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(54) FOUNDRY ALLOY

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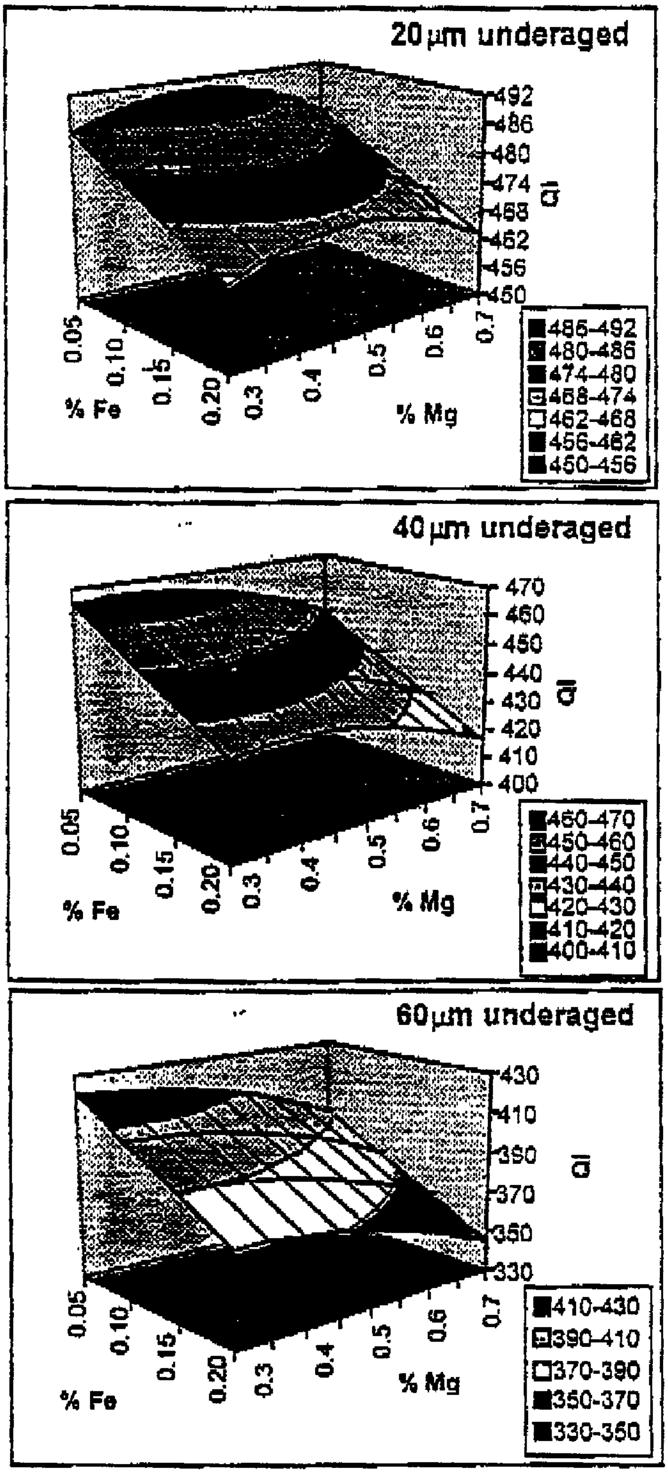
(57) ABSTRACT

An aluminium-based alloy having 6.5-7.5 wt. % silicon and 0.35-0.50 wt. % magnesium as the major alloying elements and a method of manufacturing an article from the alloy are disclosed. The alloy is characterised by a microstructure in which β phase (Al_5SiFe) that forms during heat treatment as a transformation product of π phase ($Al_8Si_6Mg_3Fe$) is the sole or predominant iron-containing phase in the alloy.


