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(54) **Low temperature underaging of lithium bearing alloys.**

(57) The combination of strength and fracture toughness properties of aluminum-lithium alloys are significantly enhanced by underaging the alloys at temperatures ranging from 200°F to below 300°F for relatively long periods of time.

EP 0 250 656 A1

LOW TEMPERATURE UNDERAGING OF LITHIUM BEARING ALLOYSTechnical Field

5 The invention relates to aluminum alloys containing lithium as an alloying element, and particularly to a process for improving the fracture toughness of aluminum-lithium alloys without detracting from their strength.

Background of the Invention

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It has been estimated that some current large commercial transport aircraft may be able to save from 15 to 20 gallons of fuel per year for every pound of weight that can be saved when building the aircraft. Over the projected 20 year life of an airplane, this savings amounts to 300 to 400 gallons of fuel. At current fuel costs, a significant investment to reduce the structural weight of the aircraft can be made to improve overall economic efficiency of the aircraft.

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The need for improved performance in aircraft of various types can be satisfied by the use of improved engines, improved airframe design, or by the use of new or improved structural materials. Improvements in engines and aircraft design have been vigorously pursued, but only recently has the development of new and improved structural materials received commensurate attention, and their implementation in new aircraft designs is expected to yield significant gains in performance.

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Materials have always played an important role in dictating aircraft structural concepts. Since the early 1930's, structural materials for large aircraft have remained remarkably consistent, with aluminum being the primary material of construction in the wing, body and empennage, and with steel being utilized for landing gears and certain other speciality applications requiring very high strength. Over the past several years, however, several important new materials concepts have been under development for incorporation into aircraft structures. These include new metallic materials, metal matrix composites and resin matrix composites. It is believed by many that improved aluminum alloys and carbon fiber resin matrix will dominate aircraft structural materials in the coming decades. While composites will be used in increased percentages as aircraft structural materials, new lightweight aluminum alloys, and especially aluminum-lithium alloys show great promise for extending the usefulness of materials of this type.

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Heretofore, aluminum-lithium alloys have been used only sparsely in aircraft structures. The low use has been caused by their relatively low fracture toughness and by casting difficulties associated with lithium-bearing aluminum alloys compared to other more conventional aluminum alloys. Lithium additions to aluminum, however, provide a substantial lowering of the density which has been determined to be very important in decreasing the overall structural weight of aircraft. While substantial strides have been made in improving the aluminum-lithium processing technology, a major challenge is still to obtain a good blend of fracture toughness and high strength in these alloys.

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Summary of the Invention

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The present invention provides a method for aging aluminum-lithium alloys of various compositions at relatively low temperatures to develop a high and improved fracture toughness without reducing the strength of the alloy. Simply, after the alloy is formed into an article, solution heat treated and quenched, the alloy is aged at a relatively low temperature for a relatively long time. This process may be generally referred to as low temperature underaging. More specifically, the alloy can be aged at temperatures ranging from 200°F to below 300°F for a period of time ranging from 1 up to 80 or more hours. This low temperature aging regimen will result in an alloy having a greater fracture toughness, often on the order of 150 to 200 percent, than that of materials aged at conventional higher temperatures while maintaining an equivalent strength.

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Brief Description of the Drawing

A better understanding of the present invention can be derived by reading the ensuing specification in conjunction with the accompanying drawing wherein:

- 5 FIGURE 1 is a graph showing fracture toughness/strength combinations of several specimens of an aluminum-lithium alloy aged at various times and various temperatures as described in the Example.

Detailed Description of the Invention

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An aluminum-lithium alloy formulated in accordance with the present invention can contain from about 1.0 to about 3.2 percent lithium. The current data indicates that the benefits of the low temperature underaging are most apparent at lithium levels of 2.7 percent and below. All percentages herein are by weight percent (wt%) based on the total weight of the alloy unless otherwise indicated. Additional alloying
15 agents such as magnesium, copper and manganese can also be included in the alloy. Alloying additions function to improve the general engineering properties but also affect density somewhat. Zirconium is also present in these alloys as a grain refiner at levels between 0.08 to 0.15 percent. Zirconium is essential to the development of the desired combination of engineering properties in aluminum-lithium alloys, including those subjected to our low temperature underaging treatment.

