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(54) **ALUMINUM ALLOY FORMULATIONS FOR REDUCED HOT TEAR SUSCEPTIBILITY**

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(57) **ABSTRACT**

The present invention relates to modified alloy compositions for reduced hot tear susceptibility, the aluminum alloy comprising from 0.01 to 0.025% by weight of Sr; and $TiB2$, measured by its boron content, from 0.001 to 0.005% by weight of B. The invention also relates to a method of preventing or eliminating hot tears in an aluminum alloy comprising the step of combining with aluminum: from 0.01 to 0.025% by weight of Sr; and $TiB2$, measured by its boron content, from 0.001 to 0.005% by weight of B.

ALUMINUM ALLOY FORMULATIONS FOR REDUCED HOT TEAR SUSCEPTIBILITY

FIELD OF INVENTION

[0001] The invention relates to modified alloy compositions for reduced hot tear susceptibility.

BACKGROUND OF THE INVENTION

[0002] Hot tears occur during casting wherein brittle interdendritic fractures initiate during the solidification process. Alloys which are generally considered to be prone to hot tearing have relatively long freezing/solidification ranges, defined as the temperature difference between the liquidus and solidus temperatures. In addition, during the final stages of freezing, these alloys have very little eutectic liquid remaining, and the limited amounts of this eutectic liquid must pass through narrow spaces left between the solidified grains. This poor feeding in the final stages of solidification is a significant contributor to the phenomenon of hot tearing.

[0003] A method of reducing hot tearing is disclosed in WO2005/056846. WO2005/056846 is silent to the combination of strontium and titanium diboride of the present invention and primarily addresses the problem of hot tearing by casting a mix of a pure aluminum at a first specified temperature and a second aluminum alloy mixed with copper, zinc, or magnesium at a second specified temperature. Temperature control of the two alloys is a central aspect of the method disclosed in WO2005/056846.

[0004] U.S. Pat. No. 4,681,152 is directed to twin roll casting of an 5xxx alloy. The composition can contain up to 0.05% Sr and uses a grain refiner comprising aluminum wire containing about 5% by weight titanium and 0.2% by weight boron. The boron content can be as much as 1% by weight. Sufficient grain refining alloy is added to bring the titanium content up to about 0.02% by weight. U.S. Pat. No. 4,681,152 is not directed to reducing hot tearing. The alloys of U.S. Pat. No. 4,681,152 are cast by strip casting.

[0005] U.S. Pat. No. 5,453,244 is directed to a bearing alloy including Al—Zn base (7xxx). The alloy is broadly described as containing 0.05 to 0.5% Sr and Ti+B in the range 0.03 to 0.5%. U.S. Pat. No. 5,453,244 is not directed to reducing hot tearing.

[0006] U.S. Pat. No. 5,211,910 mentions Sr from a list consisting of Zn, Ge, Sn, Cd, In, Be, Sr, Sc, Y, and Ca to be present in about 0.5 to about 4 weight percent total and Ti and/or TiB_2 from a list comprising Zr, Cr, Mn, Ti, Hf, V, Nb, B and TiB_2 in the range 0.01 to 2% as constituents of 2xxx alloy. However, the specific combination of additives of the present invention are not disclosed, nor in the range of the present invention. U.S. Pat. No. 5,211,910 is not directed to reducing hot tearing.

[0007] EP0432184 mentions Sr from a list consisting of Zn, Ge, Sn, Cd, In, Be, Sr, Sc, Y, and Ca to be present in about 0.01 to 1.5 and Ti and/or TiB_2 from a list comprising Zr, Cr, Mn, Ti, Hf, V, Nb, B and TiB_2 in the range 0.01 to 1.5%. However, the specific combination of additives of the present invention are not disclosed, nor in the range of the present invention. EP0432184 is not directed to reducing hot tearing.

[0008] WO 96/10099 discloses a broad range of possible alloys, and includes grain refiners (including Ti and TiB_2) and modifiers (including Sr). The principal alloying element is Sc. Alloys are useful for shape casting and are said to give properties comparable to wrought alloys.

[0009] U.S. Pat. No. 6,562,165 describes an Al—Si alloy suitable for semi-solid processing containing Ti 0.005 to 0.5% and Sr 0.005 to 0.030, with spheroidized structure. U.S. Pat. No. 6,562,165 mentions that excessive Ti addition can lead to large, detrimental TiB_2 crystals and is silent to TiB_2 levels. The additives of U.S. Pat. No. 6,562,165 are not intended to reduce hot tearing.

SUMMARY OF THE INVENTION

[0010] The inventors have found that aluminum-based alloys comprising as additives a narrowly specified range of both strontium and titanium diboride have surprisingly low incidences of hot tearing, thereby allowing die casting of these alloys.

[0011] The present invention is directed to a modified alloy composition applicable to aluminum alloys to control hot tearing by the selective use of additives, thereby providing for these alloys to be subject to die casting, wherein the alloys of the invention have a strength and ductility properties absent in conventional aluminum alloys. These properties allow for shape casting of either above the liquidus of the alloy or in the semi-solid region of the alloy.

[0012] Without being bound to a particular theory, it is thought that the strontium and titanium diboride additives work in a synergistic manner on the alloy, wherein the strontium promotes the formation of spheroidal grains in the alpha grains and the titanium diboride initiates the formation of new grains. When used in combination in the amounts specified, these alloying components allow the liquid aluminum based alloy to flow until the final solidification, thereby preventing or significantly reducing the incidence of hot tearing.

