An improved non-isothermal aging process for aluminum alloys is disclosed. The non-isothermal aging process enhances the aging process for 7000 series aluminum alloys. In particular embodiments, the process involves continuous heating increasing at a linear rate of about 25°F for about 11 hours and maintains high strength and corrosion properties. In an exemplary embodiment, a 7085 aluminum alloy containing 6 to 10 wt. % zirconium; 1.2 to 1.9 wt. % magnesium; 1.2 to 2.2 wt. % copper, with magnesium begin less than of equal to the weight % of copper plus 0.3%; and 0.05 to 0.4 wt. % zirconium, the balance aluminum, incidental elements and impurities is aged.
**Fig. 1**

**Linear Heating Rate**

- Temperature (°F)
- Time (hours)

**Fig. 2**

**Linear Heating Results - Yield Strength**

- Yield Strength
- Time (hours)
FIG. 3

Linear Heating Results - Conductivity

FIG. 4

Continuous Heating

Continuous Heating Results - Yield Strength

Fig. 5

Continuous Heating Results - Conductivity

Fig. 6
METHOD AND PROCESS OF NON-ISOTHERMAL AGING FOR ALUMINUM ALLOYS

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application is based on and claims the benefit of U.S. Provisional application Ser. No. 60/781,811, filed Mar. 13, 2006.

BACKGROUND

[0002] 1. Field

[0003] The present disclosure relates to non-isothermal heat treatments of aluminum alloys. More particularly, an improved aging process is disclosed for an aluminum alloy utilizing non-isothermal aging via linear heating.

[0004] 2. General Background

[0005] Precipitation hardenable alloys

[0006] Typically, aluminum which have been heat treated and quenched are then subjected to an aging process to enhance the certain physical properties, including tensile properties. Previously, all precipitation hardenable aluminum alloys have been aged utilizing isothermal aging methods, through either single or multistage treatments.

[0007] 7000 series aluminum alloys, which generally contain zinc, magnesium and copper, are used in a variety of applications due to its high strength in comparison to other Al-based alloys. The predominant strengthening mechanism in 7000 series alloy is precipitation hardening, where dislocation movement is inhibited by precipitates. The general precipitation sequence of 7000 aluminum alloy is as follows:

\[
\text{Super saturated solid solution} \rightarrow \text{GPZ} \rightarrow \eta (\text{MgZn}_2) \rightarrow \eta
\]

[0008] The first step in the precipitation sequence is the homogeneous nucleation of solute-rich Gunner-Preston (GP) zones. These zones serve as heterogeneous nucleation sites for the intermetallic precipitates. In 7000 series alloys, these zones nucleate as coherent spheres enriched in solute. As GP zones grow, they become less coherent and elastically strain the matrix which provides the initial increase in strength in the metal. Dislocation movement is inhibited by having to cut these elastically strained zones. Even though they increase strength, GP zones are not a new phase and still have the face centered cubic structure of the aluminum matrix. As pre-precipitation sites these zones lower the energy needed to precipitate the MgZn2 particles and serve as a more favorable site for precipitation than grain boundaries and dislocations. By promoting precipitation within the grains, the final alloy strength is increased. In order to prevent decreases in strength due to coarsened precipitates, it is important to obtain the finest size distribution of GP zones that will not dissolve at any given temperature. Therefore, heating rate is critical—a heating rate that is too fast will dissolve rather than grow the GP zones.

[0009] A fine dispersion of GP zones results in a fine dispersion of precipitates. The initial precipitate formed will be metastable \(\eta\), which is believed to be a monoclinic MgZn2 phase with a plate morphology. The maximum yield strength is due to these precipitates. Overaging begins when these metastable \(\eta\) precipitates transform into equilibrium hexagonal \(\eta\) phase particles. These particles coarsen as averaging continues, causing them to become incoherent with the matrix. This coarsening process causes a drop in yield strength because dislocation movement is made easier by Orowan looping. Orowan looping predominates because the interprecipitate spacing increases with precipitation coarsening. While cutting predominates during underaging and looping predominates during overaging, the maximum strength is obtained when both cutting and looping occur.

