching or its equivalent is combined with artificial aging, an alloy product in accordance with the present invention can be obtained having significantly increased combinations of fracture toughness and strength.

While the inventors do not necessarily wish to be bound by any theory of invention, it is believed that deformation or working, such as stretching, applied after solution heat treating and quenching, results in a more uniform distribution of lithium-containing metastable precipitates after artificial aging. These metastable precipitates are believed to occur as a result of the introduction of a high density of defects (dislocations, vacancies, vacancy clusters, etc.) which can act as preferential nucleation sites for these precipitating phases (such as  $T_1'$ , a precursor of the  $Al_2CuLi$  phase) throughout each grain. Additionally, it is believed that this practice inhibits nucleation of both metastable and equilibrium phases such as  $Al_3Li$ ,  $AlLi$ ,  $Al_2CuLi$  and  $Al_5CuLi_3$  at grain and sub-grain boundaries. Also, it is believed that the combination of enhanced uniform precipitation throughout each grain and decreased grain boundary precipitation results in the observed higher combination of strength and fracture toughness in aluminum-lithium alloys worked or deformed as by stretching, for example, prior to final aging.

In the case of sheet or plate, for example, it is preferred that stretching or equivalent working is greater than 1%, e.g. about 2% or greater, and less than 14%. Further, it is preferred that stretching be in the range of about 2 to 10%, e.g., 3.7 to 9% increase over the original length with typical increases being in the range of 5 to 8%.

When the ingot of the alloy is roll cast or slab cast, the cast material may be subjected to stretching or the equivalent thereof without the intermediate steps or with only some of the intermediate steps to obtain strength and fracture toughness in accordance with the invention.

After the alloy product of the present invention has been worked, it may be artificially aged to provide the combination of fracture toughness and strength which are so highly desired in aircraft members.

Specific strength, as used herein, is the tensile yield strength divided by the density of the alloy. Plate products, for example, made from alloys in accordance with the invention, have a specific strength of at least  $0.75 \times 10^6$  ksi in<sup>3</sup>/lb and preferably at least  $0.80 \times 10^6$  ksi in<sup>3</sup>/lb. The alloys have the capability of producing specific strengths as high as  $1.00 \times 10^6$  ksi in<sup>3</sup>/lb.  $1 \text{ ksi in}^3/\text{lb} \approx 110,9 \text{ MPa kg/m}^3$

The wrought product in accordance with the invention can be provided either in a recrystallized grain structure form or an unrecrystallized grain structure form, depending on the type of thermomechanical processing used. When it is desired to have an unrecrystallized grain structure plate product, the alloy is hot rolled and solution heat treated, as mentioned earlier. If it is desired to provide a recrystallized plate product, then the Zr is kept to a very low level, e.g., less than 0.05 wt.%, and the thermomechanical processing is carried out at rolling temperatures of about 426-454 °C (800 to 850 °F) with the solution heat treatment as noted above. For unrecrystallized grain structure, Zr should be above 0.10 wt.% and the thermomechanical processing is as above except a heat-up rate of not greater than 5 °F/min and preferably less than 1 °F/min is used in solution heat treatment.

If recrystallized sheet is desired having low Zr, e.g., less than 0.1 wt.%, typically in the range of 0.05 to 0.08 Zr, the ingot is first hot rolled to slab gauge of about 2 to 5 inches as above. Thereafter, it is reheated to between 371-454 °C (700 to 850 °F) then hot rolled to sheet gauge. This is followed by an anneal at between 260-454 °C (500 to 850 °F) for 1 to 12 hours. The material is then cold rolled to provide at least a 25% reduction in thickness to provide a sheet product. The sheet is then solution heat treated, quenched stretched and aged as noted earlier. Where the Zr content is fairly substantial, such as about 0.12 wt.%, a recrystallized grain structure can be obtained if desired. Here, the ingot is hot rolled at a temperature in the range of 426-538 °C (800 to 1000 °F) and then annealed at a temperature of about 426-454 °C (800 to 850 °F) for about 4 to 16 hours. Thereafter, it is cold rolled to achieve a reduction of at least 25% in gauge. The sheet is then solution heat treated at a temperature in the range of 510-549 °C (950 to 1020 °F) using heat-up rates of not slower than about 5.6 °C/min (10 °F/min) with typical heat-up rates being as fast as 200 °F/min with faster heat-up rates giving finer recrystallized grain structure. The sheet may then be quenched, stretched and aged.

Wrought products, e.g., sheet, plate and forgings, in accordance with the present invention develop a solid state precipitate along the (100) family of planes. The precipitate is plate like and has a diameter in the range of about 50 to 100 Angstroms and a thickness of 4 to 20 Angstroms. The precipitate is primarily copper or copper-magnesium containing; that is, it is copper or copper-magnesium rich. These precipitates are generally referred to as GP zones and are referred to in a paper entitled "The Early Stages of GP Zone Formation in Naturally Aged Al-4 Wt Pct Cu Alloys" by R. J. Rioja and D. E. Laughlin, Metallurgical Transactions A, Vol. 8A, August 1977, pp. 1257-61, incorporated herein by reference. It is believed that the precipitation of GP zones results from the addition of Mg and Zn which is believed to reduce solubility of Cu in the Al matrix. Further, it is believed that the Mg and Zn stimulate nucleation of this metastable strengthening precipitate. The number density of precipitates on the (1 0 0) planes per cubic centimeter ranges from  $1 \times 10^{15}$  to  $1 \times 10^{17}$  with a preferred range being higher than  $1 \times 10^{15}$  and typically as high as  $5 \times 10^{16}$ . These precipitates aid in producing a high level of strength without losing fracture toughness, particularly if short aging times, e.g., 15 hours at 350 °F, are used for unstretched products.

The alloy of the present invention is useful also for extrusions and forgings with improved levels of mechanical properties, as shown in Figure 2, for example. Extrusions and forgings are typically prepared by hot working at temperatures in the range of 315-538 °C (600 to 1000 °F), depending to some extent on the properties and microstructures desired.