20μm underaged
492
486
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ql
0.05
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% Fe
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% Mg
■486-492
▨480-486
■474-480
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■456-462
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40μm underaged
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■460-470
▨450-460
■440-450
▨430-440
□420-430
■410-420
■400-410
60μm underaged
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0.10
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% Fe
0.3
0.4
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0.7
% Mg
■410-430
▨390-410
□370-390
■350-370
■330-350

Figure 1

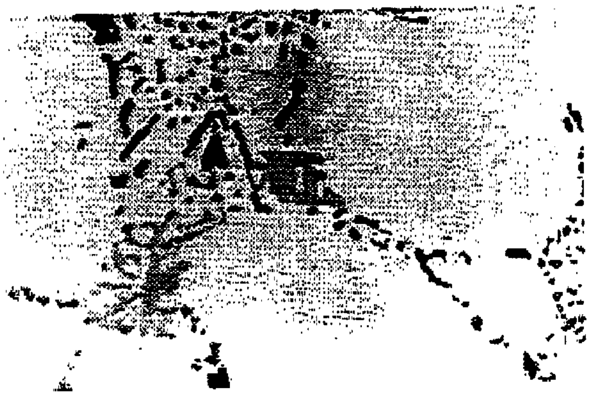

Figure 2 a Mag. X200

Figure 2 b Mag. X200

Figure 2 c Mag. X500

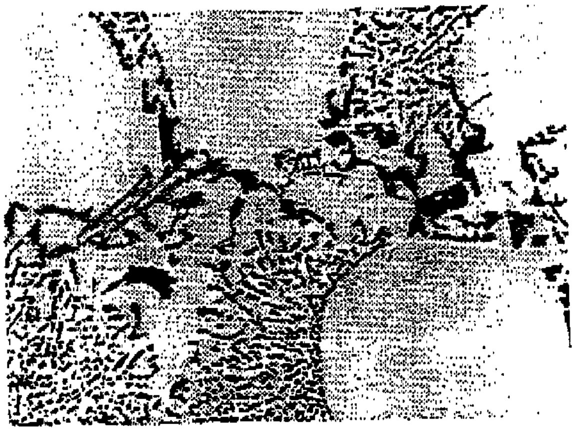

Figure 2 d Mag. X200

FOUNDRY ALLOY

[0001] The present invention relates to an improved foundry alloy and to a method of producing an improved foundry alloy. In particular, the improved foundry alloy is an aluminium-based alloy,

[0002] Primary metal based foundry alloys are largely used for structural or safety type applications where there is a requirement for high and consistent mechanical properties. The majority of components made from aluminium foundry alloys are made from hypoeutectic aluminium-silicon-magnesium alloys containing a nominal silicon level of 7% by weight (601 and 603 designations). In simple terms these alloys are a composite of hard, discontinuous silicon particles and large, brittle iron intermetallics embedded in a ductile aluminium matrix.

[0003] There are three registered Australian compositions for strontium-modified aluminium—7% silicon alloys. These are given in Table 1. The magnesium content of the alloys covers the range 0.25 to 0.4 wt % (601 alloys) and 0.45 to 0.7 wt % (603 alloys). The addition of magnesium allows castings to be heat treated to form magnesium silicide precipitates. These harden the matrix of the alloy to obtain the desired combination of strength and ductility.

TABLE 1

Registered alloy composition for strontium modified 601/603 type foundry alloys

Alloy Code	Si	Fe	Cu	Mn	Mg	Zn	Ti	Other Each	Other Total	Al
AC601	6.5–7.5	0.20	0.05	0.05	0.30–0.40	0.05	0.20	0.05	0.15	Rem
CC601	6.5–7.5	0.20	0.05	0.05	0.25–0.35	0.05	0.20	0.05	0.15	Rem
AC603	6.5–7.5	0.15	0.05	0.03	0.45–0.7	0.05	0.20	0.05	0.15	Rem

♠Compositions in weight percent. Compositions indicate a maximum unless a range is given

[0004] The main impurity found in these alloys is iron. The iron solidifies from the eutectic liquid into a number of brittle phases.

[0005] The two major iron-containing phases found in these alloys are the π phase ($Al_8Si_6Mg_3Fe$) which is the predominant phase formed in high Mg content alloys and the β phase (Al_5SiFe) which forms in low magnesium content alloys. The π phase forms into a script morphology while the β phase is less voluminous and forms into acicular plates. Both phases are detrimental to mechanical properties. High Mg contents (ie greater than 0.6 wt % Mg) are desirable to provide higher strength, but the presence of π phase at high Mg contents causes the ductility of the alloys to unfavourably decrease.

