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(19) **United States**(12) **Patent Application Publication****Ogris et al.**(10) **Pub. No.: US 2005/0000608 A1**(43) **Pub. Date: Jan. 6, 2005**(54) **ALUMINUM-SILICON ALLOYS HAVING
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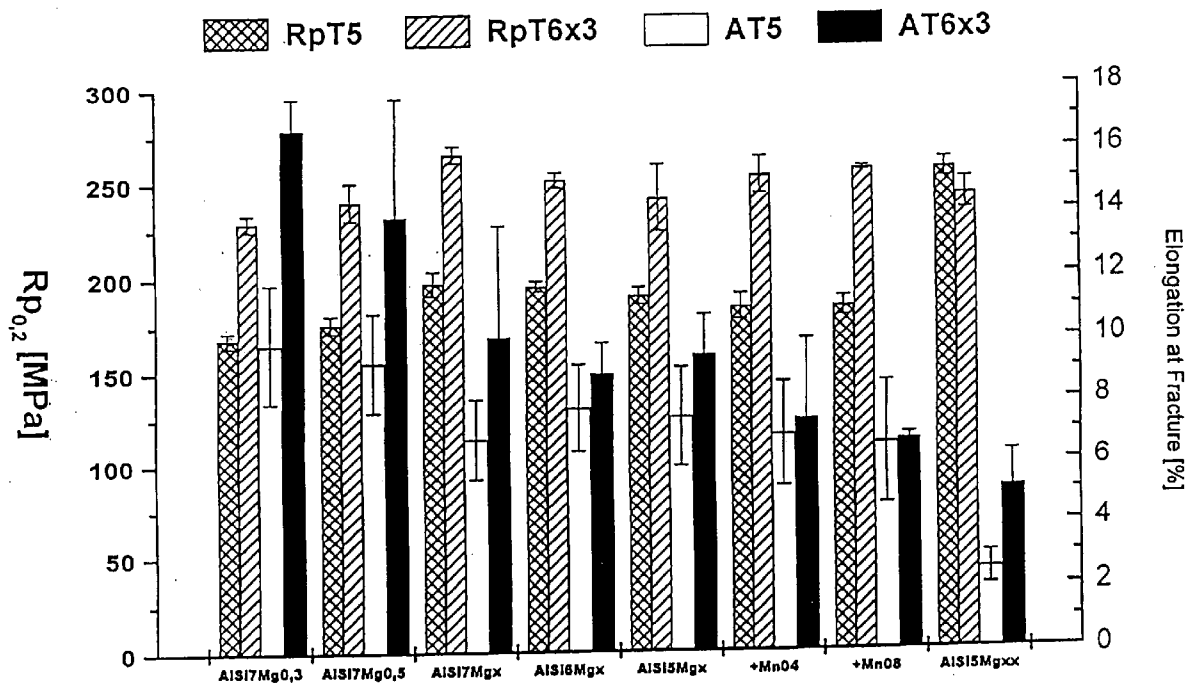
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schaft, Lend (AT)**(21) Appl. No.: **10/837,665**(22) Filed: **May 4, 2004****Related U.S. Application Data**(63) Continuation of application No. PCT/AT02/00309,
filed on Nov. 5, 2002.(30) **Foreign Application Priority Data**

Nov. 5, 2001 (AT)..... 1733/2001

Publication Classification(51) Int. Cl.⁷ **C22C 21/00; C22F 1/04**(52) U.S. Cl. **148/698; 148/437**(57) **ABSTRACT**

A thermal treatment process for an article of a cast or wrought aluminum-silicon alloy with an eutectic phase. The process comprises a rapid heating of the article to an annealing temperature of 400° C. to 555° C. and maintaining the article at this temperature for a not more than 14.8 minutes.