[0013] A first aspect of the invention is directed to an aluminum alloy comprising i) from 0.010 to 0.025% by weight Sr; and ii) TiB_2, measured by its boron content, from 0.001 to 0.005% by weight B. Preferably, the aluminum alloy further comprises iii) 0.16% or less of excess Ti over the amount bound stoichiometrically with the B in TiB_2. It has been found that a number of alloys normally susceptible to hot tearing are highly suitable to the use of the additives of the invention in their specified ranges.

[0014] A related aspect of the invention relates to a method of preventing or eliminating hot tears in an aluminum alloy comprising the step of combining with aluminum i) from 0.010 to 0.025% by weight Sr; and ii) TiB_2, measured by its boron content, from 0.001 to 0.005% by weight B.

[0015] A further object of the invention is to provide a shape cast part, cast from an alloy defined by the present invention. Notably, the shape cast may be a die cast, which is difficult with hot tearing susceptible aluminum alloys. Further advantages are provided by the present invention in that the cast from the alloy may be in a semi-solid state.

[0016] The invention may be alternatively defined as providing a method of providing an aluminum alloy comprising combining with aluminum i) from 0.010 to 0.025% by weight Sr and ii) TiB_2, measured by its boron content, from 0.001 to 0.005% by weight B.

[0017] A particularly interesting aspect of the invention relates to a method for processing an aluminum alloy said aluminum alloy having i) from 0.010 to 0.025% by weight Sr and ii) TiB_2, measured by its boron content, from 0.001 to 0.005% by weight B, and said alloy having a liquidus temperature and a solidus temperature, the method comprising the steps of providing the alloy having a semi-solid range between the liquidus temperature and the solidus temperature of the alloy; heating the alloy to an alloy initial elevated temperature above the liquidus temperature to fully melt the alloy; reducing the temperature of the alloy from the initial metallic alloy elevated temperature to a semi-solid temperature of less than the liquidus temperature and more than the solidus temperature; maintaining the alloy at the semi-solid temperature for a sufficient time to produce a semi-solid structure in the alloy of a globular solid phase dispersed in a liquid phase. Optionally, one may remove some, but not all, of the liquid phase present in the semi-solid structure of the metallic alloy to form a solid-enriched semi-solid structure of the alloy, wherein the optional step of removing includes the step of removing liquid phase; and forming the alloy having the solid-enriched semi-solid structure into a shape.

DESCRIPTION OF THE INVENTION

[0018] The invention relates to aluminum based alloys. The aluminum based alloys may be selected from the group consisting of alloys comprising primarily aluminum and copper such as of the 2xxx and 2xx type; alloys comprising primarily aluminum and manganese such as of the 3xxx type; alloys comprising primarily aluminum and silicon such as of the 4xxx type; alloys comprising primarily aluminum and magnesium such as of the 5xxx and 5xx type; alloys comprising primarily aluminum, magnesium and silicon such as of the 6xxx type; and alloys comprising primarily aluminum and zinc such as of the 7xxx type. The term "primarily" in the context of the alloys of the present invention is intended to mean that these elements provide the highest weight content in the alloy, with aluminum being the highest contributor to the weight content.

[0019] As stated, the aluminum alloys of the present invention, comprise the unique combination of strontium and titanium diboride, namely i) from 0.010 to 0.025% by weight Sr and ii) TiB_2, measured by its boron content, from 0.001 to 0.005% by weight B. Although TiB_2 is a known grain refiner, in this specific combination of this specified grain refiner with strontium, the liquid alloy left in the solidifying alloy is not flow restricted.

[0020] Titanium, zirconium and their borides and carbides are all known grain refiners. Surprisingly, titanium diboride when used in combination with strontium, a crystal modifier, gave surprising improvements to the properties of the aluminum alloy preventing or eliminating the incidence of hot tearing.

[0021] In a preferred embodiment of the invention, the aluminum alloy further comprises 0.16% or less by weight excess Ti and more preferably 0.12% or less by weight excess Ti. By excess Ti, we mean the amount of Ti over that which forms TiB_2. Although the Ti can be introduced by a number of manners known to the skilled person, it is typically introduced either by the addition of metallic titanium or through the use of a "grain refiner" rod, which is an aluminum rod or wire containing specified levels of Ti and B with a stoichiometry designed to generate TiB_2 with an excess of Ti, as known by the skilled person.

[0022] Suitably, the aluminum alloy of the invention may comprise additives in addition to strontium and titanium diboride, and optionally titanium, for a wide range of purposes such as Mg, Cu and Zn for strength, Mn and Fe for strength and reduction of die soldering in die casting, and Ca, Na and Sb for grain modification.

[0023] As can be seen from the Examples, in alloys where the content of TiB_2 (measured by its boron content) is less than 0.001% by weight, there is no effect on grain nucleation. Conversely, in alloys where the content of TiB_2 (measured by its boron content) is more than 0.005% by weight, there is no measurable benefit in terms of hot tearing but levels of TiB_2 (measured by its boron content) which exceed 0.005% by weight are expected to have a negative effect on some semi-solid processes. Excessive titanium diboride has a negative effect on the degree of control in some embodiments of the semi-solid process and also can reduce the strength of the cast part. Accordingly, the invention is directed to an alloy comprising TiB_2 (measured by its boron content) from 0.001 to 0.005% by weight B, preferably from 0.002 to 0.004% by weight TiB_2 (measured by its boron content).

[0024] As can also be seen from the Examples, in alloys where the content of Sr is less than 0.010%, there is insufficient spheroidizing or globularizing effect (too many acicular or needle shaped grains remain). Above 0.025%, the Sr has a negative effect on the final cast strength. Accordingly, the invention relates to an aluminum alloy comprising from 0.010 to 0.025% by weight Sr, preferably 0.010% to 0.020% by weight Sr.