[0010] Current commercial aging practices of 7000-77X alloys (77X indicates overaged condition) include a pre-aging step at temperatures in the range of 225°F to 250°F. This duplex aging practice is employed because aging performed directly above 300°F results in the dissolution of GP Zones, which creates large precipitate-free zones and favors precipitation on dislocations and grain boundaries, both of which result in lower yield strength. Generally a single-step pre-age is used, but for products that are slowly quenched, pre-aging at two temperatures may be employed. For applications requiring high strength with adequate corrosion characteristics, a final aging step of 24 hours may be employed. This final aging step slightly increases yield strength (by a few ksi) without sacrificing other desirable material properties such as corrosion resistance.

[0011] The traditional aging process require long aging times and utilize high amounts of energy, increasing costs. For mold block applications, there is a need to develop an aging process that creates similar physical characteristics of the aluminum alloy at a more economic costs and efficient times.

SUMMARY

[0012] In one aspect of the present disclosure, a method is disclosed wherein an aluminum alloy is aged in a non-isothermal process. In an exemplary method, the aluminum alloy is heated at a linear rate of about 27°F for about 11 hours.

[0013] In particular embodiments, the 7000 series aluminum alloys are aged utilizing the non-isothermal aging process. By utilizing a non-isothermal linear heating rate, a per-aging step is eliminated aging time is drastically reduced. As a result, decreased costs are associated and become viable for more applications. For example, mold block applications are economically viable using this method.

[0014] In an exemplary embodiment, the 7085 aluminum alloy is aged using the disclosed method. The 7085 alloy comprises about 6 to 10 wt. % zinc; 1.2 to 1.9 wt. % magnesium; 1.2 to 2.2 wt. % copper, with magnesium begin less than of equal to the weight % of copper plus 0.3%; and 0.05 to 0.4 wt. % zirconium, the balance aluminum, incidental elements and impurities.

DRAWINGS

[0015] The foregoing aspects and advantages of present disclosure will become more readily apparent and understood with reference to the following detailed description, when taken in conjunction with the accompanying drawings, wherein:

[0016] FIG. 1 illustrates the linear heating rate of an exemplary aluminum alloy.
FIG. 2 illustrates the yield strength generated by heating an exemplary aluminum alloy at a linear rate as a function of time.

FIG. 3 illustrates the electrical conductivity of an exemplary aluminum alloy after heating the alloy at a linear rate as a function of time.

FIG. 4 illustrates the continuous heating rate run to a set point in a furnace.

FIG. 5 illustrates the yield strength generated by continuously heating an exemplary aluminum alloy to a set point as a function of time.

FIG. 6 illustrates the electrical conductivity of an exemplary aluminum alloy after continuously heating the alloy to a set point as a function of time.

DETAILED DESCRIPTION

In accordance with the present disclosure, an aluminum base alloy is aged in a non-isothermal process with continuous heating. By providing a continuously increasing heat rate, the separate aging stages at different temperatures can be replaced. In exemplary embodiments, the heating rate is increased linearly.

In addition to aluminum alloys, precipitation hardenable alloys can also be aged in a non-isothermal process. For example, copper and nickel alloys are precipitation hardenable alloys that could be aged using the disclosed non-isothermal aging process.

In particular embodiments, the non-isothermal aging method is used with 7000 series aluminum alloys. The 7000 series alloy comprises aluminum, about 1.5 to 14 wt. % zinc, 0.8 to 3.8 wt. % magnesium, 0.25 to 2.6 wt. % copper and at least one additional alloying element selected from the group consisting of 0.05 to 0.4 wt. % chromium, 0.1 to 0.75 wt. % manganese, 0.05 to 0.3 wt. % zirconium, 0.05 to 0.3 wt. % vanadium, 0.05 to 0.3 wt. % molybdenum and 0.05 to 0.3 wt. % tungsten, the ratio of magnesium to zinc being 0.2 to 0.5 parts by weight magnesium per part by weight of zinc. Other aluminum alloys may also be aged using the non-isothermal aging method. For example, 2000 series and 6000 series aluminum alloys may also be utilized in this aging process. In exemplary embodiments, the non-isothermal process is utilized for 7000 series alloys in overaged tempers.