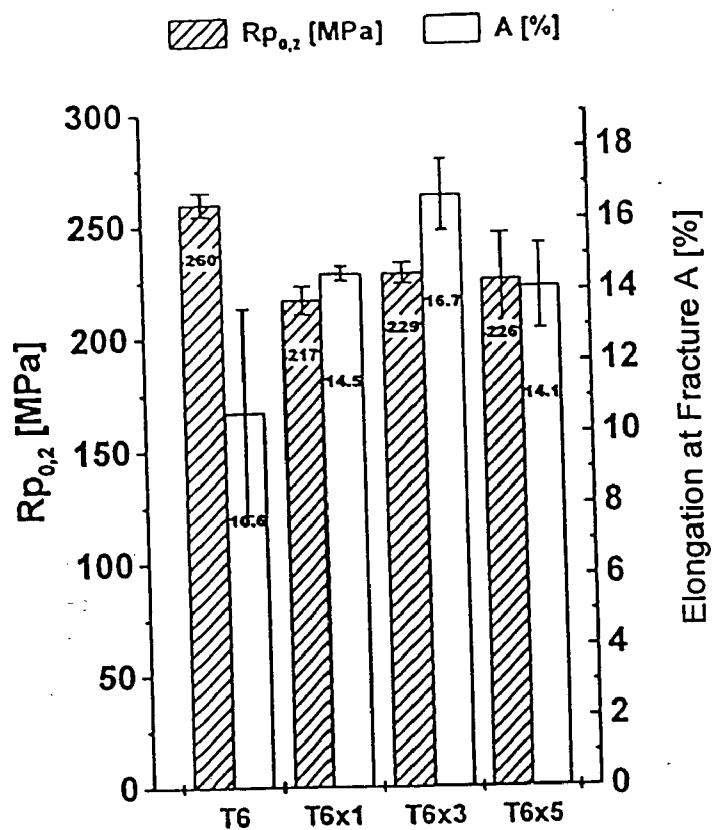


Fig. 1

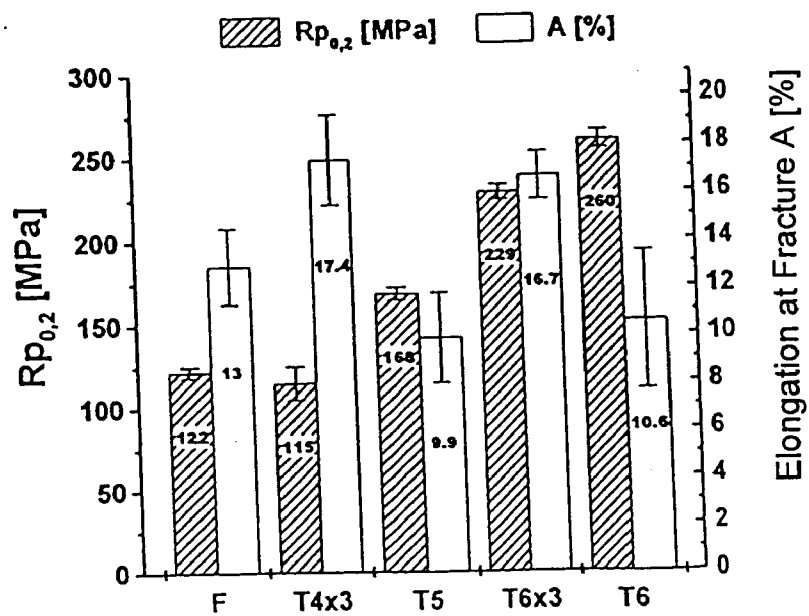


Fig. 2

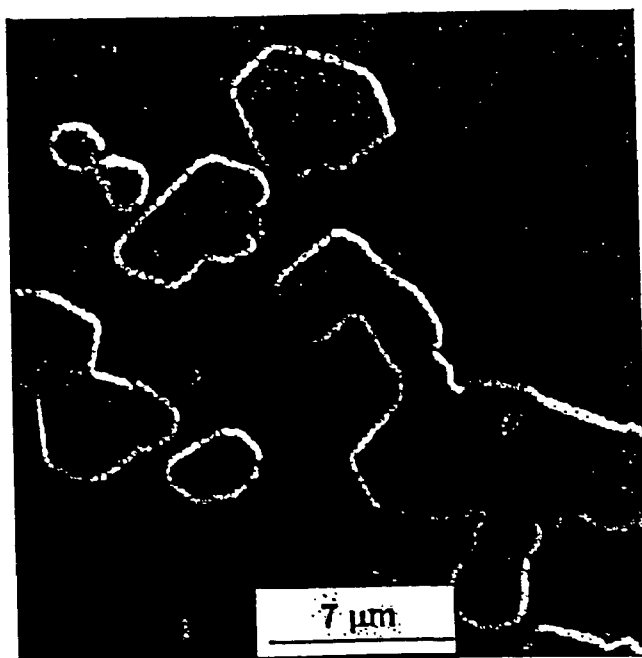


Fig. 3

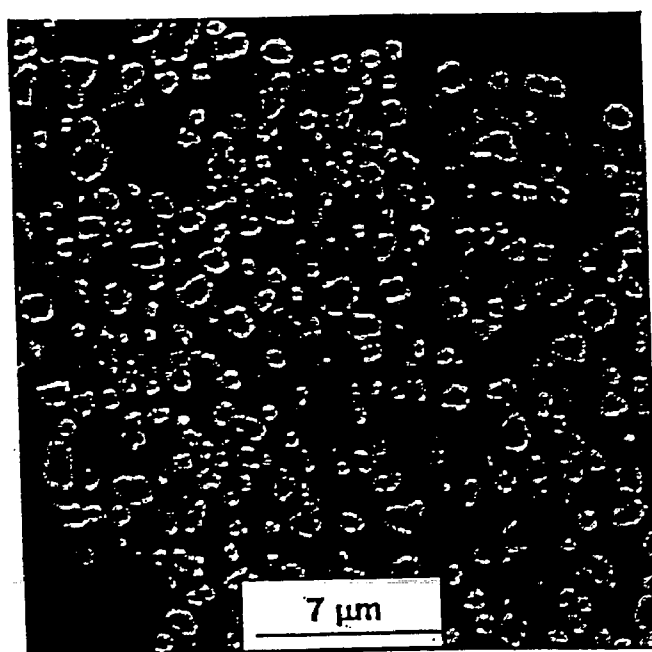


Fig. 4

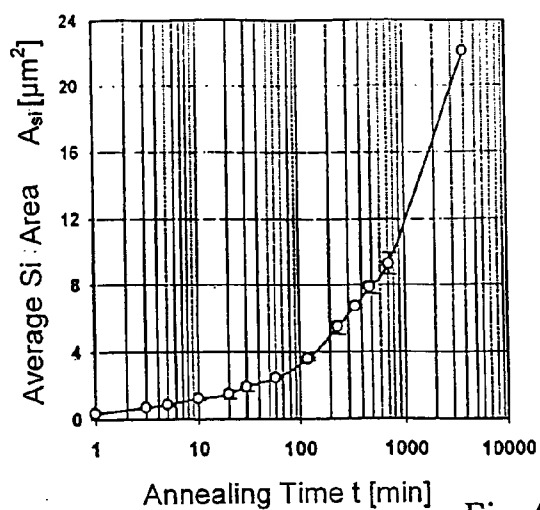


Fig. 5

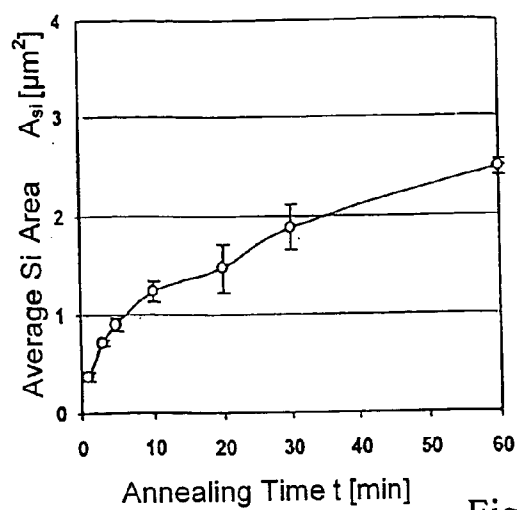


Fig. 6

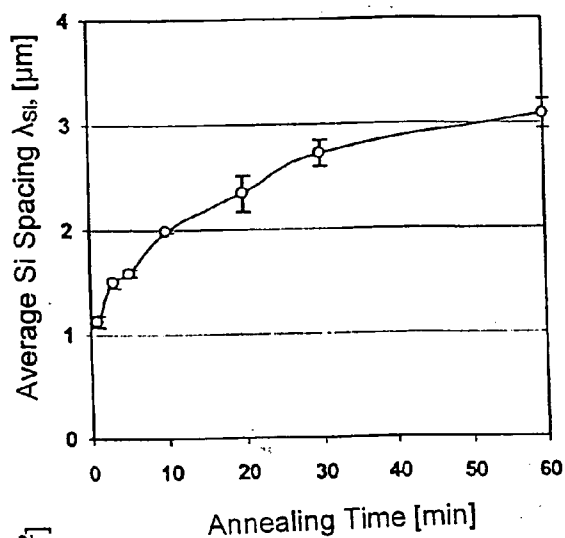


Fig. 7

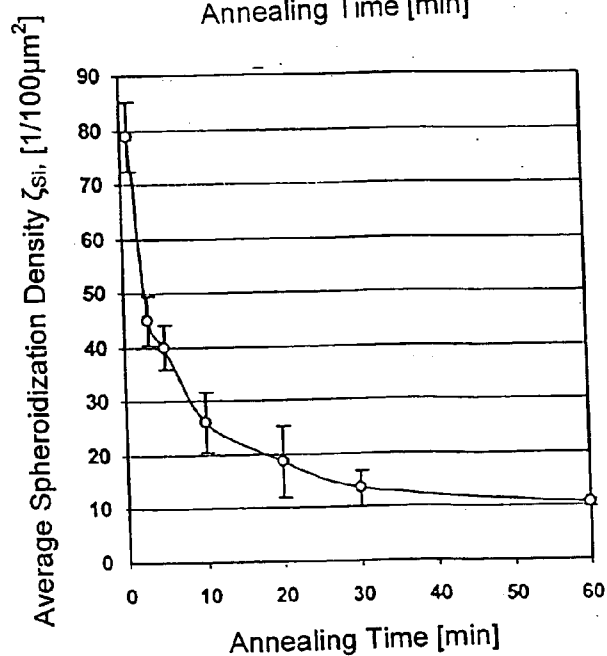


Fig. 8

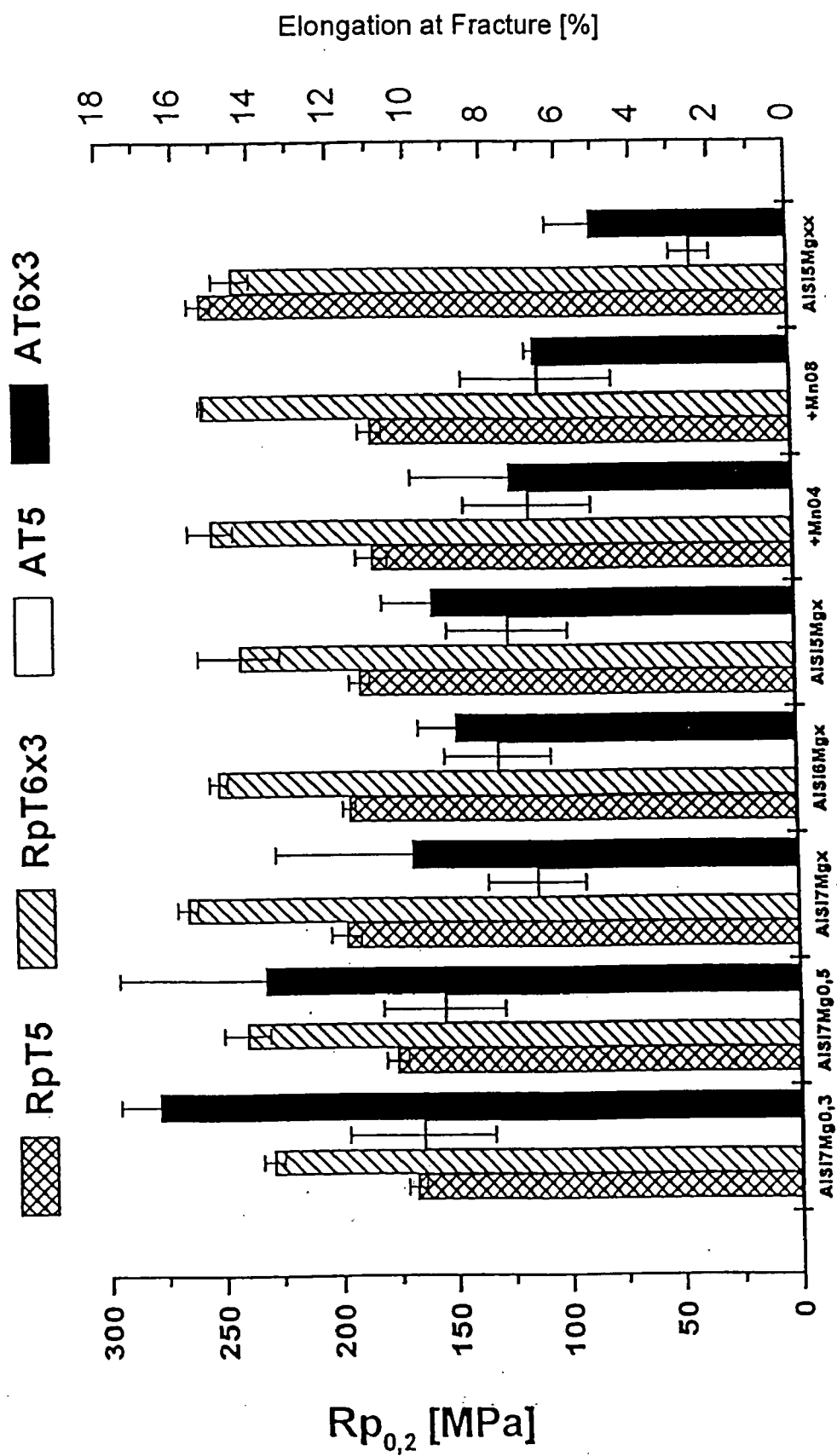


Fig. 9

ALUMINUM-SILICON ALLOYS HAVING IMPROVED MECHANICAL PROPERTIES

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present application is a continuation of International Application No. PCT/AT02/00309, filed Nov. 5, 2002, the entire disclosure whereof is expressly incorporated by reference herein, which claims priority under 35 U.S.C. § 119 of Austrian Patent Application A 1733/2001, filed Nov. 5, 2001.

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention

[0003] The present invention relates to a method for improving the mechanical properties of aluminum-silicon alloys. More specifically, the present invention relates to a thermal treatment process for improving the ductility of articles of a preferably enriched/refined or purified cast or wrought aluminum-silicon alloy with an eutectic phase, which optionally contains other alloying and/or contaminating elements, said articles being subjected to an annealing treatment and subsequent aging.

[0004] Further, the present invention relates to an aluminum-silicon alloy that contains at least one processing element, optionally magnesium, as well as additional alloying and/or contaminating elements with an eutectic phase consisting essentially of an α_{Al} -matrix and silicon precipitates.

[0005] 2. Discussion of Background Information

[0006] With silicon, aluminum forms a simple eutectic system, the eutectic point being at a silicon concentration of 12.5 %-wt and a temperature of 577° C.