[0025] As can be further seen from the Examples, the use of excess titanium (other than in the form of titanium diboride) is not advantageous in terms of the controlling the hot tearing effect as it contributes to the formation of excessively large and elongated grains. Excess Ti has a negative effect on hot tearing and, if in excess of 0.16%, results in the formation of Al—Ti intermetallics which are acicular and contribute to hot tearing as well as increasing the brittleness of the cast product. The alloys of the present invention have preferably 0.16% or less by weight excess Ti, more preferably 0.12% or less by weight excess Ti.

[0026] The additives of the invention are highly suited to an aluminum alloy comprising primarily aluminum, magnesium, and silicon. Accordingly, an interesting embodiment of the invention relates to an aluminum alloy comprising primarily aluminum, magnesium, and silicon and further comprising 0.010 to 0.025% by weight Sr, and TiB_2 (measured by its boron content) from 0.001 to 0.005% by weight B. A further interesting embodiment of the invention relates to an aluminum alloy comprising primarily aluminum, magnesium, and silicon and 0.010 to 0.025% by weight Sr, TiB_2 (measured by its boron content) from 0.001 to 0.005% by weight B and preferably 0.16% or less by excess Ti over the amount bound stoichiometrically with the B in TiB_2.

[0027] Furthermore, the additives of the invention are considered to be highly suited to an aluminum alloy comprising primarily aluminum and copper. Accordingly, an interesting embodiment of the invention relates to an aluminum alloy comprising primarily aluminum and copper and further comprising 0.010 to 0.025% by weight Sr, and TiB_2 (measured by its boron content) from 0.001 to 0.005% by weight B. In a further interesting embodiment of the invention relates to an aluminum alloy comprising primarily aluminum, and copper and 0.010 to 0.025% by weight Sr, TiB_2 (measured by its boron content) from 0.001 to 0.005% by weight B and preferably 0.16% or less by excess Ti over the amount bound stoichiometrically with the B in TiB_2.

[0028] In a further suitable embodiment, the additives of the invention are highly suited to an aluminum alloy comprising primarily aluminum and magnesium. Accordingly, an interesting embodiment of the invention relates to an aluminum alloy comprising primarily aluminum and magnesium and further comprising 0.010 to 0.025% by weight Sr, and

TiB_2 (measured by its boron content) from 0.001 to 0.005% by weight B. In a further interesting embodiment of the invention relates to an aluminum alloy comprising primarily aluminum and magnesium and 0.010 to 0.025% by weight Sr, TiB_2 (measured by its boron content) from 0.001 to 0.005% by weight B and preferably 0.16% or less by weight excess Ti over the amount bound stoichiometrically with the B in TiB_2.

[0029] In this application, alloys are referred to by the International Alloy Designations of the Aluminum Association. A 2xxx alloy therefore refers to a wrought alloy that is principally aluminum with Cu as the main alloying element (where the Cu may be present, for example, up to about 7 percent by weight), a 2xx alloy therefore refers to a foundry alloy that is principally aluminum with Cu as the main alloying element (where the Cu may be present, for example, up to about 9 percent by weight). An example of an aluminum Cu alloy would be the 206 alloy, which has a composition in weight percent of Si less than 0.1, Fe less than 0.15, Cu 4.2 to 5.0, Mn 0.20 to 0.50, Mg 0.15 to 0.35, Ni less than 0.05, Zn less than 0.10, Sn less than 0.05, balance Al with incidental impurities each less than 0.05 and total less than 0.15, plus 0.010 to 0.025% by weight Sr, TiB_2 (measured by its boron content) from 0.001 to 0.005% by weight B, and preferably 0.16% or less by weight excess Ti over the amount bound stoichiometrically with the B in TiB_2. Another example of an aluminum Cu alloy would be the 2024 alloy, which has a composition in weight percent of Si less than 0.5, Fe less than 0.5, Cu 3.8 to 4.9, Mn 0.30 to 0.9, Mg 1.2 to 1.8, Cr less than 0.10, Zn less than 0.25, balance Al with incidental impurities each less than 0.05 and total less than 0.15, plus 0.010 to 0.025% by weight Sr, TiB_2 (measured by its boron content) from 0.001 to 0.005% by weight B and preferably 0.16% or less by excess Ti over the amount bound stoichiometrically with the B in TiB_2.

[0030] A 3xxx alloy refers to a wrought alloy that is principally aluminum with Mn as the main alloying element up to about 1.5 percent by weight. A 4xxx alloy refers to a wrought alloy that is principally aluminum with Si as the main alloying element up to about 14 percent by weight.

[0031] A 5xxx alloy refers to a wrought alloy that is principally aluminum with Mg as the main alloying element up to about 6 percent by weight. A 5xx alloy refers to a foundry alloy that is principally aluminum with Mg as the main alloying element up to about 11 percent by weight. An example of an aluminum Mn alloy would be the 5182 alloy, which has a composition in weight percent of Si less than 0.2, Fe less than 0.35, Cu less than 0.15, Mn 0.20 to 0.50, Mg 4.0 to 5.0, Cr less than 0.1, Zn less than 0.25, balance Al with incidental impurities each less than 0.05 and total less than 0.15, plus 0.010 to 0.025% by weight Sr, TiB_2 (measured by its boron content) from 0.001 to 0.005% by weight B and preferably 0.16% or less by excess Ti over the amount bound stoichiometrically with the B in TiB_2.