In a particular embodiment, the alloy is continuously heated and increasing at rates less than about 25°F for about 11 hours. In particular embodiments, the 7000 series aluminum alloy is heated at this rate to reach linear heating of 7000 series aluminum alloys for about 11 hours demonstrates similar yield strength and resistance to corrosion as in previous aging techniques. In other embodiments, the temperature can be increased at a rate somewhere between 25 and 50°F per hour.

In exemplary embodiments, the alloy is continuously heated at increasing temperatures. In particular embodiments, the increase of the temperature is done at linear rates. However, heating does not have to be linear, but can also increase at varying rates as the process proceeds. In particular embodiments, the method commences at about 250°F.

In other embodiments, other aluminum alloys can also be aged by the non-isothermal process. For example, 6000 series alloys containing major alloying elements of magnesium and silicon and 2000 series alloys containing alloying elements of copper can be aged using the disclosed process. For other aluminum alloys, the temperature can be increased at much higher rates. In particular, the 6061 alloy can be increased at much higher rates.

In an exemplary embodiment, the aluminum 7085 alloy is aged using the disclosed process. The aluminum 7085 series alloy comprises about: 6 to 10 wt. % zinc; 1.2 to 1.9 wt. % magnesium; 1.2 to 2.2 wt. % copper, with magnesium begin less than of equal to the weight % of copper plus 0.3%, and 0.05 to 0.4 wt. % zirconium, the balance aluminum, incidental elements and impurities. In further exemplary embodiments, the 7085 alloy contains 6.9 to 8.5 wt. % zinc; 1.2 to 1.7 wt. % magnesium, and 1.3 to 2 wt. % copper.

In traditional aging processes, the 7085 aluminum alloy was heated in a four step procedure to create high strength and good corrosion resistance. First, the aluminum alloy would be heated at a first pre-age treatment at about 225°F for 4-5 hours and then heated in a second pre-age treatment at about 275°F for about 8 hours. A third aging treatment was completed at about 315°F for 17 hours. For extremely high strength applications where the increased cost is not as big of an issue, a final aging step is performed, heating the aluminum at 250°F for 24 hours.

Another multistage aging process has also been developed where the two-stage pre-ageing process is limited to a one-step pre-age treatment of heating the aluminum for 3 hours at 250°F. However, these aging times are still inefficient and result in higher costs for the aging of the alloy.

By linearly heating the aluminum alloy, the aging process is shortened by replacing the first step with slow continuous heating to 300°F and replacing the second stage with continuous heating above 300°F.

Samples of the 7085 alloy were linearly heated. First, the specimens were solution heat treated ½ hour at 890°F and air cooled. The slow cooling rate simulated the cooling rate achieved during quenching a thick 7085 mold block. The specimens were then naturally aged for 24 hours. Next, they were heated at linear rates of 25, 50, and 100°F/hr. The linear heating rate past 300°F was continued. One specimen for each heating group was removed after a time that would leave it in the underaged condition. Other specimens were removed at times selected using a model of overaging kinetics. A graph of heating rates with scheduled pull times is shown below in FIG. 1. Times were selected to provide peak strength and a number of overaged conditions about 4-5 ksi apart.

FIG. 2 shows the results of yield strength versus time for each linear heating rate, and FIG. 3 shows the electrical conductivity versus time for those same heating rates.

The yield strengths of the linearly heated specimens reveal that 7085 aluminum alloys heated at a rate of 250°F/hr developed higher yield strengths than material heated at higher rates. It is estimated that the maximum attainable yield strength of air cooled 7085 tensile speci-
mens is 60 ksi. This agrees favorably with the maximum yield strength observed in the material heated at 25 F/hr. Estimates obtained by using a value of 60 ksi for YSmax calculate that the 7085 alloys aged at 250 F/hr would attain 54 ksi yield strength in 10.9 hours. It is also calculated that 7085 continuously aged in the same manner for the equivalent of 17 hours at 315 F. would attain a yield strength of 51.4 ksi.