[0007] By alloying magnesium, which can be dissolved in the α_{Al} -matrix up to a content of at most 0.47 %-wt at a temperature of about 550° C., it is possible to achieve a considerable increase in the strength of the material by means of thermal treatment and the Mg_2Si precipitates formed thereby.

[0008] When an Al—Si—Mg smelt cools, the residual smelt can harden eutectically, whereby silicon separates out therein in a coarse, lamellar form. For a considerable time sodium or strontium have been added to alloys of this kind to thereby impede the growth of the silicon crystals during hardening; this is referred to as enrichment or refinement and always results in an improvement of the mechanical properties, in particular an improvement of elongation at fracture.

[0009] The mechanical properties of semifinished products or of articles of aluminum alloys can be greatly influenced by thermal treatment methods, and the thermal treatment states are defined in European Standard EN 515. In this Standard, the letter F stands for “production state” and T stands for “thermally treated to stable states”. The particular thermal treatment state is characterized by the number that is associated with the letter T.

[0010] In the following description the thermal treatment states of the material are indicated by the following short forms:

[0011] F—production state

[0012] T5—quenched from the production temperature and thermally aged

[0013] T6—solution quenched and thermally aged

[0014] T6x—thermally treated according to the present invention

[0015] T4x—thermally treated according to the present invention

[0016] On the one hand, the properties of the material and, on the other hand, the costs or economic factors involved in production are important for marketing or the industrial use of objects of Al—Si alloys, since in particular long annealing treatments at high temperatures and the straightening processes that may be necessitated by so-called gravitational creep during protracted annealing are themselves costly.