[0032] A 6xxx alloy refers to a wrought alloy that is principally aluminum with Mg and Si as the main alloying elements with Mg present up to about 1.6 percent by weight and Si present up to about 1.7 percent by weight and where magnesium silicide forms during solidification. An example of an aluminum Mg—Si alloys would be 6061 alloy, which has a composition in weight percent of Si 0.40 to 0.80, Fe less than 0.7, Cu 0.15 to 0.40, Mn less than 015, Mg 0.8 to 1.2, Cr 0.04 to 0.35, Zn less than 0.25, balance Al with incidental impurities each less than 0.05 and total less than 0.15, plus 0.010 to 0.025% by weight Sr, 0.005 to 0.025% by weight TiB_2 (measured by its boron content) from 0.001 to 0.005% by weight B and preferably 0.16% or less by excess Ti over the amount bound stoichiometrically with the B in TiB_2.

[0033] A 7xxx alloy refers to a wrought alloy that is principally aluminum with Zn as the main alloying element, typically present up to about 9 percent by weight.

[0034] The preceding alloys would have, in addition to the elements named, TiB_2, Sr, and optionally Ti in the ranges stated above to give reduced hot tearing. These alloys may also contain additional alloying elements including Si, Fe, Cu, Mn, Mg, Cr, Ni, Zn, and V.

[0035] The additives of the present invention, namely 0.010 to 0.025% by weight Sr, and TiB_2 (measured by its boron content) from 0.001 to 0.005% by weight B, are also considered to be highly suitable for 2xxx and 2xx aluminum-copper alloys. 2xxx and 2xx Al—Cu alloys are known to be crack prone. The Sr and TiB_2 additives, in their stated amounts allow for die casting of 2xxx and 2xx alloys and thereby allowing for complex part shapes and designs. By controlling hot tearing in aluminum-copper alloys (2xxx and 2xx alloys), it has been possible to die cast 2xxx and 2xx alloys, which is normally difficult using conventional alloys. The alloys of the invention retain strength and ductility properties similar to the unmodified alloys even though die cast. In an embodiment of the invention, the alloy is cast, such as shape cast or die cast.

[0036] Similarly, alloys comprising primarily aluminum and magnesium such as of the 5xxx and 5xx type are known to be crack prone. The use of 0.010 to 0.025% by weight Sr, and TiB_2 (measured by its boron content) from 0.001 to 0.005% by weight B in aluminum and magnesium such as of the 5xxx and 5xx type allow for die casting of 5xxx and 5xx alloys and thereby allowing for complex part shapes and designs. By controlling hot tearing in alloys comprising primarily aluminum and magnesium such as of the 5xxx and 5xx type, it has been possible to die cast 5xxx and 5xx alloys, which is normally difficult using conventional alloys. The alloys of the invention retain strength and ductility properties similar to the unmodified alloys even though die cast. In an embodiment of the invention, the alloy is cast, such as shape cast or die cast.

[0037] The alloy formulations of the invention are suitable for use in any number of shape casting processes including, but not limited to, sand casting, permanent mold casting, and die casting. Example processes would include gravity permanent mold, low pressure permanent mold, and vacuum permanent mold. Most remarkably, they are also suitable for high pressure diecasting processes, including both conventional high pressure diecasting and high integrity diecasting processes such as high-vacuum diecasting, semi-solid forming, and squeeze casting.

[0038] Hot tearing is not, of course, a phenomenon unique to the shape casting of near-net shape parts but is also a limitation frequently encountered when casting billets, blooms, or T-Ingot cross sections via either semi-continuous or continuous casting processes (e.g. direct-chill casting or horizontal continuous casting). The formulations of the invention are, of course, applicable to the reduction in hot tear susceptibility when casting these types of products as well.

[0039] Remarkably, by controlling hot tearing in Al—Mg—Si alloys (6xxx alloys), it has been possible to die cast 6xxx alloys, which is normally difficult using conventional alloys. The alloys of the invention retain the strength and ductility properties of the unmodified alloys even when die cast and provide properties normally absent in conventional aluminum shape casting alloys. In an embodiment of the invention, the alloy is cast, such as shape cast or die cast.

[0040] It has been found that the casting can be done at either above the liquidus of the alloy or in the semi-solid region. Surprisingly for aluminum alloys, the present invention is directed, in one embodiment, to casting in the semi-solid region since it has been found that not only is hot tearing resistance observed, this gives further improvements in die filling and general suitability for casting. The semi-solid structure may have a globular solid phase under certain processing conditions and this is particularly favourable for casting.

[0041] The casting of the alloy of the invention into a useful shape starting from a temperature above the liquidus (where the alloy is fully molten) can be done by any technique known to those skilled in the art.

[0042] Most of the alloys of the invention can also be cast in semi-solid form, at a temperature where the alloy is partly solid and partly liquid (between the "solidus" and "liquidus" temperatures). Various techniques can be employed.

[0043] A particularly preferred 6xxx alloy for casting by semi-solid or fully molten processes has a composition in weight percent of Si 0.6 to 0.8, Fe up to 0.12, Cu 0.15 to 0.40, Mg 0.8 to 1.2, Cr 0.04 to 0.10, Sr 0.006 to 0.025, 0.005 to 0.025% by weight TiB_2 (measured by its boron content) from 0.001 to 0.005% by weight B and preferably 0.16% or less by excess Ti over the amount bound stoichiometrically with the B in TiB_2. For processing by semi-solid processing the particularly preferred 6xxx alloy balance Al with incidental impurities each less than 0.05 and total less than 0.15, whereas for processing in the fully molten state the particularly preferred 6xxx alloy will have additionally up to 0.45% by weight Mn, provided that the total Mn+Fe is between 0.55 to 0.65% by weight, balance Al with incidental impurities each less than 0.05 and total less than 0.15. Semi-solid processing can beneficially use lower levels of Fe and Mn since the process is less susceptible to die-sticking. For processing above the liquidus, control of the total Fe+Mn is advantageous to reduce die sticking.