[0006] Conventional theories on the micro-mechanics of failure of premodified 601 and 603 alloys state that the iron rich intermetallic phases are critical in determining the fracture toughness as the silicon particles are small and round. Increases in the magnesium content of these alloys increase the amount of the π phase, which has a negative impact on the ductile properties of the alloys.

[0007] Further, as some magnesium is contained in the π phase, the maximum volume fraction of magnesium silicide precipitates cannot be obtained. Thus, the alloys do not achieve the maximum possible strength consistent with their magnesium content.

[0008] Also, as the magnesium content of an alloy increases the magnesium content of the π phase may change leading to even greater volume fractions of the phase for a given Fe content.

[0009] It is thus concluded that the overall quality of an alloy, as given by the quality index, decreases as increasing volume fractions of the π phase forms at increased magnesium contents. The quality index is given by the formula:

$$Q.I.=UTS+150\ \log_{10} E$$

[0010] where:

[0011] Q.I.=Quality Index (Mpa)

[0012] UTS=Ultimate Tensile Strength (Mpa)

[0013] E=Elongation at Fracture (%)

[0014] Attempts have been made to eliminate the π phase and thus remove its detrimental impact on mechanical properties.

[0015] By way of example, beryllium additions can be used to precipitate the iron impurity as part of the $BeSiFe_2Al_8$ phase. This beryllium-containing phase forms in preference to the π phase, leading to alloys with improved mechanical properties. Unfortunately, there are serious health hazards associated with using beryllium. Consequently, beryllium modification is not widely practised and the deleterious effect of the π phase on alloy quality remains.

[0016] Other attempts to modify the iron-containing phases, for example by using Mn, have been tried in secondary alloys but have not been used in primary alloys.

[0017] It is an object of the present invention to provide an improved foundry alloy.

[0018] In accordance with the present invention this object is achieved by an alloy having a microstructure in which β phase that forms during heat treatment as a transformation product of π phase is the sole or predominant iron-containing phase. The reduction in π phase results in an improvement in ductility. Moreover, the β phase that forms as the transformation product has a fine structure that improves ductility. Further, the reduction in π phase means that there are higher levels of Mg in solution which are available for precipitation during ageing to improve the strength of the alloy.

[0019] In a first aspect, the present invention provides an alloy which comprises:

[0020] Si: 6.5-7.5 wt %

[0021] Fe: up to 0.20 wt %

[0022] Cu: up to 0.05 wt %

[0023] Mn: up to 0.05 wt %

[0024] Mg: 0.35 to 0.50 wt %

[0025] Zn: up to 0.05 wt %

[0026] Ti: up to 0.20 wt %

[0027] Balance: Al and other components, the other components comprise a total of not more than 0.15 wt % and any single component of the other components does not exceed 0.05 wt %, the alloy having a microstructure which includes a primary aluminium-containing matrix and one or more iron-containing phases dispersed in the matrix, and wherein the sole or predominant iron-containing phase is β phase that formed as a transformation product of π phase.

[0028] It is preferred that the dendrite arm spacing of the matrix be 10-45 μm.

[0029] Where there is more than one iron-containing phase, preferably the iron-containing phases also include π phase.

[0030] Preferably, the iron-containing phases include π phase in an amount up to 30 vol % of the iron-containing phases. The amount of π phase may be higher if the Mg content is in the upper end of the range.

[0031] The Mg content of the alloy is preferably 0.40-0.45 wt %. Within this Mg range, the alloy is a variant of the 601/603 type foundry alloy. It has been realised by the applicant that close control of the magnesium content to be between 0.40 and 0.45 wt % can lead to an increase in alloy quality and improved mechanical properties. In particular, when the magnesium content is controlled to be between 0.40 and 0.45 wt % the variation in alloy quality for a small change in magnesium level is minimal. Thus, the consistency in the mechanical properties of the alloy is maximised.

[0032] The present invention also provides a method for manufacturing an alloy article.