[0017] In principle, it can be said that an Al—Si alloy in State F has for the most part a low material strength R_p and a relatively high value of the elongation at fracture A.

[0018] At a thermal treatment state T5, which is to say quenched from the production temperature and thermally aged, for example at 155° C. to 190° C. for a period of 1 to 12 hours, higher strength values R_p will be achieved, but at lower elongation at fracture values A of the samples.

[0019] At a thermal-treatment state corresponding to T6, with solution annealing at a temperature of, for example, 540° C. for a period of 12 hours and subsequent thermal aging, it is possible to achieve a significant increase in the strength of the material at an almost identical elongation at fracture of the samples, or ductility of the material as compared to State F. The long duration of the solution annealing permits an advantageous diffusion of the magnesium atoms in the material, for example, whereby after quenching and thermal aging of the article fine, evenly distributed Mg_2Si precipitates are formed in the α_{Al} -matrix, and these precipitates result in a significant increase in the strength of the material.

[0020] As discussed above, solution annealing at high temperatures and for protracted periods entails the disadvantages of gravitational creep and costly temperature-time treatment schedule. For reasons of economy, very frequently achieving great strength and good ductility of the material by T6 is abandoned and a treatment state T5 is selected for the article. The lower strength that results from T5 must, if necessary, be compensated for by making design changes to the component in question.

[0021] It would be desirable to provide a new, cost-effective method of thermal treatment, with which the ductility of the material can be greatly increased without causing major losses in material strength as compared to T6, or with which significantly greater ductility and greater material strength can be achieved in comparison to T5.