[0044] In some embodiments, a solid rod or ingot that may have been specially cast to have a fine globular structure in the solid phase is reheated to a temperature between the solidus and liquidus temperatures and then transferred to a shape casting mould.

[0045] In other embodiments, a fully liquid alloy is cooled to a temperature between the liquidus and solidus temperature to create a semi-solid slurry which is then cast. Generally the process is controlled to ensure that the solid fraction has a globular rather than dendritic structure. This may be accomplished by rapid cooling, optionally with the addition of solid nuclei, or by vigorous agitation (e.g. electromagnetic stirring) during cooling to a predefined temperature. The semi-solid mixture may be held at this temperature (for a few seconds to several minutes) to allow the solid particles to grow into globular structures. The semi-solid slurry having a globular structure is generally thixotropic which enhances its mould filling capabilities.

[0046] The vessel in which the slurry is formed may be heated and/or cooled by external means to ensure that the correct predefined temperature is maintained. In a particularly preferred embodiment, the temperature and weight of the fully liquid alloy is adjusted so that when it is added to a vessel of known mass, heat capacity and temperature, the alloy attains the desired predefined temperature in the semi-solid region and stabilizes there for a period of time to permit globularization of the structure.

[0047] In some preferred embodiments, some of the unsolidified liquid alloy may be removed (e.g. by draining through a filter or orifice) during or after the period at the predefined temperature. This achieves a further improvement in the structure of the semi-solid alloy and permits easier removal of the semi-solid material to the casting machine.

[0048] The semi-solid slurry after preparation may be cast by known shape casting techniques. Die casting is a particularly preferred technique.

[0049] The present invention provides aluminum alloys with reduced incidences of hot tearing. Without being bound to a particular theory, the combination of modifiers and grain refiner addition, in the stated amounts, controls both the primary alpha and secondary phases of the alloy. The high degree of control of the grain size and morphology provided by the present invention is achieved using a narrow range of titanium diboride, preferably well distributed within the melt. A high control of the primary alpha phase allows for the eutectic liquid to move more freely (compared to in the absence of titanium diboride) within the solidifying network. In addition, the precipitation of the secondary phase, comprising the intermetallics (such as Mg_2Si in 6xxx alloys) is considered to affect the flow of the eutectic liquid between the globular structures and prevent feeding of any incipient hot tears.

[0050] As stated, the grain refiners and modifiers control the size and morphology of both the secondary and primary phases. As the primary alpha phase is generally the last phase to form during solidification, the present invention in particular controls the size and shape of the alpha phase to ensure that the eutectic liquid is free to move in the solidifying network. The secondary phase between the alpha grains affects the flow of eutectic fluid and therefore refinement and modification of the secondary phase is also important to ensure adequate alloy feeding and prevention of incipient hot tears.

[0051] When grain refinement is not very efficient, hot tears are likely to be initiated and easier to propagate. On the other hand, if the alloy is over refined, the hot tear will be difficult to initiate, but once it occurs, it propagates more easily. Consequently, when refinement is done properly, the start up of the hot tears is more difficult and they propagate with difficulty.

EXAMPLES

Example 1

[0052] Samples of two base alloys of the Al—Mg—Si type, two of the Al—Cu and one of the Al—Mg type were prepared as follows (compositions in weight percent)

Element	Base Alloy A (Al—Mg—Si)	Base Alloy B (Al—Mg—Si)	Base Alloy C (Al—Cu)	Base Alloy D (Al—Cu)	Base Alloy E (Al—Mg)
Si	0.7%	1.2%	0.5%	0.05%	0.20%
Fe	0.12%	0.12%	0.5%	0.07%	0.35%

-continued

Element	Base Alloy A (Al—Mg—Si)	Base Alloy B (Al—Mg—Si)	Base Alloy C (Al—Cu)	Base Alloy D (Al—Cu)	Base Alloy E (Al—Mg)
Cu	0.25%	0.25%	4.5%	4.8%	0.15%
Mn	<0.01%	<0.01%	0.6%	0.40%	0.35%
Mg	1.10%	1.10%	1.5%	0.28%	4.5%
Cr	0.07%	0.07%	0.07%		0.10%
Zn	<0.002%	<0.002%			0.25%

[0053] To these base alloys, varying amounts of Sr, TiB_2 and excess Ti were added. The Ti and Sr were added to the casting furnace in the form of aluminium master alloys. The TiB_2 was added as an Al-5Ti-1B grain refiner rod in the casting ladle immediately before casting to prevent settling of the TiB_2. This also increased the amount of Ti slightly because of the excess Ti in the grain refiner rod and this amount was added to the Ti in the stated alloy compositions. These alloys were cast from the fully liquid state into a Constrained Rod Casting (CRC) mould. The hot tearing sensitivity index was measured in each case using the following method.

[0054] Cracks on the CRC cast bars were inspected visually. Five categories of hot tear severity are described below and an index number Cj for that crack assigned:

[0055] No crack: A casting that appears to be crack free (Cj=0);

[0056] Hairline crack: A hairline crack that extends over half the circumference of the bar (Cj=1);

[0057] Light crack: A hairline crack that extends over the entire circumference of the bar (Cj=2);

[0058] Severe crack: A crack that extends over the entire circumference of the bar (Cj=3); and

[0059] Complete crack: A complete or almost separation of the bar (Cj=4).