[0033] In a second aspect, the present invention provides a method for manufacturing an alloy article which comprises:

[0034] (a) providing a melt having a composition of:

> **[0035]** Si: 6.5-7.5 wt %
>
> **[0036]** Fe: up to 0.20 wt %
>
> **[0037]** Cu: up to 0.05 wt %
>
> **[0038]** Mn: up to 0.05 wt %
>
> **[0039]** Mg: 0.35 to 0.50 wt %
>
> **[0040]** Zn: up to 0.05 wt %
>
> **[0041]** Ti: up to 0.20 wt %
>
> **[0042]** Balance: Al and other components, the other components comprising a total of not more than 0.15 wt % and any single component of the other components not exceeding 0.05 wt %,

[0043] (b) casting said melt and solidifying a casting at a cooling rate that produces a microstructure of an aluminium-containing matrix and π and β iron-containing phases dispersed in the matrix;

[0044] (c) solution heat treating the casting to at least partially transform π phase to β phase; and

[0045] (d) quenching the casting to form the alloy article.

[0046] It is preferred that the cooling rate be sufficient to produce a dendrite arm spacing in the matrix in the casting of 10-45 μm.

[0047] Preferably, the sole or predominant iron-containing phase in the alloy article is β phase.

[0048] Where there is more than one iron-containing phase in the alloy article, preferably the iron-containing phases also include π phase. More preferably, the iron-containing phases in the alloy article include π phase in an amount of up to 30 vol % of the iron-containing phases. Higher levels of π phase may be present if the Mg content is at the upper end of the above range.

[0049] It is preferred that the step of solidifying the casting produces iron-containing phases that include a substantial proportion of the π phase and the subsequent solution heat treatment step is effective to convert at least some and preferably a majority of the π phase to β phase to give a microstructure in the alloy article that includes iron-containing phases which are predominantly β phase.

[0050] The melt prior to casting may be at a temperature above the liquidus temperature of the alloy, with the melt having sufficient superheat to fill the mould, that is at a temperature of 680-720° C.

[0051] The solution treatment of the casting may be carried out at any suitable temperature and for any suitable time to achieve a desired level of transformation of π phase β phase. In any given situation, the selection of the parameters of temperature and tine will depend on variables, such as the concentrations of magnesium and other elements in the casting. By way of example, the applicant has found that for castings having a Mg concentration of 0.5 wt %, solution treatment at 540° C. for 2 or more hours produced desired levels of transformation of π to β phase.

[0052] After the solution heat treatment, the casting is preferably quenched, more preferably quenched in hot water, such as hot water having a temperature of 70-80° C.

[0053] After quenching, the alloy article is cooled to room temperature and optionally subjected to an ageing heat treatment.

[0054] The ageing heat treatment may include heating the alloy article to a temperature of 140-170° C. and holding at that temperature for 1-10 hours. After the ageing heat treatment, the alloy article may be air cooled to room temperature.

[0055] Results to support the present invention are given in **FIG. 1**, in which plots of typical response surfaces derived from experimentally determined quality index data are shown. The three surfaces correspond to alloys that were cast at different solidification rates and thereafter solution treated and aged. Solidification rate is commonly measured by the as-cast dendrite cell size or secondary dendrite arm spacing (DAS) but other methods exist. The results here use secondary dendrite arm spacing to indicate solidification rate, with a small dendrite arm spacing corresponding to a high solidification rate.

[**0056**] It can be seen from **FIG. 1** that:

[**0057**] (i) at the high solidification rate (=20 μm DAS) the alloy quality peaks at a magnesium level of 0.45-0.50 weight percent;

[**0058**] (ii) at the intermediate solidification rate (=40 μm DAS) the quality peaks at a magnesium level of 0.35-0.40 weight percent; and

[**0059**] (iii) at the low solidification rate (=60 μm DAS) the quality maximum occurs at a magnesium level of 0.25-0.30 weight percent.

[**0060**] Further, it can be seen from **FIG. 1** that the magnesium level for the peak quality is independent of the iron level for the iron levels examined. Also, the rate of change of the response surfaces with magnesium is least near the peak in quality index. This means that the alloys at the peak are less sensitive to changes in magnesium than other alloys. The peak quality from **FIG. 1** corresponds well with microstructural evidence for small amounts of π phase in the alloy. By increasing the magnesium content of the alloy, it can be seen that in some circumstances improved quality results.