[0022] It would also be desirable to have available a microstructure of an article of the type described in the introduction hereof, which results in advantageous mechanical properties of the material.

SUMMARY OF THE INVENTION

[0023] The present invention provides a thermal treatment process for improving the material ductility of an article

which comprises a cast or wrought aluminum-silicon alloy with an eutectic phase. This process comprises subjecting the article to an annealing treatment and a subsequent aging treatment. The annealing treatment is carried out as a shock annealing treatment which comprises (a) a rapid heating of the material to an annealing temperature of 400° C. to 555° C., (b) maintaining the material at this temperature for a holding period of not more than 14.8 minutes, and (c) a subsequent forced cooling of the material to essentially room temperature.

[0024] In one aspect of the process, the aluminum-silicon alloy may further comprise one or more alloying elements and/or one or more contaminating elements. For example, the aluminum-silicon alloy may further comprises Mg, Mn and/or Fe.

[0025] In another aspect of the process, the aluminum-silicon alloy may be enriched/refined and/or purified.

[0026] In another aspect of the process, the holding period may be shorter than 6.8 minutes and/or the holding period may be not shorter than 1.7 minutes. For example, the holding period may be not longer than 5 minutes.

[0027] In a still further aspect of the process, the aging treatment may comprise a treatment at a temperature of from 150° C. to 200° C., e.g., for from 1 to 14 hours.

[0028] In yet another aspect of the process, the aging treatment may comprise a cold aging treatment at essentially room temperature.

[0029] In another aspect of the process, the holding period may be from 1.7 to less than 6.8 minutes and the aging treatment may comprise a treatment at a temperature of from 150° C. to 200° for from 1 to 14 hours, or a cold aging treatment at essentially room temperature.

[0030] In yet another aspect, the article may have been made by a thixocasting method.

[0031] The present invention also provides an article which is obtainable by the above process, including the various aspects thereof.

[0032] The present invention also provides an article which comprises an aluminum-silicon alloy with an eutectic phase. The eutectic phase consists essentially of an α_{Al} -matrix and spheroidized silicon precipitates. These precipitates have an average cross-sectional area, A_{Si} , of not more than $4 \mu m^2$, A_{Si} being represented by the following equation:

$$A_{Si} = \frac{1}{n} \sum_{k=1}^n A \leq 4 \mu m^2$$

[0033] wherein

[0034] A_{Si} =average area of the silicon particles in μm^2

[0035] A =average area of the silicon particles per image, in μm^2

[0036] n =number of images sampled.

[0037] In one aspect of the article, A_{Si} may be less than $2 \mu m^2$.

[0038] In another aspect of the article, the aluminum-silicon alloy may further comprise one or more alloying elements and/or one or more contaminating elements. For example, the alloy may further comprises Mg, Mn and/or Fe.

[0039] In another aspect, the aluminum-silicon alloy may further comprise at least one processing element.

[0040] The present invention further provides an article which comprises an aluminum-silicon alloy with an eutectic phase. The eutectic phase consists essentially of an α_{Al} -matrix and silicon precipitates comprising silicon particles. The average free path length between the silicon particles, λ_{Si} , in the eutectic phase is not higher than $4 \mu m$. λ_{Si} is represented by the following equation:

$$\lambda_{Si} = \frac{1}{n} \sum_{k=1}^n \sqrt{\frac{A_{square}}{N_{Silicon}}} \leq 4 \mu m$$

[0041] wherein

[0042] λ_{Si} =average spacing between the silicon particles

[0043] A_{square} =square reference area, in μm^2

[0044] $N_{Silicon}$ =number of silicon particles

[0045] n =number of images sampled.

[0046] In one aspect of this article, the average free path length may be less than $3 \mu m$, e.g., less than $2 \mu m$.

[0047] In another aspect of the article, the aluminum-silicon alloy may further comprise one or more alloying elements and/or one or more contaminating elements. For example, the alloy may further comprises Mg, Mn and/or Fe.

[0048] In another aspect, the aluminum-silicon alloy may further comprise at least one processing element.

[0049] The present invention further provides an article which comprises an aluminum-silicon alloy with an eutectic phase. The eutectic phase consists essentially of an α_{Al} -matrix and silicon precipitates which comprise silicon particles. The average spheroidization density, ζ_{Si} , thereof, defined as the number of silicon particles per $100 \mu m^2$, is at least 10:

$$\zeta_{Si} = \frac{1}{n} \sum_{k=1}^n \frac{N_{Si}}{A} \times 100 \geq 10$$

[0050] wherein

[0051] ζ_{Si} =average spheroidization density of the eutectic Si particles

[0052] N_{Si} =number of silicon particles

[0053] A =reference area in μm^2

[0054] n =number of images sampled.

[0055] In one aspect of the article, the average spheroidization density may be greater than 20.

[0056] In another aspect of the article, the aluminum-silicon alloy may further comprise one or more alloying elements and/or one or more contaminating elements. For example, the alloy may further comprises Mg, Mn and/or Fe.

[0057] In another aspect, the aluminum-silicon alloy may further comprise at least one processing element.

[0058] The present invention also provides any of the above articles, including the various aspects thereof, which is made by a thixocasting method and is heat treated by a process according to the present invention as set forth above, including the various aspects thereof.

[0059] According to the present invention, the solution annealing is conducted as shock annealing which comprises rapid heating of the material to an annealing temperature of 400° C. to 555° C., maintaining it at this temperature for a period of at most 14.8 minutes, and subsequent forced cooling, essentially to room temperature.