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The impurity elements iron and silicon can be present in amounts up to 0.3 and 0.5 percent, respectively. It is preferred, however, that these elements be present only in trace amounts of less than 0.10 percent. Certain trace elements such as zinc and titanium may be present in amounts up to but not to exceed 0.25 percent and 0.15 percent, respectively. Certain other trace elements such as cadmium and chromium must each be held to levels of 0.05 percent or less. If these maximums are exceeded, the
25 desired properties of the aluminum-lithium alloy will tend to deteriorate. The trace elements sodium and hydrogen are also thought to be harmful to the properties of aluminum-lithium alloys and should be held to the lowest levels practically attainable, for example on the order of 15 to 30 ppm (0.0015-0.0030 wt%) maximum for the sodium and less than 15 ppm (0.0015 wt%) and preferably less than 1.0 ppm (0.0001 wt%) for the hydrogen. The balance of the alloy, of course, comprises aluminum.

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The following Table represents the proportions in which the alloying and trace elements may be present. The broadest ranges are acceptable under some circumstances, while the preferred ranges provide a better balance of fracture toughness and strength. The most preferred ranges yield alloys that presently provide the best set of overall properties for use in aircraft structures.

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TABLE

| 5 | Element | Amount (wt%) | | |
|----|----------------------|--------------|--------------|----------------|
| | | Acceptable | Preferred | Most Preferred |
| | Li | 1.0 to 3.2 | 1.5 to 3.0 | 1.8 to 2.7 |
| 10 | Mg | 0 to 5.5 | 0 to 4.2 | 0 to 3.2 |
| | Cu | 0 to 4.5 | 0 to 3.7 | 0.5 to 3.0 |
| | Zr | 0.08 to 0.15 | 0.08 to 0.15 | 0.08 to 0.15 |
| 15 | Mn | 0 to 1.2 | 0 to 0.8 | 0 to 0.6 |
| | Fe | 0.3 max | 0.15 max | 0.10 max |
| | Si | 0.5 max | 0.12 max | 0.10 max |
| | Zn | 0.25 max | 0.10 max | 0.10 max |
| 20 | Ti | 0.15 max | 0.10 max | 0.10 max |
| | Na | 0.0030 max | 0.0015 max | 0.0015 max |
| | H | 0.0015 max | 0.0005 max | 0.0001 max |
| 25 | Other trace elements | | | |
| | each | 0.05 max | 0.05 max | 0.05 max |
| | total | 0.25 max | 0.25 max | 0.25 max |
| 30 | Al | Balance | Balance | Balance |

An aluminum-lithium alloy formulated in the proportions set forth in the foregoing paragraphs and Table is processed into an article utilizing known techniques. The alloy is formulated in molten form and cast into
 35 an ingot. The ingot is then homogenized at temperatures ranging from 925°F to approximately 1000°F. Thereafter, the alloy is converted into a usable article by conventional mechanical forming techniques such as rolling, extrusion or the like. Once an article is formed, the alloy is normally subjected to a solution treatment at temperatures ranging from 950°F to 1010°F, followed by quenching into a medium such as water that is maintained at a temperature on the order of 70°F to 150°F. If the alloy has been rolled or
 40 extruded, it is generally stretched on the order of 1 to 3 percent of its original length to relieve internal stresses and improve engineering properties. The aluminum alloy may then be further worked and formed into the various shapes for its final application. Additional heat treatments such as those outlined above may then be employed if desired.

Thereafter, in accordance with the present invention, the article is subjected to an aging treatment that
 45 will increase the strength of the material while maintaining its fracture toughness and other engineering properties at relatively high levels. In accordance with the present invention, the article is subjected to a low temperature underage heat treatment at temperatures ranging from about 200°F to less than 300°F. Low temperature underaging at temperatures in the range of from about 250°F to about 275°F is considered preferred for most alloys, taking into consideration the economic impetus for minimizing the time spent in
 50 commercial heat-treatment facilities. At the higher temperatures, less time is needed to bring about the proper balance between strength and fracture toughness than at lower aging temperatures, but the overall property mix will be slightly less desirable. For example, when the aging is conducted at temperatures on the order of 275°F to just below 300°F, it is preferred that the product be subjected to the aging temperature for periods of from 1 to 40 hours. On the other hand, when aging is conducted at temperatures
 55 on the order of 250°F or below, aging times from 2 to 80 hours or more are preferred to bring about the proper balance between fracture toughness and strength. After the aging treatment, the aluminum-lithium article is cooled to room temperature.