The following examples are further illustrative of the invention ( $^{\circ}\text{C} = \frac{5}{9} (^{\circ}\text{F}-32)$ ); 1in = 25,4 mm; 1000 psi = 6.875 MPa = 1ksi)

Example 1

The alloys of the invention (Table 1) in this Example were cast into ingot suitable for rolling. Alloy A corresponds to AA2090, Alloy B corresponds to AA2090 plus 0.3 wt.% Mg, and Alloy C corresponds to AA2090 plus 0.6 wt.% Mg. Alloys A, B and C were provided for comparative purposes. The ingots were then homogenized at 950 °F for 8 hours followed by 24 hours at 1000 °F, hot rolled to 1 inch thick plate and solution heat treated for one hour at 1020F. The specimens were quenched and aged. Other specimens were stretched 2% and 6% of their original length at room temperature and then artificially aged. Unstretched samples were aged at 350 °F. Samples stretched 2% and 6% were aged at 325 °F. Table 2 shows the highest attained specific strengths. Stretched and unstretched samples were also aged to measure corrosion performance. EXCO (ASTM G34) is a total immersion test designed to determine the exfoliation corrosion resistance of high strength 2XXX and 7XXX aluminum alloys. Table 3 shows that Alloys E, F and G, which had ratios of Mg to Zn less than 1, performed better in the four day accelerated test than Alloys A, B, C and D which either contained no Zn (A, B, C) or had an Mg to Zn ratio of 1 (alloy D). Alloys A, B, C and D received many ratings of EC (severe exfoliation corrosion) or ED (very severe exfoliation). Alloy C suffered especially severe attack; all four samples received ED ratings after four days exposure to EXCO. Conversely, Alloys E, F and G received ratings that were predominantly EA (mild exfoliation) or EB (moderated exfoliation). Only one specimen from these three alloys was rated worse than EB. This was the 2% stretch 25 hour aging of Alloy E which was rated ED. This data indicates that Al-Cu-Li alloys with Mg to Zn ratios of less than 1 have improved resistance to exfoliation corrosion.

Tables 5, 6 and 7 list the strength and toughness exhibited by these alloys at 0, 2 and 6% stretch, respectively. Figure 1 shows the properties of alloys E, F and G which exhibit improved combinations of corrosion resistance, strength and toughness.

Table 1

Composition of the Seven Alloys in Weight Percent								
Alloy	Cu	Li	Mg	Zn	Zr	Si	Fe	Al
A	2.5	2.2	0	0	0.12	0.04	0.07	Balance
B	2.5	2.2	0.3	0	0.12	0.04	0.07	Balance
C	2.5	2.1	0.6	0	0.12	0.04	0.07	Balance
D	2.6	2.2	0.6	0.6	0.12	0.04	0.07	Balance
E	2.5	2.2	0.5	1	0.12	0.04	0.07	Balance
F	2.6	2.1	0.3	0.5	0.12	0.04	0.07	Balance
G	2.6	2.2	0.3	0.9	0.12	0.04	0.07	Balance



Table 2

Specific Tensile Yield Strengths ( $\times 10^6$ KSI in <sup>3</sup> /lb)				
Alloy	0% Stretch	2% Stretch	6% Stretch	Calculated Density
A	0.71	0.81	0.82	0.0909
B	0.80	0.82	0.88	0.0908
C	0.81	0.84	0.93	0.0910
D	0.79	0.89	0.93	0.0915
E	0.83	0.87	0.90	0.0913
F	0.81	0.85	0.92	0.0910
G	0.90	0.90	0.93	0.0912

Example 2

The alloys of the invention in this example are the same as those from Example 1 except they were hot rolled to 1.5 inch thick plate rather than to 1 inch plate before they were solution heat treated for one hour at 1020F. The specimens were quenched and artificially aged at 350 °F for 20 and 30 hours. Alloys E, F and G, which had ratios of Mg to Zn of less than 1, had better resistance to stress corrosion cracking (SCC) than Alloys A, B, C and D which either contained no Zn (A, B, C) or had a Zn to Mg ratio of 1 (Alloy D). The stress corrosion cracking test results are listed in Table 4 which also contains a description of the test procedures.

Alternate immersion testing in 3.5 wt.% NaCl solution (ASTM G44) is commonly used to evaluate the stress corrosion cracking performance of high strength aluminum alloys, per ASTM G47. It can be seen in the table that Alloys E, F and G have superior SCC resistance to the other four alloys since specimens from Alloys E, F and G have all survived 30 days in alternate immersion at 40,000 psi. One difference between the groups is the Mg to Zn ratio which is less than 1 (based on weight) and achieves high resistance to stress corrosion.

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Table 3

EXCO Ratings of Several Al-Li Alloys 1.0 Inch Thick Plate in T8 (Cold Work Prior to Aging) Temper					
Alloy	Stretch (%)*	Age (hr/° F)	Tensile Yield Strength (Longitudinal) ksi	2 Day	4 Day
A	2	25/325	66.8	EC	ED
A	2	35/325	71.5	EC	EC
A	6	15/325	68.4	EA	EB
A	6	20/325	72.4	EA	EB
B	2	25/325	73.7	EB	EC
B	2	35/325	73.5	EB	EB
B	6	15/325	75.7	EC	EC
B	6	20/325	78.0	EC	EC
C	2	25/325	73.9	EC	ED
C	2	35/325	77.6	ED	ED
C	6	15/325	78.0	EC	ED
C	6	20/325	81.5	EC	ED
D	2	25/325	77.8	EB	EB
D	2	35/325	73.5	EB	EB
D	6	15/325	75.8	EC	ED
D	6	20/325	76.7	EC	EC
E	2	25/325	77.4	EC	EC
E	2	35/325	79.5	EB	EB
E	6	15/325	79.2	EB	EB
E	6	20/325	84.1	EB	EB
F	2	25/325	83.1	EA	EA
F	2	35/325	78.4	EA	EA
F	6	15/325	81.8	EB	EB
F	6	20/325	84.8	EB	EB
G	2	25/325	80.3	EB	EB
G	2	35/325	80.8	EB	EB
G	6	15/325	77.8	EB	EB
G	6	20/325	89.5	EB	EB
EXCO testing conducted per ASTM G34. EA = Mild Exfoliation EB = Moderate Exfoliation EC = Severe Exfoliation ED = Very Severe Exfoliation					

\*In the unstretched condition, the alloys had a rating of EC or ED after four days.

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Table 4

Stress Corrosion Cracking Performance of Several Al-Li Alloy Specimens 1.5 Inch Thick Plate in T6 Condition (No Cold Work Prior to Aging)					
Alloy	Age (hr/° F)	25 KSI*		40 KSI*	
		F/N**	Days***	F/N**	Days***
A	20/350	1/3	3,11,11	3/3	1,2,2
A	30/350	1/3	9,11	3/3	2,3,6
B	20/350	2/3	8,15	3/3	1,2,2
B	30/350	0/3	-	2/3	1,6,7
C	20/350	3/3	1,1,1	2/2	1,1
C	30/350	2/2	1,1	1/1	1
D	20/350	1/3	2	3/3	1,3,3
D	30/350	1/3	3	2/3	6,2
E	20/350	0/3	-	0/3	-
E	30/350	0/3	-	0/3	-
F	20/350	0/3	-	0/3	-
F	30/350	0/3	-	0/3	-
G	20/350	0/3	-	0/3	-
G	30/350	0/3	-	0/3	-

One eighth inch diameter smooth tensile bars tested in 3.5 wt.% NaCl solution by alternate immersion for 30 days, per ASTM G44.