[**0061**] It should be noted that the present invention works best with those casting designs or casting methods which produce high solidification rates (≦45 μm DAS), such as permanent mould, mould chill methods with sand, and squeeze casting. Indeed, the trend in the automotive industry is to move away from thick section, low solidification rate (high DAS) castings towards lightweight castings with thinner sections and higher solidification rates (low DAS).

[**0062**] The common belief prior to the present invention was that low magnesium levels produce high quality castings. The results shown here confirm this to be true at low solidification rates (**FIG. 1***c*). However, at higher solidification rates, the magnesium contents covered by this invention show, surprisingly, improved alloy quality and therefore improved mechanical properties.

[**0063**] FIGS. **2**(*a*) to **2**(*c*) are photomicrographs of hypoeutectic alloys having a Si concentration of 7 wt % and various Mg concentrations which were cast at the same solidification rate (60 μm DAS), solution treated, and aged. **FIG. 2** (*d*) is a photomicrograph of the as-cast alloy of **FIG. 2**(*c*), ie before heat treatment.

[**0064**] In **FIG. 2**(*a*), the Mg content of the alloy is higher than the Mg content of the alloy of the present invention. The main phases shown in **FIG. 2**(*a*) are spheroidal silicon-containing phase and the iron-containing π phase.

[**0065**] **FIG. 2**(*b*) shows the microstructure of an alloy containing less Mg than the alloy of the present invention. The phases present include spheroidal silicon-containing phase and iron-containing β phase. The β phase is present as structures of high aspect ratio dispersed throughout the matrix.

[**0066**] **FIG. 2**(*c*) shows the microstructure of an alloy of the present invention. The phases include spheroidal silicon-containing phases, a small amount of π phase an β phase. The β phase is present as structures of high aspect ratio clumped together. This is consistent with the β phase being formed by transformation of π phase during heat treatment.

[**0067**] **FIG. 2**(*d*) shows that prior to heat treatment the as-cast alloy of **FIG. 2**(*c*) had regions of π phase. As is evident from **FIG. 2**(*c*) these π phase regions were largely transformed to β phase during heat treatment.

[**0068**] The drive for alloys with improved mechanical properties stems from the major restraint that mechanical properties place on the design of the casting, or even if a cast alloy can be used to manufacture a certain component. The thickness of critical sections needs to be sufficiently large that the cast component can operate without failure. Mechanical properties of the alloys therefore limit the minimum weight of a cast component. Further, the thickness of sections of a casting will determine the time required for the casting to solidify. For certain casting methods, such as low pressure die casting, the production rate is often determined by the solidification rate as the casting machine is tied up until the casting has fully solidified. Finally, the solution treatment, quench rate and ageing treatment of a cast component may be tailored to its design so as not to induce unnecessarily high residual stresses. High residual stresses can cause distortion of the component requiring additional machining. The mechanical properties of the base alloy therefore affect all stages of manufacturing from design, to casting the component, heat treatment, machining, final weight and production rate.

[**0069**] The present invention therefore has the following more specific applications:

[**0070**] (i) New markets for aluminium—7% silicon foundry alloys. Cast alloys generally have inferior mechanical properties but lower manufacturing costs compared to similar components made from wrought alloys. The high mechanical property requirements of some components necessitates the use of wrought alloys. The achievement of alloys of the present invention which have higher and more consistent mechanical properties than conventional alloys may allow the use of the alloy of the present invention to replace wrought alloys, or other cast alloys, for some components.

[**0071**] (ii) Cast components with thinner sections and lower total weight. The improved and more consistent mechanical properties of the alloy of the present invention allows components with thinner sections to be designed and cast. Despite their thinner sections, these components can still operate without failure and will have a lower total weight.

[**0072**] (iii) Cast components with an improved production rate. Castings with thinner sections may require less time to solidify. Production equipment will then be tied up for less time waiting for a component to solidify. The production rate is thus increased.