When the low temperature underaging treatment is conducted in accordance with the parameters set forth above, the treatment will result in an aluminum-lithium alloy having an ultimate strength typically on the order of 45 to 95 ksi, depending on the composition of the particular alloy. The fracture toughness of the alloy will be greater, often on the order of 1 1/2 to 2 times greater, than that of similar aluminum-lithium alloys aged to equivalent strength levels by conventional aging treatments at temperatures greater than 300°F.

The following Example is presented to illustrate the superior strength and toughness combination achieved by low temperature underaging an aluminum-lithium alloy in accordance with the present invention and to assist one of ordinary skill in making and using the present invention. The following Example is not intended in any way to otherwise limit the scope of this disclosure or the protection granted by Letters Patent hereon.

EXAMPLE

An aluminum alloy containing 2.4 percent lithium, 1 percent magnesium, 1.3 percent copper, 0.15 percent zirconium with the balance being aluminum was formulated. The trace elements present in the formulation constituted less than 0.25 percent of the total. The iron and silicon present in the formulation constituted less than 0.07 percent each of the formulation. The alloy was cast and homogenized at 975°F. Thereafter, the alloy was hot rolled to a thickness of 0.2 inches. The resulting sheet was then solution treated at 975°F for about 1 hour. The sheet was then quenched in water maintained at about 70°F. Thereafter, the sheet was subjected to a stretch of 1 1/2 percent of its initial length and was then cut into specimens. Some specimens were cut to a size of 0.5 inch by 2.5 inch by 0.2 inch for precrack Charpy impact tests, a known method of measuring fracture toughness. Other specimens prepared for tensile strength tests were 1 inch by 4 inches by 0.2 inches. A plurality of specimens were then aged at 350°F for 4, 8, and 16 hours; at 325°F for 8, 16, and 48 hours; at 305°F for 8 hours; at 275°F for 16 and 40 hours; and at 250°F for 40 and 72 hours. Specimens aged at each of the temperatures and times were then subjected to precrack Charpy impact and tensile strength tests in accordance with standard testing procedures. The test values of the specimens aged at a particular temperature and time were then averaged. These average test values are set forth in the graph shown in FIGURE 1.

By examining FIGURE 1 it will be readily observed that specimens aged at temperatures greater than 300°F exhibited a toughness on the order of from 225 to 525 inch-pounds per square inch as measured by the Charpy impact test. In contrast, the specimens underaged at a low temperature in accordance with the present invention exhibited toughnesses on the order of 650 to almost 850 inch-pounds per square inch as indicated by the Charpy impact test. At the same time, the average strengths of the materials fell generally within the 64 to 71 ksi range, with the exception of the specimens aged at 350°F for 16 hours. (The 350°F age specimens, however, exhibited the lowest toughness of any of the specimens.) Thus, the test results indicate that aging at a temperature less than 300°F for a relatively long time will clearly provide a strength/toughness combination that is superior to that of specimens aged in accordance with conventional procedures at temperatures on the order of 325 to 350°F or more for relatively short periods of time. The test results also show that there is a remarkable improvement in the strength-toughness combination of properties as the aging temperature is lowered below 300°F, i.e., a higher fracture toughness for any given strength level.

The present invention has been described in relation to various embodiments, including the preferred processing parameters and formulations. One of ordinary skill after reading the foregoing specification will be able to effect various changes, substitutions of equivalents and other alterations without departing from the broad concepts disclosed herein. For example, it is contemplated that the subject low temperature underaging treatment may be applicable to other alloying combinations not now under development, and specifically to aluminum-lithium alloys with substantial amounts of zinc, silicon, iron, nickel, beryllium, bismuth, germanium, and/or zirconium. It is therefore intended that the scope of Letters Patent granted hereon will be limited only by the definition contained in the appended claims and equivalents thereof.