\*Ksi = Thousand pounds per square inch.

\*\*F/N = Number of specimens that failed/Number of specimens in test.

\*\*\*Days = Days to failure.

Example 3

This sample illustrates that forgings made from alloys of the present invention have improved combinations of corrosion resistance, strength and fracture toughness. The alloys in this Example are the same as those in Example 1 and the ingots were prepared also as in Example 1. Specimens were prepared from these ingots by hot extruding and forging.

The forged specimens were solution heat treated from one hour at 1020 °F then artificially aged at 350 °F for 20 and 40 hours. Alloys E, F and G, which had ratios of Mg to Zn of less than 1, had better resistance to stress corrosion cracking (SCC) than Alloys A, B, C and D which either contained no Zn (A, B, C) or had an Mg to Zn ratio of 1 (Alloy D). Alloys E, F and G all survived 20 days in alternate immersion at 40,000 psi. The stress corrosion cracking results are listed in Table 8. The strength and fracture toughness are shown in Table 9.

Table 5

Plate (1" Thick) Tensile Properties at 0% Stretch

Alloy	Aged 25 hr. at 350°F				Aged 30 hr. at 350°F				Aged 35 hr. at 350°F			
	Tensile Yield Strength	Ultimate Tensile Strength	% Elongation	Fracture Toughness	Tensile Yield Strength	Ultimate Tensile Strength	% Elongation	Fracture Toughness	Tensile Yield Strength	Ultimate Tensile Strength	% Elongation	Fracture Toughness
A	55.8	67.0	4.0	34.6	58.0	67.9	5.0	30.2	62.3	71.1	5.0	32.3
A	58.0	68.4	4.0	33.0	60.3	70.3	7.0	34.5	62.5	72.3	5.0	33.5
B	65.6	75.4	4.0	33.0	78.8	77.8	6.0	26.2	66.6	76.7	6.0	30.6
B	63.1	74.1	5.0	31.7	68.8	78.2	5.0	33.1	71.4	79.6	5.0	29.9
C	72.2	84.6	8.0	30.0	73.5	84.9	8.0	29.3	74.0	85.5	9.0	28.1
C	74.4	87.4	8.0	30.4	73.0	85.1	8.0	25.9	73.7	85.0	8.0	29.6
D	71.5	82.6	8.0	35.8	72.1	81.7	7.0	32.0	71.3	81.7	7.0	31.1
D	72.9	83.7	8.0	30.6	73.3	83.1	8.0	31.5	71.5	81.8	9.0	32.1
E	75.6	86.6	8.0	29.7	73.2	83.4	8.0	29.9	75.4	85.0	8.0	29.5
E	75.7	86.3	7.0	31.9	75.4	83.8	9.0	31.0	73.3	83.5	8.0	28.7
F	67.3	77.4	7.0	28.9	70.3	78.6	5.0	27.4	70.3	78.6	8.0	24.7
F	73.1	80.4	6.0	29.1	70.0	78.2	7.0	29.8	72.5	80.2	5.0	26.3
G	69.2	80.1	6.0	29.0	70.7	80.1	7.0	25.7	71.7	81.1	7.0	26.4
G	69.9	80.1	7.0	30.3	71.3	80.2	7.0	26.3	73.9	82.3	8.0	26.1

†ksi  
#ksi √in.

Table 6  
Plate (1" Thick) Tensile Properties at 2% Stretch

Alloy	Aged 25 hr. at 325°F				Aged 30 hr. at 325°F				Aged 35 hr. at 325°F			
	Tensile Yield Strength	Ultimate Tensile Strength	% Elongation	Fracture Toughness	Tensile Yield Strength	Ultimate Tensile Strength	% Elongation	Fracture Toughness	Tensile Yield Strength	Ultimate Tensile Strength	% Elongation	Fracture Toughness
A	66.8	75.6	8.0	33.0	67.7	76.0	7.0	32.2	71.5	77.9	10.0	31.3
A	67.2	75.6	10.0	34.0	68.4	76.9	10.0	31.4	70.1	77.4	10.0	29.6
B	73.7	79.8	8.0	36.2	74.3	80.4	9.0	36.0	73.5	80.7	8.0	35.3
B	76.0	83.1	8.0	36.2	76.3	82.5	7.0	34.8	73.2	80.1	7.0	33.4
C	73.9	83.0	9.0	35.6	76.4	84.3	8.0	33.8	77.6	84.8	8.0	34.9
C	75.6	83.9	7.0	35.0	76.6	84.5	7.0	35.7	78.5	86.2	8.0	33.8
D	77.8	84.9	8.0	37.2	79.4	86.1	9.0	34.8	73.5	80.9	7.0	34.7
D	76.6	84.5	7.0	34.5	79.1	86.5	7.0	36.2	76.0	83.1	7.0	36.1
E	77.4	86.6	7.0	34.3	77.7	86.7	8.0	33.9	79.5	87.6	6.0	33.9
E	78.4	87.4	7.0	34.9	77.9	86.8	7.0	32.5	77.1	85.8	7.0	32.8
F	83.1	88.1	7.0	33.0	79.4	85.5	9.0	32.2	78.4	85.2	7.0	31.3
F	79.5	84.8	8.0	34.2	79.7	85.3	8.0	31.4	80.7	87.3	8.0	29.6
G	80.3	86.3	8.0	32.5	79.8	86.1	7.0	30.8	80.8	85.8	6.0	30.6
G	78.6	85.3	9.0	33.5	83.7	89.1	7.0	31.2	78.8	84.7	8.0	31.8