[0060] The advantages that are obtained are that the highest ductility values are achieved for the material by a simple short-time high-temperature annealing. In addition, the so-called shock annealing causes little or no component deformation or warping of the article, so that there is no need to straighten it. The short-time annealing treatment is very economical and can be incorporated very easily into a production sequence, for example by using a continuous heating furnace. Material strength can be adjusted by an adapted thermal aging technology. With the majority of Al—Si alloys, the greatest increase will be achieved if, as can be provided for, the shock annealing is effected with a holding time of less than 6.8 minutes, preferably for a period ranging from 1.7 up to optionally at most 5 minutes.

[0061] If the article is thermally aged after the shock annealing, it is advantageous to do this at a temperature in the range between 150° C. and 200° C., for a period ranging from 1 to 14 hours.

[0062] It can also be advantageous from the material standpoint if the aging of the article that follows shock annealing be effected as cold aging, essentially at room temperature.

[0063] An additional advantage of the present invention is achieved in that the silicon precipitates are spheroidized in the eutectic phase and have a cross-sectional area A_{Si} , of less than $4 \mu m^2$.

[0064] The formula for determining the cross-sectional area is shown below:

$$A_{Si} = \frac{1}{n} \sum_{k=1}^n A \leq 4 \mu m^2$$

[0065] wherein:

[0066] A_{Si} =average area of the silicon particles in μm^2

[0067] A =average area of the silicon particles per image, in μm^2

[0068] n =number of images sampled.

[0069] The advantages of a microstructure of this kind are essentially that crack initiation in the material is significantly reduced and ductility of the material is improved by spheroidization of the Si precipitates and by their fineness. In other words, the spheroidization and small size result in a favourable morphology of the brittle eutectic silicon and lead to significantly higher values for the material's elongation at fracture. In the case of mechanical loading, the stress peaks on the Si—Al phase boundary surface are reduced. A transcrystalline break was also found during tests, and this indicates the highest ductility of the material.

[0070] From the method standpoint, but also for high values of elongation at fracture, it may be advantageous if the silicon precipitates in the eutectic phase are spheroidized and have an average cross-sectional area of less than $2 \mu m^2$.

[0071] If, as was shown during development, the present invention entails that the average free path length between the silicon particles λ_{Si} in the eutectic phase defined as the root of a square measured surface divided by the number of silicon particles contained within it is of a size that is less than $4 \mu m$, preferably less than $3 \mu m$, and in particular less than $2 \mu m$, an especially homogeneous stress distribution at low stress peak values will be achieved in the material that is stressed, since the spacing between the small-area silicon particles significantly affects the flow behaviour of the material in a corresponding stress state. Determination of the distance between the silicon particles λ_{Si} , is shown formally below.

$$\lambda_{Si} = \frac{1}{n} \sum_{k=1}^n \sqrt{\frac{A_{square}}{N_{Silicon}}} \leq 4 \mu m$$

[0072] wherein

[0073] λ_{Si} =average spacing between of the silicon particles

[0074] A_{square} =square reference area in μm^2

[0075] $N_{Silicon}$ =number of silicon particles

[0076] n =number of images sampled.

[0077] Although solution annealing according to the prior art which is effected as long-time annealing for 2 to 12 hours for a diffusion of the alloying components that are effective for hardening and the enrichment thereof in the mixed crystal entails spheroidization of the silicon particles as a secondary effect, the particles are very large and distributed unevenly as a result of the long annealing time; which can have a deleterious effect on the material's behaviour at fracture. It was most surprising that according to the present invention an eutectic silicon network can be spheroidized by a shock annealing for a short time span of just a few minutes, whereby an advantageous microstructure of the material can be achieved. In this connection, it is important that the temperature for the shock annealing be as high as possible, although below the lowest smelting phase, preferably 5 to 20° C. below this.

[0078] With increasing annealing times, the silicon particles are subjected to a diffusion-controlled growth, and the initially favourable high spheroidization density ζ_{Si} becomes smaller.

[0079] In one aspect of the present invention, the highest ductility of an article of an Al—Si alloy was found if the mean spheroidization density ζ_{Si} , defined as the number of spheroidized eutectic silicon particles per $100 \mu m^2$, has a value that is greater than 10, and preferably greater than 20.

$$\zeta_{Si} = \frac{1}{n} \sum_{k=1}^n \frac{N_{Si}}{A} \times 100 \geq 10$$

[0080] wherein

[0081] ζ_{Si} =average spheroidization density of the eutectic Si particles

[0082] N_{Si} =number of silicon particles

[0083] A =reference area in μm^2

[0084] n =number of images sampled.

[0085] The above is once again a formal specification of the formula.

[0086] Studies have shown that essentially each Al—Si alloy that contains the eutectic can be provided with a structure according to the present invention, and that the articles formed therefrom exhibit high material-ductility values. The improvement of the quality and an improvement of elongation at fracture are particularly efficient if the article is manufactured by the thixocasting method.

BRIEF DESCRIPTION OF THE DRAWINGS

[0087] The present invention will be described in greater detail below on the basis of test results and drawings appended hereto. The drawings show the following:

[0088] FIG. 1: Bar chart showing mechanical values for a material as a function of the thermal treatment state;

[0089] FIG. 2: As in FIG. 1

[0090] FIG. 3: SEM image of a cut

[0091] FIG. 4: As in FIG. 3

[0092] FIG. 5: Mean area of the Si precipitates as a function of the annealing time

[0093] FIG. 6: As in FIG. 5

[0094] FIG. 7: Mean free path length between the Si particles

[0095] FIG. 8: Mean spheroidization density

[0096] FIG. 9: Bar chart showing material mechanical properties of various Al—Si alloys

[0097] Table 1: Numerical values for FIG. 9.