Samples were also run in a furnace run to a set point of 360, 380, and 400 F. A set point is the temperature at which the furnace set. By testing different set points the optimum practice that will yield the desired properties can be found. In these runs, the temperature was increased continuously by about 50 F. per hour. FIG. 4 shows simulated furnace heat-up for a load consisting of six 16&times;48&times;48" mold blocks with pull times predicted by integrating the isothermal overaging equations. As with the linear heating rate experiment, pull times were selected to provide peak strength and a number of overaged conditions about 4.5 ksi apart.

FIG. 5 shows the results of yield strength versus time for each set point, and FIG. 6 shows the electrical conductivity versus time for those same set points. Since the temperature increase was too high, the yield strengths did not reach the desired maximum attainable yield strength.

In accordance with the disclosed method, the need for pre-ageing treatments of 7000 series alloys is eliminated. Two stages of the prior aging process have been combined into one, greatly reducing the time involved in aging of the alloy. Consequently, the disclosed method greatly reduces the time to age the alloy mold blocks.

While the above description contains many particulars, these should not be considered limitations on the scope of the present disclosure, but rather a demonstration of embodiments thereof. The method of non-isothermal aging and the associated uses disclosed herein include any combination of the different species or embodiments disclosed. Accordingly, it is not intended that the scope of the present disclosure in any way be limited by the above description. The various elements of the claims and claims themselves may be combined in any combination, in accordance with the teachings of the present disclosure, which includes the claims.

What is claimed is:

1. A process for aging a precipitation hardenable alloy comprising continuously heating the alloy at a continuous rate of increasing temperatures a time sufficient to age the alloy.

2. The process of claim 1, wherein the precipitation hardenable alloy is a 7000 series aluminum alloy.

3. The process of claim 1, wherein the need for a pre-aging step is eliminated.

4. The process of claim 2, wherein the aluminum alloy comprises about 6 to 10 wt. % zinc; 1.2 to 1.9 wt. % magnesium; 1.2 to 2.2 wt. % copper with magnesium begin less than or equal to the weight % of copper and 0.05 to 0.4 wt. % zirconium, the balance aluminum, incidental elements and impurities.

5. The process of claim 1, wherein the aluminum alloy exhibits a yield strength of 54 ksi after the aging process is completed.

6. The process of claim 1 wherein the continuous rate is increased linearly.

7. A process for aging an aluminum alloy containing alloying amounts of zinc, magnesium, and copper comprising continuously heating the alloy at a continuous rate less than about 250 F. per hour for about 8-15 hours.

8. The process of claim 6, wherein the aluminum alloy is a 7000 series alloy.

9. The process of claim 6, wherein the need for a pre-aging step is eliminated.

10. The process of claim 6, wherein the aluminum alloy comprises about 6 to 10 wt. % zinc; 1.2 to 1.9 wt. % magnesium; 1.2 to 2.2 wt. % copper with magnesium begin less than or equal to the weight % of copper and 0.05 to 0.4 wt. % zirconium, the balance aluminum, incidental elements and impurities.

11. The process of claim 6, wherein the aluminum alloy exhibits a yield strength of 54 ksi after the aging process is completed.

12. A process for aging an aluminum alloy containing alloying amounts of zinc, magnesium, and copper comprising continuously heating the alloy at a continuous rate of less than about 250 F. per hour for about 11 hours.

13. The process of claim 11, wherein the aluminum alloy is a 7000 series alloy.

14. The process of claim 11, wherein the need for a pre-aging step is eliminated.

15. The process of claim 11, wherein the aluminum alloy comprises about 6 to 10 wt. % zinc; 1.2 to 1.9 wt. % magnesium; 1.2 to 2.2 wt. % copper, with magnesium begin less than or equal to the weight % of copper and 0.05 to 0.4 wt. % zirconium, the balance aluminum, incidental elements and impurities.

16. The process of claim 11, wherein the aluminum alloy exhibits a yield strength of 54 ksi after the aging process is completed.

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