ksi  
#ksi/in.  
1 ksi/in. = 1.0988 MPa/√m  
1" = 2.54cm

Table 7  
Plate (1" Thick) Tensile Properties at 6% Strain

Alloy	Aged 15 hr. at 325°F				Aged 20 hr. at 325°F				Aged 25 hr. at 325°F			
	Tensile Yield Strength	Ultimate Tensile Strength	% Elongation	Fracture Toughness#	Tensile Yield Strength	Ultimate Tensile Strength	% Elongation	Fracture Toughness#	Tensile Yield Strength	Ultimate Tensile Strength	% Elongation	Fracture Toughness#
A	68.4	75.2	9.0	34.4	72.4	78.4	8.0	31.6	73.4	79.1	9.0	29.3
A	68.0	74.9	9.0	33.3	72.7	78.2	8.0	30.7	73.3	79.1	12.0	31.6
B	75.7	81.8	6.0	39.7	78.0	83.5	7.0	36.0	80.4	84.2	8.0	37.5
B	75.1	81.5	6.0	36.8	77.0	81.9	8.0	39.7	80.3	84.5	8.0	38.0
C	78.0	85.3	7.0	35.3	81.5	88.6	9.0	37.5	84.5	89.9	8.0	35.8
C	77.4	85.2	8.0	37.3	82.7	87.9	7.0	35.6	84.2	89.3	8.0	34.2
D	75.8	83.2	9.0	37.3	76.7	83.6	6.0	38.1	81.3	86.6	8.0	33.7
D	74.1	81.7	7.0	36.5	77.9	84.9	7.0	35.4	82.2	87.9	6.0	34.3
E	79.2	85.5	7.0	39.5	84.1	88.1	5.0	36.6	85.1	88.3	6.0	34.0
E	79.4	86.2	7.0	38.0	84.8	89.6	9.0	36.4	85.0	89.4	6.0	34.9
F	81.8	86.9	6.0	34.8	84.8	86.8	9.0	31.2	82.2	86.6	7.0	34.7
F	81.6	86.8	9.0	37.0	81.5	88.6	8.0	36.0	81.8	87.8	7.0	32.5
G	77.8	83.3	6.0	33.9	89.5	86.6	7.0	34.0	80.9	85.6	6.0	32.7
G	80.7	86.3	7.0	33.6	79.6	84.8	7.0	32.8	79.4	84.3	7.0	33.7

#ksi  
#ksi / in.

**Table 8**  
**Stress Corrosion Cracking Results for Die Forgings**  
**Short Transverse Properties**

Alloy	Age (hr./°F)	25 ksi*		40 ksi*	
		F/N**	Days***	F/N**	Days***
A	20/350	3/3	1,1,4	3/3	1,2,2
A	40/350	3/3	4,7,12	3/3	2,3,4
B	20/350	2/3	7,15	3/3	4,11,11
B	40/350	3/3	1,3,3	3/3	1,1,1
C	20/350	3/3	1,3,2	3/3	1,1,1
C	40/350	3/3	1,3,3	3/3	1,1,1
D	20/350	0/3	—	3/3	1,2,7
D	40/350	0/3	—	1/3	6
E	20/350	0/3	—	0/3	—
E	40/350	0/3	—	1/3	25
F	20/350	0/3	—	0/3	—
F	40/350	0/3	—	0/3	—
G	20/350	0/3	—	0/3	—
G	40/350	0/3	—	0/3	—

One eighth inch diameter smooth tensile bars tested in 3.5 wt.% NaCl solution by alternate immersion for 30 days, per ASTM G44.

\*Ksi=Thousand pounds per square inch.

\*\*F/N=Number of specimens that failed/Number of specimens in test.

\*\*\*Days=Days to failure.

**Table 9**  
**Forging Properties (U. L.T.)**

Alloy	Aged 20 hr. at 350°F				Aged 30 hr. at 350°F				Aged 40 hr. at 350°F			
	Tensile Yield Strength	Ultimate Tensile Strength	% Elongation	Fracture Toughness	Tensile Yield Strength	Ultimate Tensile Strength	% Elongation	Fracture Toughness	Tensile Yield Strength	Ultimate Tensile Strength	% Elongation	Fracture Toughness
A	65.2	70.1	7.1	35.2	68.3	75.4	4.0	32.7	70.9	78.9	4.0	30.6
A	67.7	74.3	4.0	37.9	69.2	74.1	4.0	28.6	76.2	81.8	8.6	-
B	81.6	88.1	5.0	42.6	77.4	83.6	6.0	30.9	86.4	90.6	6.0	19.2
B	80.7	87.8	5.0	37.6	79.4	85.2	8.0	22.5	82.1	87.8	6.0	-
C	82.8	88.2	8.0	29.1	84.0	90.1	8.0	15.5	81.5	86.6	8.0	24.4
C	85.7	90.9	6.0	10.9	82.7	85.8	8.0	10.3	83.8	88.6	7.0	-
D	81.8	86.8	6.0	27.0	88.3	91.9	6.0	22.7	80.2	86.0	6.0	21.1
D	81.4	85.1	4.0	28.0	89.8	92.4	5.0	-	82.3	86.7	5.0	-
E	78.8	85.9	8.0	27.7	81.6	87.3	5.0	24.1	82.4	87.4	6.0	24.1
E	85.2	80.9	7.0	24.4	85.5	89.8	7.0	25.5	84.5	88.8	6.0	-
F	77.8	83.8	6.0	21.6	83.2	87.6	4.0	15.2	83.0	88.1	5.0	16.7
F	76.8	83.9	5.0	20.1	80.2	87.8	5.0	16.3	89.2	93.7	6.0	-
G	87.0	87.9	5.0	28.5	87.1	92.2	5.0	36.0	81.7	87.0	6.0	29.3
G	78.4	85.9	5.0	25.9	86.6	91.6	5.0	28.5	82.8	88.7	5.0	-

†ksi  
#ksi √in.

55 **Claims**

1. An aluminum base alloy suitable for forming into a wrought product having improved combinations of strength, corrosion resistance and fracture toughness, the alloy comprised of 0.2 to 5.0 wt.% Li, 0.05 to



6.0 wt.% Mg, 2.45 to less than 4.0 wt.% Cu, 0.01 to 0.16 wt.% Zr, 0.05 to 2.0 wt.% Zn, 0.5 wt.% max. Fe, 0.5 wt.% max. Si and optional components consisting of 0 to 1.0 wt.% Mn, 0.05 to 0.2 wt.% Cr, V, Hf, Ti; the balance aluminum and incidental impurities, and having an Mg-Zn ratio of 0.1 to less than 1.0 when Mg is in the range of 0.1 to 1.0 wt.%.

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2. The alloy in accordance with claim 1, wherein the combination of Li and Cu does not exceed 5.5 wt.% with Li being at least 1.5 wt.%.

3. The alloy in accordance with claim 1 or 2, wherein:

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Li is from 1.5 to 3.0;  
Mg is from 0.2 to 2.5;  
Zr is from 0.05 to 0.12 wt.%;  
Cu is from 2.55 to 2.90 wt.%; and  
Zn is from 0.2 to 2.0 wt.%.