[0060] Two different CRC moulds were used with cast bars (A to D) of different length and these were assigned length parameters as shown in the following tables:

(a) Mould CRC-1		(b) Mould CRC-2	
A (2.0)	4		
B (3.5)	3	B (6.5)	3
C (5.0)	2	C (8.5)	2
D (6.5)	1	D (10.5)	1

[0061] The value of HTS for a sample is then given by:

$$HTS = \sum_{i=A}^{D} (C_i \times L_i)$$

[0062] Where "C" is the assigned numerical value for the severity of the crack in the bars, "L" is the assigned numerical value corresponding to the length of the bar, and "i" represents the bars A, B, C, and D. The HTS value for the specific alloy compositions was the average value of the five castings that were cast using the CRC mould.

[0063] The following results were obtained (all additions are in weight percent):

Alloy Number	Base Alloy	Ti (excess) (wt %)	Total Ti (wt %)	B (wt %)	Added Sr (wt %)	Hot Tearing Sensitivity Index	Equivalent TiB_2 (wt %)
A1	A	0	0.000	0	0	14.50	0.000
A2	A	0.002	0.005	0.001	0.002	10.50	0.003
A3	A	0.052	0.055	0.001	0.005	12.80	0.003
A4	A	0.152	0.155	0.001	0.020	17.00	0.003
A5	A	0.202	0.205	0.001	0	16.80	0.003
A6	A	0.004	0.010	0.002	0.005	14.80	0.006
A7	A	0.154	0.160	0.002	0	17.80	0.006
A8	A	0.204	0.210	0.002	0.002	16.20	0.006
A9	A	0.105	0.115	0.003	0	11.40	0.010
A10	A	0.155	0.165	0.003	0.002	17.20	0.010
A11	A	0.205	0.215	0.003	0.005	14.50	0.010
A12	A	0.107	0.120	0.004	0.002	15.80	0.013
A13	A	0.157	0.170	0.004	0.005	12.80	0.013
A14	A	0.207	0.220	0.004	0.010	18.00	0.013
A15	A	0.102	0.105	0.001	0.010	11.60	0.003
A16	A	0.054	0.060	0.002	0.010	8.00	0.006
A17	A	0.104	0.110	0.002	0.020	11.80	0.006
A18	A	0.055	0.065	0.003	0.020	10.40	0.010
A19	A	0.007	0.020	0.004	0.020	8.80	0.013
B1	B	0	0.000	0.000	0	17.40	0.000
B2	B	0.004	0.010	0.002	0.005	9.00	0.006
B3	B	0.154	0.160	0.002	0.010	6.00	0.006
B4	B	0.105	0.115	0.003	0	15.60	0.010
B5	B	0.155	0.165	0.003	0.005	12.20	0.010
B6	B	0.157	0.170	0.004	0	9.20	0.013
B7	B	0.054	0.060	0.002	0.010	4.40	0.006
B8	B	0.104	0.110	0.002	0.020	3.20	0.006
B9	B	0.005	0.015	0.003	0.010	1.40	0.010
B10	B	0.055	0.065	0.003	0.020	4.00	0.010
B11	B	0.007	0.020	0.004	0.020	3.80	0.013
B12	B	0.057	0.070	0.004	0.010	4.00	0.013
C1	C	0	0.000	0.000	0	16.40	0.000
C2	C	0.052	0.055	0.001	0.005	17.20	0.003
C3	C	0.152	0.155	0.001	0.005	15.60	0.003
C4	C	0.152	0.155	0.001	0.020	15.75	0.003
C5	C	0.202	0.205	0.001	0.010	18.00	0.003
C6	C	0.004	0.010	0.002	0.005	16.20	0.006
C7	C	0.154	0.160	0.002	0	19.80	0.006
C8	C	0.204	0.210	0.002	0.002	20.60	0.006
C9	C	0.105	0.115	0.003	0	23.20	0.010
C10	C	0.102	0.105	0.001	0.010	12.80	0.003
C11	C	0.054	0.060	0.002	0.010	13.20	0.006
C12	C	0.104	0.110	0.002	0.020	16.20	0.006
C13	C	0.005	0.015	0.003	0.010	12.00	0.010
C14	C	0.055	0.065	0.003	0.020	8.80	0.010
C15	C	0.105	0.115	0.003	0.010	15.40	0.010
C16	C	0.007	0.020	0.004	0.010	15.20	0.013
C17	C	0.007	0.020	0.004	0.020	10.40	0.013
C18	C	0.057	0.070	0.004	0.010	11.80	0.013
C19	C	0.057	0.070	0.004	0.020	6.90	0.013
D1	D	0	0.000	0.000	0	16.50	0.000
D2	D	0.052	0.055	0.001	0.005	21.33	0.003
D3	D	0.152	0.155	0.001	0.005	18.50	0.003