DETAILED DESCRIPTION OF THE INVENTION

[0098] In FIG. 1, a bar chart shows the $R_{p0.2}$ limiting values and the values for elongation at fracture A of samples

manufactured from a test component produced from an AlSiMg_{0.3} alloy, said component having been produced by the thixocasting method. The values for thermal treatment state T6 (12 hours 540° C.+4 hours 160° C.) of the material are compared to those that were achieved with the T6x method according to the present invention after shock annealing for 1 minute (T6x1), after 3 minutes (T6x3) and after 5 minutes (T6x5) at a temperature of 540° C. All the samples were heat-aged (4 hours) at a temperature of 160° C. The results of the tensile test show that the samples display significantly higher values for elongation at fracture after shock annealing, the T6x3 effecting an increase of A by approximately 60% as compared to T6.

[0099] In FIG. 2, using identically produced samples, the state values F , T4x3, T5, T6x3 and T6 are compared in a bar chart with respect to $R_{p0.2}$ and elongation at fracture A . When compared, they display marked increases of the values for elongation at fracture. As can be seen from FIG. 2, the material can be cold-aged (T4x3) or heat-aged (T6x3) after shock annealing for 3 minutes in order to obtain superior elongation at fracture characteristics according to the present invention.

[0100] FIG. 3 and FIG. 4 show scanning electron microscope images of Si precipitates. With respect to the imaging and evaluation method, it must be noted that it is essential to have binary images available in order to permit quantitative evaluation. The images were taken with a scanning electron microscope for an annealing period of 2 hours inclusive, after which the cut was etched for 30 seconds using a solution of 99.5% water and 0.5% hydrofluoric acid. After annealing for 4 hours, the cut was etched with the Keller solution and the images could be taken by an optical microscope. All the images were processed digitally using Adobe Photoshop 5, and evaluated with the Leica QWin V2.2 image analysis software; the minimal detection area amounted to $0.1 \mu m$. FIG. 3 shows the AlSi₇Mg_{0.3} after a normal T6 annealing time of 12 hours, using an SEM image. FIG. 4 shows the microstructure of the same material after shock annealing for three minutes. It is clear that even after a very short time there is spheroidization of the silicon precipitates (FIG. 4) and the diffusion-controlled growth thereof after long annealing times can be seen (FIG. 3).

[0101] FIG. 5 and FIG. 6 show the mean cross-sectional area A_{Si} of the silicon particles during cut testing as a function of the annealing time at 540° C. The increase of average cross-sectional area of the silicon particles, which characterizes the size of the particles, can be clearly seen from the details of FIG. 5 with the logarithmic time axis. The increase of the average silicon surface within the first 60 minutes, which is governed by diffusion, can be clearly seen from FIG. 6. The average size of the silicon particles, which increases with annealing time, is to a large extent dependent on the initial size of the silicon particles in the eutectic. Since an extremely well refined and finely divided silicon is present in this particular case, in some cases that involve silicon particles that have not been refined so well, which is to say with initially larger silicon particles, the time within which a critical average silicon area A_{Si} of approximately $4 \mu m^2$ can be achieved can become shorter.

[0102] The change of the average distance between the silicon particles as a function of annealing time is shown in FIG. 7, using test results. The increase in the average spacing of the silicon inclusions can be clearly seen.

[0103] Finally, FIG. 8 shows the decrease of the average spheroidization density, ζ_{Si} , as a function of annealing time. The sharp decrease of the average spheroidization density begins as soon as at 1.7 minutes and starting at a value of <10 for ζ_{Si} , results in a pronounced loss of ductility. At higher annealing temperatures, this value may already be reached after 14 to 25 minutes, and a density value of greater than 20 has to be provided for superior values of elongation at fracture.

[0104] The bar chart of FIG. 9 shows the measured values for yield strength and elongation at fracture which are listed in Table 1 for eight Al—Si alloys of different composition. In all of these alloys, an increase in the ductility of the material is achieved according to the present invention.

TABLE 1

Variants	F		T5		T6x3		T6	
	Rp [MPa]	A [%]	Rp [MPa]	A [%]	Rp [MPa]	A [%]	Rp [MPa]	A [%]
AlSi7Mg03	121.7	13.0	167.5	9.9	228.5	16.7	259.8	10.6
AlSi7Mg05	143.9	10.4	175.8	9.3	240.2	13.9	311.7	9.1
AlSi7Mgx	159.8	8.3	197.2	6.8	265.2	10.1	322.9	7.6
AlSi6Mgx	159.7	10.2	195.3	7.8	250.6	8.9	318.6	6.5
AlSi5Mgx	154.9	10.1	189.6	7.5	240.6	9.5	313.6	8.7
+Mn04	157.1	10.6	183.7	6.9	252.7	7.4	322.7	7.6
+Mn08	154.8	9.9	184.0	6.6	255.9	6.7	324.4	4.9
AlSi5Mgxx	211.7	3.5	256.4	2.5	242.1	5.1	291.6	5.3

What is claimed is:

1. A thermal treatment process for improving the material ductility of an article which comprises a cast or wrought aluminum-silicon alloy with an eutectic phase, which process comprises subjecting the article to an annealing treatment and a subsequent aging treatment, wherein the annealing treatment is carried out as a shock annealing treatment which comprises (a) a rapid heating of the material to an annealing temperature of 400° C. to 555° C., (b) maintaining the material at this temperature for a holding period of not more than 14.8 minutes, and (c) a subsequent forced cooling of the material to essentially room temperature.