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4. The alloy in accordance with claim 1, 2 or 3, wherein:

Li is 1.8 to 2.5 wt.%; and  
Mg is 0.2 to 2.0 wt.%.

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5. A product in accordance with any of claims 1 to 4, wherein the product has a solid state plate-shaped precipitate in the planes, the alloy product developing a number density of precipitates per cubic centimeter of at least  $1.0 \times 10^{15}$  in an unstretched condition prior to aging and having a specific strength as defined herein of greater than  $83.2 \times 10^6$  MPa kg/m<sup>3</sup> ( $0.75 \times 10^6$  ksi in<sup>3</sup>/lb).

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6. The alloy in accordance with any of claims 1 to 5, having a solid state plate-shaped precipitate in the family of 1,0,0 planes, the alloy product having a number density of precipitates per cubic centimeter in the range of  $1 \times 10^{16}$  to  $5.6 \times 10^{16}$  and having a specific tensile yield strength as defined herein of greater than  $88.0 \times 10^6$  MPa kg/m<sup>3</sup> ( $0.8 \times 10^6$  ksi in<sup>3</sup>/lb).

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7. The alloy in accordance with any of claims 1 to 6, having an Mg-Zn ratio of 0.2 to 0.9, or of 0.3 to 0.8.

8. The alloy in accordance with any one of claims 1 to 7, wherein Zr is 0.05 to 0.12 wt. %, the product having imparted thereto, prior to an aging step, a working effect equivalent to stretching so that after an aging step the product has improved combinations of strength and toughness.

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9. The alloy in accordance with claim 8, wherein said working effect is equivalent to stretching said product in an amount greater than its original length, said amount being chosen from 1 to 14%, 1 to 10% or 1 to 8%.

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10. A method of producing an unrecrystallized aluminum-lithium wrought product having improved levels of strength, fracture toughness and corrosion resistance, the method comprising the steps of:

(a) providing a body of a lithium containing aluminum base alloy as defined in any of claims 1 to 6,  
(b) heating the body to a hot working temperature;  
(c) hot working the body to provide a wrought product; and

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(d) solution heat treating, quenching and aging said product to provide a substantially unrecrystallized product having improved levels of strength and fracture toughness.

11. Method of making aluminum base alloy products having combinations of improved strength, corrosion resistance and fracture toughness, the method comprising the steps of:

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(a) providing a lithium-containing aluminum base alloy product consisting essentially of 0.2 to 5.0 wt.% Li, 0.05 to 6.0 wt.% Mg, 2.45 to 2.95 wt.% Cu, 0.05 to 0.12 wt.% Zr, 0.2 to 2.0 wt.% Zn, 0.5 wt.% max. Fe, 0.5 wt.% max. Si, the balance aluminum and incidental impurities, and having an Mg-Zn ratio of 0.1 to less than 1.0 when Mg is in the range of 0.1 to 1.0 wt.%; and

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(b) imparting to said product, prior to an aging step, a working effect equivalent to stretching said product at room temperature in order that, after an aging step, said product can have improved combinations of strength and fracture toughness in addition to corrosion resistance.

**Patentansprüche**

1. Legierung auf Aluminiumbasis, die zu einem Halbzeug geformt werden kann, das in Kombination eine verbesserte Festigkeit, Korrosionsbeständigkeit und Bruchzähigkeit besitzt, wobei die Legierung aus 0,2 bis 5,0 Gew.-% Li, 0,05 bis 6,0 Gew.-% Mg, 2,45 bis weniger als 4,0 Gew.-% Cu, 0,01 bis 0,16 Gew.-% Zr, 0,05 bis 2,0 Gew.-% Zn, max. 0,5 Gew.-% Fe, max. 0,5 Gew.-% Si besteht und wahlweise 0 bis 1,0 Gew.-% Mn, 0,05 bis 0,2 Gew.-% Cr, V, Hf, Ti enthält; der Rest ist Aluminium und zufällige Verunreinigungen, und die Legierung besitzt ein Mg-Zn-Verhältnis von 0,1 bis weniger als 1,0, wenn Mg im Bereich von 0,1 bis 1,0 Gew.-% vorhanden ist.
2. Legierung nach Anspruch 1, dadurch gekennzeichnet, daß die Kombination aus Li und Cu 5,5 Gew.-% nicht übersteigt, wobei Li mindestens 1,5 Gew.-% ausmacht.
3. Legierung nach Anspruch 1 oder 2, dadurch gekennzeichnet, daß
  - Li 1,5 bis 3,0 Gew.-%;
  - Mg 0,2 bis 2,5 Gew.-%;
  - Zr 0,05 bis 0,12 Gew.-%;
  - Cu 2,55 bis 2,90 Gew.-%; und
  - Zn 0,2 bis 2,0 Gew.-% ausmacht.
4. Legierung nach Anspruch 1, 2 oder 3, dadurch gekennzeichnet, daß
  - Li 1,8 bis 2,5 Gew.-%; und
  - Mg 0,2 bis 2,0 Gew.-% ausmacht.
5. Produkt nach einem der Ansprüche 1 bis 4, dadurch gekennzeichnet, daß das Produkt einen festen plättchenförmigen Niederschlag in den Ebenen besitzt, wobei das Legierungsprodukt im ungestreckten Zustand vor dem Vergüten eine Niederschlagsdichte pro Kubikzentimeter von mindestens  $1,0 \times 10^{15}$  und eine hierin definierte spezifische Festigkeit von mehr als  $83,2 \times 10^6$  MPa kg/m<sup>3</sup> ( $0,75 \times 10^6$  ksi in<sup>3</sup>/lb) besitzt.
6. Legierung nach einem der Ansprüche 1 bis 5 mit einem festen plättchenförmigen Niederschlag in der Gruppe der Ebenen 1, 0 und 0, wobei das Legierungsprodukt eine Niederschlagsdichte pro Kubikzentimeter im Bereich von  $1 \times 10^{16}$  bis  $5,6 \times 10^{16}$  und eine hierin definierte spezifische Zugfestigkeit von mehr als  $88,0 \times 10^6$  MPa kg/m<sup>3</sup> ( $0,8 \times 10^6$  ksi in<sup>3</sup>/lb) besitzt.
7. Legierung nach einem der Ansprüche 1 bis 6 mit einem Mg-Zn-Verhältnis von 0,2 bis 0,9 oder von 0,3 bis 0,8.
8. Legierung nach einem der Ansprüche 1 bis 7, dadurch gekennzeichnet, daß Zr 0,05 bis 0,12 Gew.-% ausmacht, wobei das Produkt vor dem Vergüten einer dem Strecken äquivalenten Bearbeitung unterzogen wurde, so daß das Produkt nach dem Vergüten in Kombination eine verbesserte Festigkeit und Zähigkeit aufweist.
9. Legierung nach Anspruch 8, dadurch gekennzeichnet, daß die Bearbeitung dem Strecken des Produktes auf mehr als seine ursprüngliche Länge entspricht, wobei der Betrag des Streckens wahlweise 1 bis 14%, 1 bis 10% oder 1 bis 8% ausmacht.
10. Verfahren zur Herstellung eines nicht wieder auskristallisierten Aluminium-Lithium-Halbzeugs mit einer verbesserten Festigkeit, Bruchzähigkeit und Korrosionsbeständigkeit, wobei das Verfahren die folgenden Schritte umfaßt:
  - (a) Bereitstellen eines Körpers aus Lithium, der eine Legierung auf Aluminiumbasis nach einem der Ansprüche 1 bis 6 enthält;
  - (b) Erhitzen des Körpers auf eine Warmformtemperatur;
  - (c) Warmformen des Körpers zu einem Halbzeug; und
  - (d) Lösungsglühen, Abschrecken und Vergüten des Produkts, so daß man ein im wesentlichen nicht wieder auskristallisiertes Produkt mit einer verbesserten Festigkeit und Bruchzähigkeit erhält.