-continued

Alloy Number	Base Alloy	Ti (excess) (wt %)	Total Ti (wt %)	B (wt %)	Added Sr (wt %)	Hot Tearing Sensitivity Index	Equivalent TiB_2 (wt %)
D4	D	0.152	0.155	0.001	0.020	12.50	0.003
D5	D	0.202	0.205	0.001	0.010	12.25	0.003
D6	D	0.004	0.010	0.002	0.005	11.60	0.006
D7	D	0.204	0.210	0.002	0.002	12.25	0.006
D8	D	0.207	0.220	0.004	0.010	14.25	0.013
D9	D	0.102	0.105	0.001	0.010	9.00	0.003
D10	D	0.054	0.060	0.002	0.010	8.40	0.006
D11	D	0.104	0.110	0.002	0.020	8.00	0.006
D12	D	0.005	0.015	0.003	0.010	7.00	0.010
D13	D	0.055	0.065	0.003	0.020	10.60	0.010
D14	D	0.105	0.115	0.003	0.010	9.00	0.010
D15	D	0.007	0.020	0.004	0.010	7.50	0.013
D16	D	0.007	0.020	0.004	0.020	8.00	0.013
D17	D	0.057	0.070	0.004	0.010	8.20	0.013
D18		0.057	0.070	0.004	0.020	9.00	0.013
E1	E	0	0.000	0.000	0	9.40	0.000
E2	E	0.052	0.055	0.001	0.005	3.20	0.003
E3	E	0.152	0.155	0.001	0.020	6.40	0.003
E4	E	0.202	0.205	0.001	0.010	4.40	0.003
E5	E	0.004	0.010	0.002	0.005	2.40	0.006
E6	E	0.204	0.210	0.002	0.002	5.00	0.006
E7	E	0.105	0.115	0.003	0	5.00	0.010
E8	E	0.207	0.220	0.004	0.010	3.20	0.013
E10	E	0.102	0.105	0.001	0.010	3.40	0.003
E11	E	0.054	0.060	0.002	0.010	1.40	0.006
E12	E	0.104	0.110	0.002	0.020	2.60	0.006
E13	E	0.005	0.015	0.003	0.010	1.20	0.010
E14	E	0.055	0.065	0.003	0.020	0.80	0.010
E15	E	0.007	0.020	0.004	0.010	0.80	0.013
E16	E	0.007	0.020	0.004	0.020	1.00	0.013
E17	E	0.057	0.070	0.004	0.010	0.40	0.013
E18	E	0.057	0.070	0.004	0.020	0.60	0.013

[0064] In the above table, the boron is present as TiB_2. Total Ti is the total amount of Ti from all sources and Ti (excess) is the amount of Ti that is not bound up in TiB_2.

[0065] Alloys A15 to A19, B7 to B12, C10 to C19, D9 to D18 and E10 to E18 represent alloys within the inventive range of additives, whereas the remaining alloys are outside the range. Alloys A1, B1, C1, D1 and E1 represent the base alloys with no additive elements.

[0066] The Hot Tearing Susceptibility Index for the alloys within the inventive range is less than those outside the range. The change is sufficient that in actual castings the presence of cracks due to hot tearing in the inventive alloys is substantially reduced.

Example 2

[0067] Die cast parts in the form of U-shaped sections (simulated suspension arm) were prepared from Base Alloys A and B and several modifications having the preferred compositions of this application.

[0068] Samples were produced using both a liquid alloy die casting process and the preferred semi-solid process described above, in which a mass of alloy above the liquidus was cooled rapidly to a temperature in the semi-solid region, the temperature determined by the relative masses and temperatures of the alloy and holding crucible, holding the mass of metal for a period of time then draining a portion of the remaining liquid from the crucible before casting. The amount of liquid alloy drained from the semi-solid mass prior to casting was from 15 to 18%. The cast parts were heat treated by two different processes.

[0069] Treatment I: Heat Treatment: 3 h@530° C.+Quench+18 h@160° C.

[0070] Treatment II: Heat Treatment: 3 h@530° C.+Quench+8 h@170° C.

[0071] Liquid die penetrant analysis was used to determine a hot tearing index for the cast parts. The straight side sections of the U shape was examined and a hot tearing index determined for these locations. Tensile tests were run on samples cut from the same locations. The hot tearing index is a semi-quantitative index which assigned a score for each defect found in the locations examined. A score of 0 means no defect, a score of 1 means a point defect (no propagation), a scope of 2 means propagation length less than or equal to the width of the side section, and a score of 3 means propagation length greater than the with of the side section. The Index was the sum of these scores for four locations along the straight side sections of the U shape.

		Hot Tearing	UTS (MPa)		YS (MPa)		% El	
Alloy	Preparation	Index	Treatment I	Treatment II	Treatment I	Treatment II	Treatment I	Treatment II
A1	Liquid	11.33	301	318	260	272	6.7	12.5
	Semi-solid	11.00	307	308	262	267	10.6	11.7
A19	Liquid	8.71	311	322	267	286	9.5	7.6
	Semi-Solid	4.77	298	299	250	257	12.0	13.1
A16	Liquid	9.13	314	316	265	286	14.0	8.4
	Semi-solid	2.00	304	295	253	248	12.7	11.2
B9	Liquid	6.00	328	334	289	294	5.2	8.7
	Semi-solid	7.00	332	331	295	297	7.7	10.3

[0072] The results indicate a lower hot tearing susceptibility for the inventive alloys A19, A16 and B9 compared to the base alloy A1. Generally then parts cast using semi-solid processing had better hot tearing performance that the liquid cast alloys and semi-solid processing resulted in tensile properties less sensitive to the heat treatment than those produced by liquid processing.

Example 3

[0073] Die cast parts were prepared from the inventive alloy A16. Samples were produced using the preferred semi-solid process described above, in which a mass of alloy above the liquidus was cooled rapidly to a temperature in the semi-solid region, the temperature determined by the relative masses and temperatures of the alloy and holding crucible, holding the mass of metal for a period of time without draining any remaining liquid from the crucible before casting. The cast parts were heat treated by the following process.

[0074] Treatment III: Heat Treatment: 8 h@540° C.+Quench+6 h@170° C.

[0075] Tensile tests were done and results are seen in the following table.