Claims

1. A process for improving the relative strength and fracture toughness of an aluminum alloy containing lithium as an alloying element, said alloy consisting essentially of:

| | <u>Element</u> | <u>Amount (wt%)</u> |
|----|----------------------|---------------------|
| | Li | 1.0 to 3.2 |
| 5 | Mg | 0 to 5.5 |
| | Cu | 0 to 4.5 |
| | Zr | 0.08 to 0.15 |
| | Mn | 0 to 1.2 |
| 10 | Fe | 0.3 max |
| | Si | 0.5 max |
| | Zn | 0.25 max |
| 15 | Ti | 0.15 max |
| | Other trace elements | |
| | each | 0.05 max |
| 20 | total | 0.25 max |
| | Al | Balance, |

said alloy first being formed into an article, solution heat treated and quenched, said process comprising the step of aging said alloy at temperatures ranging from about 200°F to less than 300°F for a period of time ranging from about one up to eighty or more hours.

2. The process of Claim 1 wherein said aging temperature is less than about 275°F.
3. The process of Claim 1 wherein said aging temperature is between about 250°F and about 275°F.
4. The process of Claim 1 wherein said aging temperature is less than about 250°F.
5. The process of Claim 1 wherein said alloy consists essentially of:

| | <u>Element</u> | <u>Amount (wt%)</u> |
|----|----------------------|---------------------|
| | Li | 1.5 to 3.0 |
| 35 | Mg | 0 to 4.2 |
| | Cu | 0 to 3.7 |
| | Zr | 0.08 to 0.15 |
| | Mn | 0 to 0.8 |
| 40 | Fe | 0.15 max |
| | Si | 0.12 max |
| | Zn | 0.10 max |
| 45 | Ti | 0.10 max |
| | Other trace elements | |
| | each | 0.05 max |
| 50 | total | 0.25 max |
| | Al | Balance. |

6. The process of Claim 5 wherein said alloy consists essentially of:

| | <u>Element</u> | <u>Amount (wt%)</u> |
|----|----------------------|---------------------|
| | Li | 1.8 to 2.7 |
| 5 | Mg | 0 to 3.2 |
| | Cu | 0.5 to 3.0 |
| | Zr | 0.08 to 0.15 |
| | Mn | 0 to 0.6 |
| 10 | Fe | 0.10 max |
| | Si | 0.10 max |
| | Zn | 0.10 max |
| 15 | Ti | 0.10 max |
| | Other trace elements | |
| | each | 0.05 max |
| 20 | total | 0.25 max |
| | Al | Balance. |

7. The product produced by the process of Claim 1.

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EP 86 20 1174

| DOCUMENTS CONSIDERED TO BE RELEVANT | | | |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------|------------------------------------------------|------------------------------------------------|
| Category | Citation of document with indication, where appropriate, of relevant passages | Relevant to claim | CLASSIFICATION OF THE APPLICATION (Int. Cl. 4) |
| X | EP-A-0 149 194 (BOEING) * Claims 1-6 * | 1-7 | C 22 F 1/04 C 22 C 21/00 |
| X | EP-A-0 149 193 (BOEING) * Claims 1-10 * | 1-7 | |
| X | EP-A-0 151 301 (BOEING) * Claims 1-10 * | 1-7 | |
| X | EP-A-0 156 995 (BOEING) * Claims 1-7 * | 1-7 | |
| X | EP-A-0 107 334 (SECRETARY OF STATE FOR DEFENCE) * Page 6, table II * | 1-7 | |
| A | WO-A-8 502 416 (CEGEDUR) * Claims 1-8 * | 1-7 | C 22 F 1/00 C 22 C 21/00 |
| A | EP-A-0 158 571 (CEGEDUR) | | |
| The present search report has been drawn up for all claims | | | |
| Place of search THE HAGUE | | Date of completion of the search 20-02-1987 | Examiner GREGG N.R. |
| <p>CATEGORY OF CITED DOCUMENTS</p> <p>X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document</p> <p>T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document</p> | | | |