11. Verfahren zur Herstellung von Legierungsprodukten auf Aluminiumbasis, die in Kombination eine verbesserte Festigkeit, Korrosionsbeständigkeit und Bruchzähigkeit aufweisen, wobei das Verfahren die folgenden Schritte umfaßt:

- 5 (a) Bereitstellen eines lithiumhaltigen Legierungsproduktes auf Aluminiumbasis, das im wesentlichen aus 0,2 bis 5,0 Gew.-% Li, 0,05 bis 6,0 Gew.-% Mg, 2,45 bis 2,95 Gew.-% Cu, 0,05 bis 0,12 Gew.-% Zr, 0,2 bis 2,0 Gew.-% Zn, max. 0,5 Gew.-% Fe, max. 0,5 Gew.-% Si besteht, der Rest ist Aluminium und zufällige Verunreinigungen, und das Produkt hat ein Mg-Zn-Verhältnis von 0,1 bis weniger als 1,0, wenn Mg im Bereich von 0,1 bis 1,0 Gew.-% vorhanden ist; und
- 10 (b) das Produkt wird vor dem Vergüten einer dem Strecken des Produktes bei Raumtemperatur äquivalenten Bearbeitung unterzogen, so daß das Produkt nach dem Vergüten in Kombination eine verbesserte Festigkeit und Bruchzähigkeit sowie außerdem eine verbesserte Korrosionsbeständigkeit aufweist.

### Revendications

- 15 1. Alliage à base d'aluminium pouvant être mis sous forme d'un produit façonné ayant des combinaisons améliorées de résistance mécanique, de résistance à la corrosion et de ténacité à la rupture, l'alliage étant constitué par 0,2 à 5,0 % en poids de Li, 0,05 à 6,0 % en poids de Mg, 2,45 à moins de 4,0 % en poids de Cu, 0,01 à 0,16 % en poids de Zr, 0,05 à 2,0 % en poids de Zn, 0,5 % en poids au maximum de Fe, 0,5 % en poids au maximum de Si et des constituants éventuels consistant en 0 à 1,0 % en poids de Mn, 0,05 à 0,2 % en poids de Cr, V, Hf, Ti, le complément étant constitué par de l'aluminium et des impuretés éventuelles, et ayant un rapport Mg-Zn de 0,1 à moins de 1,0 lorsque Mg représente 0,1 à 1,0 % en poids.
- 20 2. Alliage selon la revendication 1, dans lequel la combinaison de Li et Cu ne dépasse pas 5,5 % en poids, Li représentant au moins 1,5 % en poids.
3. Alliage selon la revendication 1 ou 2, dans lequel :
- 30 Li représente 1,5 à 3,0 % en poids ;  
Mg représente 0,2 à 2,5 % en poids ;  
Zr représente 0,05 à 0,12 % en poids ;  
Cu représente 2,55 à 2,90 % en poids ; et  
Zn représente 0,2 à 2,0 % en poids.
- 35 4. Alliage selon la revendication 1, 2 ou 3, dans lequel :  
Li représente 1,8 à 2,5 % en poids ; et  
Mg représente 0,2 à 2,0 % en poids.
- 40 5. Produit selon l'une quelconque des revendications 1 à 4, dans lequel le produit a un précipité solide en forme de plaque dans les plans, le produit à base d'alliage développant un nombre volumique de précipités par  $\text{cm}^3$  d'au moins  $1,0 \times 10^{15}$  dans un état non étiré avant le vieillissement et ayant une résistance mécanique spécifique telle qu'elle est définie ici supérieure à  $83,2 \times 10^6 \text{ MPa kg/m}^3$  ( $0,75 \times 10^6 \text{ ksi in}^3/\text{lb}$ ).
- 45 6. Alliage selon l'une quelconque des revendications 1 à 5, ayant un précipité solide en forme de plaque dans la famille des plans 1,0,0, le produit à base d'alliage ayant un nombre volumique de précipités par  $\text{cm}^3$  situé dans la plage de  $1 \times 10^{16}$  à  $5,6 \times 10^{16}$  et ayant une limite apparente d'élasticité spécifique telle qu'elle est définie ici supérieure à  $88,0 \times 10^6 \text{ MPa kg/m}^3$  ( $0,8 \times 10^6 \text{ ksi in}^3/\text{lb}$ ).
- 50 7. Alliage selon l'une quelconque des revendications 1 à 6, ayant un rapport Mg-Zn de 0,2 à 0,9 ou de 0,3 à 0,8.
- 55 8. Alliage selon l'une quelconque des revendications 1 à 7, dans lequel Zr représente 0,05 à 0,12 % en poids, un effet de façonnage équivalent à un étirage étant communiqué au produit, avant une étape de vieillissement, de sorte que, après une étape de vieillissement, le produit présente des combinaisons améliorées de résistance mécanique et de ténacité.

9. Alliage selon la revendication 8, dans lequel ledit effet de façonnage est équivalent à un étirage dudit produit en une quantité supérieure à sa longueur initiale, ladite quantité étant choisie entre 1 et 14 %, 1 et 10 % ou 1 et 8 %.