[**0073**] (iv) Cast components with refined iron and silicon intermetallic phases. The solidification time of a casting strongly determines the coarseness of the microstructure. Components with thinner sections and therefore higher solidification rates (and lower solidification times) will have a more refined microstructure. This refining of the microstructure will provide additional improvements to the mechanical properties of a casting, independent of the use of a superior alloy.

[0074] (v) Cast components with reduced heat treatment time. Castings with thinner sections require less time to homogenise. Further, the time required for the casting to reach the solution treatment temperature or ageing temperature will be less. This also benefits the production rate of components.

[0075] (vi) Cast components with increased bench rate. Thinner castings may quench more rapidly. This may lead to improved mechanical properties as it suppresses the formation of magnesium-silicide precipitates during cooling. These improved properties are independent of any refinement of the microstructure or the use of a superior alloy.

[0076] It will be appreciated that the invention described herein is susceptible to variation and modifications other than those specifically described. It is to be understood that the invention encompasses all such variations and modifications that fall within its spirit and scope.

1. An ally which comprises:

Si: 6.5-7.5 wt %

Fe: up to 0.20 wt %

Cu: up to 0.05 wt %

Mn: up to 0.05 wt %

Mg: 0.3 to 0.50 wt %

Zn: up to 0.05 wt %

T1: up to 0.20 wt %

Balance: Al and other components, the other components comprise a total of not more than 0.15 wt % and any single component of the other components does not exceed 0.05 wt %, the alloy having a microstructure which includes a primary aluminium-containing matrix and one or more iron-containing phases dispersed in the matrix, and wherein the sole or predominant iron-containing phase is β phase that formed as a transformation product of π phase.

2. The alloy defined in claim 1, wherein when the alloy includes more than one iron-containing phase, the iron-containing phases also include π phase.

3. The alloy defined in claim 2, wherein the π phase is up to 30 vol % of the iron-containing phases.

4. The alloy defined in any one of the preceding claims, wherein the Mg content of the alloy is 0.40-0.45 wt %.

5. A method for manufacturing an alloy article which comprises:

(a) providing a malt heaving a composition of:

Si: 6.5-7.5 wt %

Fe: up to 0.20 wt %

Cu: up to 0.05 wt %

Mn: up to 0.05 wt %

Mg: 0.35 to 0.50 wt %

Zn: up to 0.05 wt %

Ti: up to 0.20 wt %

Balance: Al and other components, the other components comprising a total of not more than 0.15 wt % and any single component of the other components not exceeding 0.05 wt %,

(b) casting said melt and solidifying a casting at a cooling rate that produces a microstructure of an aluminium-containing matrix and π and β iron-containing phases dispersed in the matrix;

(c) solution heat treating the casting to at least partially transform π phase to β phase; and

(d) quenching the casting to form the alloy article.

6. The method defined in claim 5, wherein the cooling rate is sufficient to produce a dendrite arm spacing in the matrix of between 10 and 4.5 μm.

7. The method defined in claim 5 or claim 6, wherein the sole or predominant iron-containing phase in the alloy article is β phase.

8. The method defined in claim 5, wherein when the alloy includes more than one iron-containing phase in the alloy article, the iron-containing phases also include π phase.

9. The method defined in claim 8, wherein the π phase is up to 30 vol % of the iron-containing phases.

10. The method defined in claim 5 or claim 6, wherein the step of solidifying the casting produces iron-containing phases that include a substantial proportion of π phase and the subsequent solution heat treatment step is effective to convert a majority of the π phase to β phase to give a microstructure in the alloy article that includes iron-containing phases which are predominantly β phase.

11. The method defined in any one of claims 5 to 10, wherein prior to casting the melt is at a temperature above the liquidus temperature of the alloy.

12. The method defined in any one of claims 5 to 12, wherein the quenching step is in hot water having a temperature of 70-80° C.

13. The method defined in any one of claims 5 to 12, further includes an ageing heat treatment of the alloy article.

14. The method defined in claim 13, wherein the ageing heat treatment includes heating the alloy article to a temperature of 140-170° C., holding the alloy article at that temperature for 1-10 hours, and air cooling the alloy article to room temperature.

* * * * *