2. The process of claim 1, wherein the aluminum-silicon alloy further comprises one or more alloying elements.

3. The process of claim 1, wherein the aluminum-silicon alloy further comprises one or more contaminating elements.

4. The process of claim 1, wherein the aluminum-silicon alloy further comprises at least one of Mg, Mn and Fe.

5. The process of claim 1, wherein the aluminum-silicon alloy is at least one of refined and purified.

6. The process of claim 1, wherein the holding period is shorter than 6.8 minutes.

7. The process of claim 1, wherein the holding period is not shorter than 1.7 minutes.

8. The process of claim 7, wherein the holding period is not longer than 5 minutes.

9. The process of claim 1, wherein the aging treatment comprises a treatment at a temperature of from 150° C. to 200° C.

10. The process of claim 9, wherein the aging treatment is carried out for from 1 to 14 hours.

11. The process of claim 1, wherein the aging treatment comprises a cold aging treatment at essentially room temperature.

12. The process of claim 1, wherein the holding period is from 1.7 to less than 6.8 minutes and the aging treatment comprises a treatment at a temperature of from 150° C. to 200° for from 1 to 14 hours.

13. The process of claim 1, wherein the holding period is from 1.7 to less than 6.8 minutes and the aging treatment comprises a cold aging treatment at essentially room temperature.

14. The process if claim 1, wherein the article is made by a thixocasting method.

15. An article which is obtainable by the process of claim 1.

16. An article comprising an aluminum-silicon alloy with an eutectic phase, wherein the eutectic phase consists essentially of an α_{Al} -matrix and spheroidized silicon precipitates, which precipitates have an average cross-sectional area, A_{Si} , of not more than $4 \mu m^2$, A_{Si} being represented by the following equation:

$$A_{Si} = \frac{1}{n} \sum_{k=1}^n A \leq 4 \mu m^2$$

wherein

A_{Si} =average area of the silicon particles in μm^2

A =average area of the silicon particles per image, in μm^2

n =number of images sampled.

17. The article of claim 16, wherein A_{Si} is less than $2 \mu m^2$.

18. The article of claim 16, wherein the aluminum-silicon alloy further comprises at least one of one or more alloying elements and one or more contaminating elements.

19. The article of claim 18, wherein the aluminum-silicon alloy further comprises at least one of Mg, Mn and Fe.

20. The article of claim 16, wherein the aluminum-silicon alloy further comprises at least one processing element.

21. An article comprising an aluminum-silicon alloy with an eutectic phase, wherein the eutectic phase consists essentially of an α_{Al} -matrix and silicon precipitates, wherein the silicon precipitates comprise silicon particles and an average free path length between the silicon particles, λ_{Si} , in the

eutectic phase is not higher than $4\text{ }\mu\text{m}$, λ_{Si} being represented by the following equation:

$$\lambda_{\text{Si}} = \frac{1}{n} \sum_{k=1}^n \sqrt{\frac{A_{\text{square}}}{N_{\text{Silicon}}}} \leq 4\text{ }\mu\text{m}$$

wherein

λ_{Si} =average spacing between the silicon particles

A_{square} =square reference area in μm^2

N_{Silicon} =number of silicon particles

n =number of images sampled.

22. The article of claim 21, wherein the average free path length is less than $3\text{ }\mu\text{m}$.

23. The article of claim 22, wherein the average free path length is less than $2\text{ }\mu\text{m}$.

24. The article of claim 21, wherein the aluminum-silicon alloy further comprises at least one of one or more alloying elements and one or more contaminating elements.

25. The article of claim 24, wherein the aluminum-silicon alloy further comprises at least one of Mg, Mn and Fe.

26. The article of claim 21, wherein the aluminum-silicon alloy further comprises at least one processing element.

27. An article comprising an aluminum-silicon alloy with an eutectic phase, wherein the eutectic phase consists essentially of an α_{Al} -matrix and silicon precipitates, wherein the silicon precipitates comprise silicon particles and an average spheroidization density, ξ_{Si} , thereof, defined as a number of silicon particles per $100\text{ }\mu\text{m}^2$, is at least 10:

$$\xi_{\text{Si}} = \frac{1}{n} \sum_{k=1}^n \frac{N_{\text{Si}}}{A} \times 100 \geq 10$$

wherein

ξ_{Si} =average spheroidization density of the eutectic Si particles

N_{Si} =number of silicon particles

A =reference area in μm^2

n =number of images sampled.

28. The article of claim 27, wherein the average spheroidization density is greater than 20.

29. The article of claim 27, wherein the aluminum-silicon alloy further comprises at least one of one or more alloying elements and one or more contaminating elements.

30. The article of claim 29, wherein the aluminum-silicon alloy further comprises at least one of Mg, Mn and Fe.

31. The article of claim 27, wherein the aluminum-silicon alloy further comprises at least one processing element.

32. The article of claim 16, wherein the article is made by a thixocasting method and is heat treated by a process which comprises subjecting the article to an annealing treatment and a subsequent aging treatment, the annealing treatment being carried out as a shock annealing treatment which comprises (a) a rapid heating of the article to an annealing temperature of 400°C . to 555°C ., (b) maintaining the article at this temperature for a holding period of not more than 14.8 minutes, and (c) a subsequent forced cooling of the article to essentially room temperature.

33. The article of claim 21, wherein the article is made by a thixocasting method and is heat treated by a process which comprises subjecting the article to an annealing treatment and a subsequent aging treatment, the annealing treatment being carried out as a shock annealing treatment which comprises (a) a rapid heating of the article to an annealing temperature of 400°C . to 555°C ., (b) maintaining the article at this temperature for a holding period of not more than 14.8 minutes, and (c) a subsequent forced cooling of the article to essentially room temperature.

34. The article of claim 27, wherein the article is made by a thixocasting method and is heat treated by a process which comprises subjecting the article to an annealing treatment and a subsequent aging treatment, the annealing treatment being carried out as a shock annealing treatment which comprises (a) a rapid heating of the article to an annealing temperature of 400°C . to 555°C ., (b) maintaining the article at this temperature for a holding period of not more than 14.8 minutes, and (c) a subsequent forced cooling of the article to essentially room temperature.

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