5 10. Procédé de production d'un produit façonné à base d'aluminium-lithium non recristallisé ayant des niveaux améliorés de résistance mécanique, de ténacité à la rupture et de résistance à la corrosion, le procédé comprenant les étapes consistant à :

(a) fournir un corps en un alliage à base d'aluminium contenant du lithium tel qu'il est défini dans l'une quelconque des revendications 1 à 6,

10 (b) chauffer le corps à une température de façonnage à chaud ;

(c) façonner à chaud le corps pour fournir un produit façonné ; et

(d) soumettre ledit produit à un traitement thermique de mise en solution, à une trempe et à un vieillissement pour fournir un produit sensiblement non recristallisé ayant des niveaux améliorés de résistance mécanique et de ténacité à la rupture.

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11. Procédé de production de produits en alliage à base d'aluminium ayant des combinaisons de résistance mécanique, de résistance à la corrosion et de ténacité à la rupture améliorées, le procédé comprenant les étapes consistant à :

20 (a) fournir un produit en alliage à base d'aluminium contenant du lithium consistant essentiellement en 0,2 à 5,0 % en poids de Li, 0,05 à 6,0 % en poids de Mg, 2,45 à 2,95 % en poids de Cu, 0,05 à 0,12 % en poids de Zr, 0,2 à 2,0 % en poids de Zn, 0,5 % en poids au maximum de Fe, 0,5 % en poids au maximum de Si, le complément étant constitué par de l'aluminium et des impuretés éventuelles, et ayant un rapport Mg-Zn de 0,1 à moins de 1,0 lorsque Mg représente 0,1 à 1,0 % en poids ; et

25 (b) communiquer audit produit, avant une étape de vieillissement, un effet de façonnage équivalent à un étirage dudit produit à la température ambiante afin que, après une étape de vieillissement, ledit produit puisse avoir des combinaisons améliorées de résistance mécanique et de ténacité à la rupture en plus d'une résistance à la corrosion.

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# STRENGTH/TOUGHNESS RELATIONSHIP

AGING AT 325 °F

STRETCHED PLATE PRODUCTS

2% STRETCH

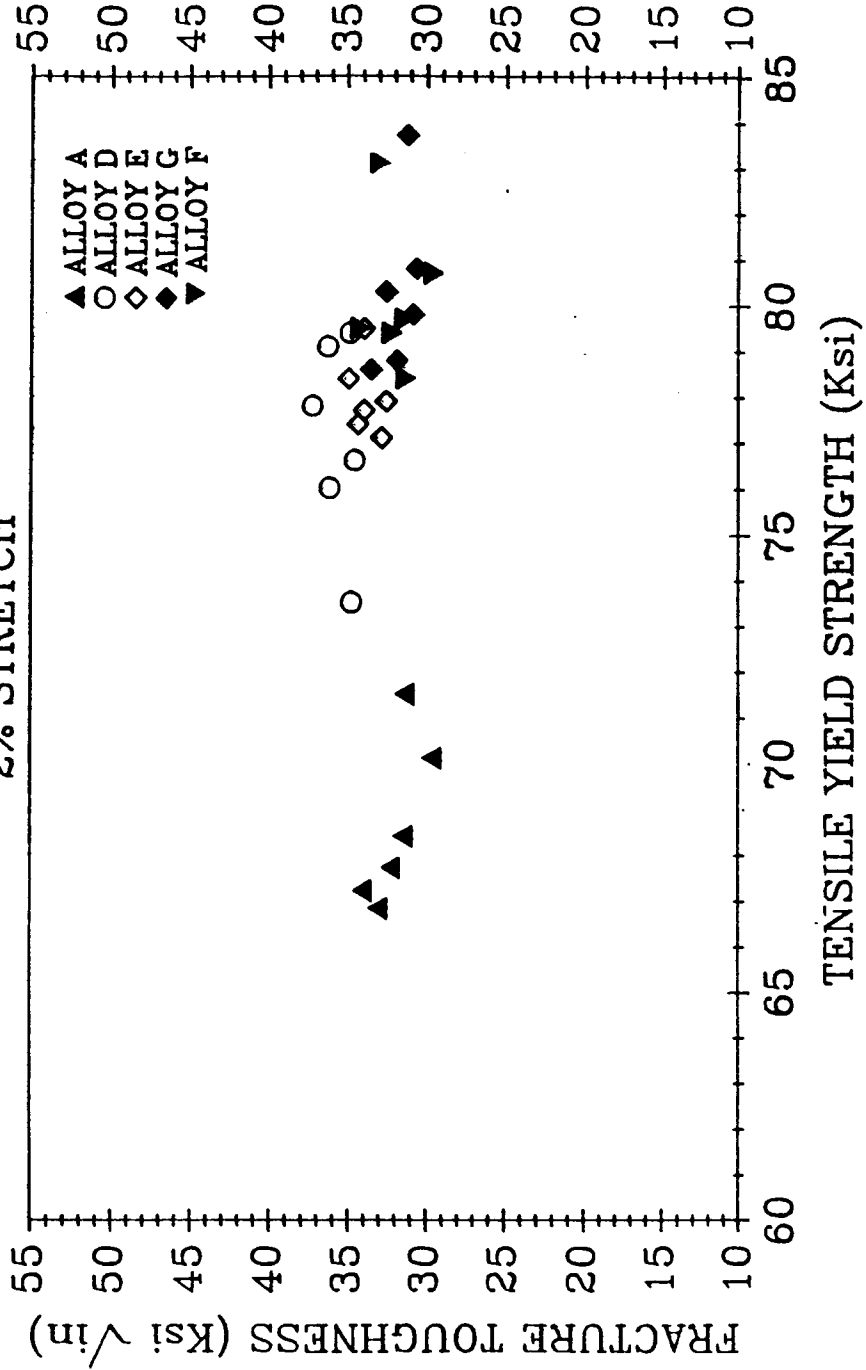


Figure 1

# FORGINGS

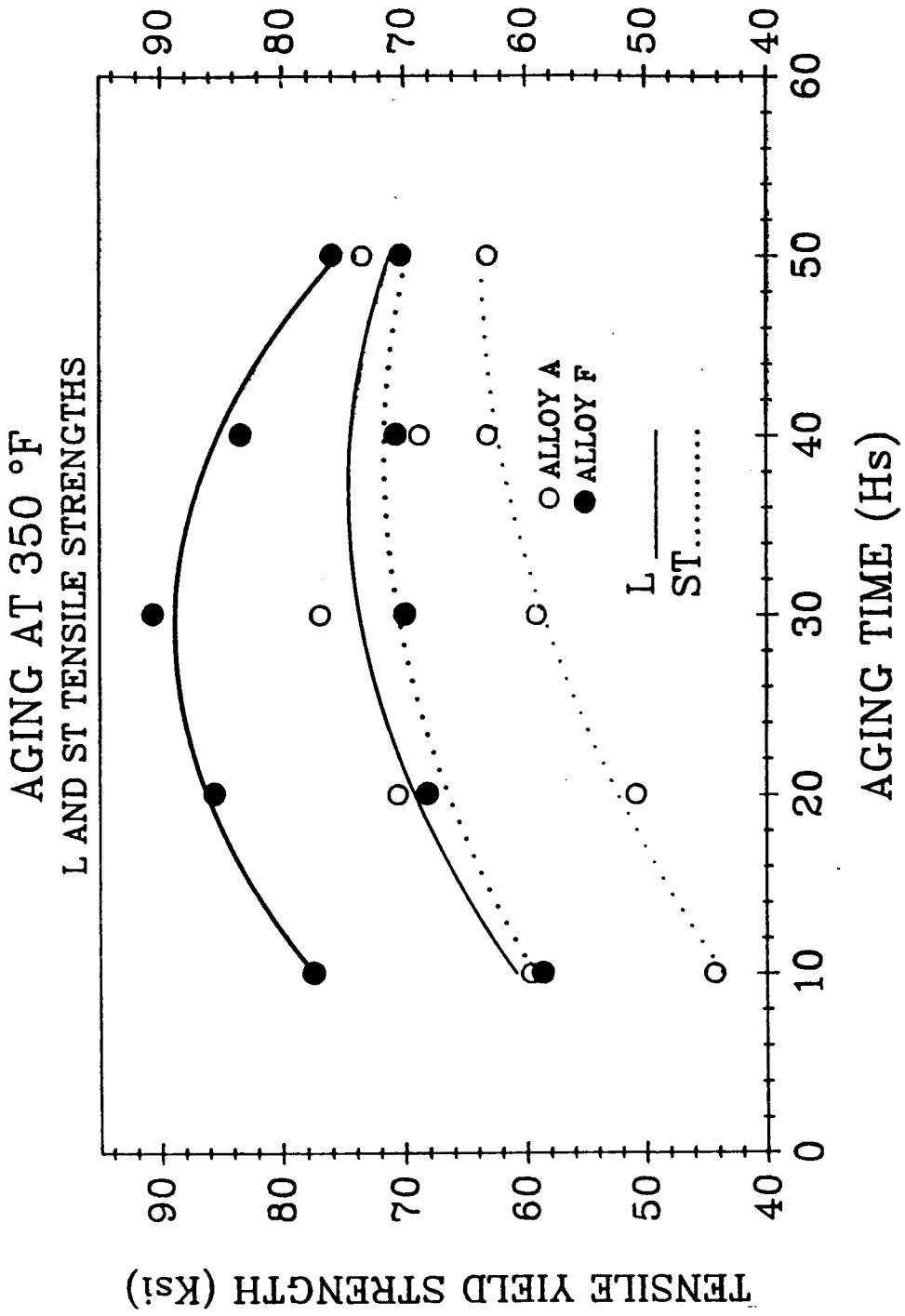


Figure 2

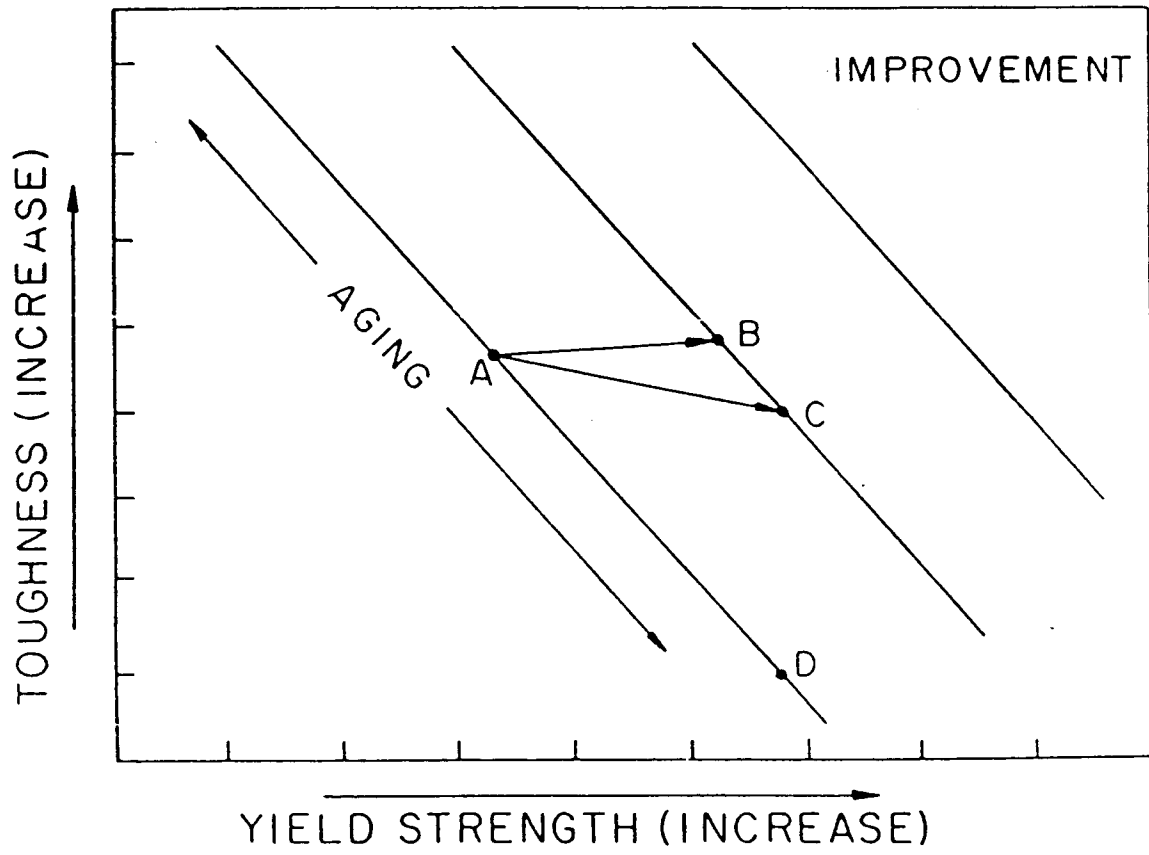


FIGURE 3