Alloy	Preparation	Hot Tearing Index	UTS (MPa) Treatment III	YS (MPa) Treatment III	% El Treatment III
A16	Semi-solid	2.00	339	296	15.4

[0076] The results indicate a lower hot tearing susceptibility for the inventive alloy A16 compared to the base alloy A1. Moreover, results confirm that this inventive alloy A16 has elasticity limits and mechanical strengths in orders of 5 to 10% above the typical values of the 6061 wrought alloy. Also, from fatigue test performed, the inventive alloy A16 in semi-solid has a fatigue life length similar to the 6061 wrought alloy.

1. An aluminum alloy comprising:

i) From 0.010 to 0.025% by weight Sr; and

ii) TiB_2, measured by its boron content, from 0.001 to 0.005% by weight B.

2. The aluminum alloy according to claim **1**, further comprising:

i) 0.16% or less by weight excess Ti over the amount bound stoichiometrically with the B in TiB_2.

3. The aluminum alloy according to claim **1**, selected from the group consisting of alloys comprising primarily aluminum and copper; alloys comprising primarily aluminum and manganese; alloys comprising primarily aluminum and silicon; alloys comprising primarily aluminum and magnesium; alloys comprising primarily aluminum, magnesium and silicon; and alloys comprising primarily aluminum, magnesium, zinc and copper.

4. The aluminum alloy according to claim **1**, comprising aluminum, magnesium, and silicon.

5. The aluminum alloy according to claim **4**, further comprising 0.010 to 0.020% by weight Sr, and TiB_2, measured by its boron content, from 0.002 to 0.004% by weight B.

6. The aluminum alloy according to claim **1**, for shape casting.

7. The aluminum alloy according to claim **1**, for die casting.

8. The aluminum alloy according to claim **1**, wherein the alloy is an alloy cast prepared using a semi-solid casting process.

9. The aluminum alloy according to claim **1**, with a composition in weight percent of 0.6 to 0.8 Si, up to 0.12 Fe, 0.15 to 0.40 Cu, 0.8 to 1.2 Mg, 0.04 to 0.10 Cr, 0.006 to 0.025 Sr, 0.005 to 0.025% TiB_2, measured by its boron content, from 0.001 to 0.005% by weight B, 0.16% or less of excess Ti over the amount bound stoichiometrically with the B in TiB_2, incidental impurities each less than 0.05 and total less than 0.15, and balance with Al.

10. The aluminum alloy according to claim **9**, for casting by semi-solid processes.

11. The aluminum alloy according to claim **1**, with a composition in weight percent of 0.6 to 0.8 Si, up to 0.12 Fe, 0.15 to 0.40 Cu, 0.8 to 1.2 Mg, 0.04 to 0.10 Cr, 0.006 to 0.025 Sr, 0.005 to 0.025% TiB_2, measured by its boron content, from 0.001 to 0.005% by weight B, 0.16% or less of excess Ti over the amount bound stoichiometrically with the B in TiB_2, up to 0.45% by weight Mn, provided that the total Mn+Fe is between 0.55 to 0.65% by weight, incidental impurities each less than 0.05 and total less than 0.15, and balance Al.

12. The aluminum alloy according to claim **11**, for processing in the fully molten state.

13. A method of preventing or eliminating hot tears in an aluminum alloy comprising the step of combining with aluminum:

i) from 0.010 to 0.025% by weight Sr; and

ii) TiB_2, measured by its boron content, from 0.001 to 0.005% by weight B.

14. The method according to claim **13**, further comprising the step of combining iii) 0.16% or less by weight excess Ti over the amount bound stoichiometrically with the B in TiB_2.

15. A shape cast part, cast from an alloy as defined in claim **1**.

16. The shape cast part according to claim **15**, being a die cast.

17. The shape cast part according to claim **15**, cast from the alloy in a semi-solid state.

18. A method of providing an aluminum alloy comprising combining with aluminum:

i) from 0.010 to 0.025% by weight Sr; and

ii) TiB_2, measured by its boron content, from 0.001 to 0.005% by weight B.

19. The method according to claim **18**, further comprising combining iii) 0.16% or less by weight excess Ti over the amount bound stoichiometrically with the B in TiB_2.

20. The method according to claim **18**, wherein the alloy comprises primarily aluminum, magnesium, and silicon.

21. The method according to claim **18**, comprising casting the alloy.

22. The method according to claim **18**, comprising die casting the alloy.

23. The method according to claim **18**, comprising casting the alloy in a semi-solid state.

24. The method according to claim **18**, wherein the alloy is cooled from its liquidus state to its semi-solid state prior to casting.

25. The method according to claim **18**, wherein the alloy in its molten state may be maintained at temperature for a period of time sufficient to produce a semi-solid structure in the alloy.

26. The method according to claim **25**, wherein the period of time is from 1 second to about 2 minutes.

27. The method according to claim **23**, when the alloy is in its semi-solid state, said semi-solid state being globular solid phase dispersed in a liquid phase, prior to casting, at least some, but not all of the liquid phase is removed.

28. The method for processing an aluminum alloy as defined in claim **1**, having a liquidus temperature and a solidus temperature, the method comprising the steps of providing the alloy having a semi-solid range between the liquidus temperature and the solidus temperature of the alloy; heating the alloy to an alloy initial elevated temperature above the liquidus temperature to fully melt the alloy; reducing the temperature of the alloy from the initial metallic alloy elevated temperature to a semi-solid temperature of less than the liquidus temperature and more than the solidus temperature; maintaining the alloy at the semi-solid temperature for a sufficient time to produce a semi-solid structure in the alloy of a globular solid phase dispersed in a liquid phase, wherein the semi-solid structure has less than about 50 weight percent solid phase; removing at least some, but not all, of the liquid phase present in the semi-solid structure of the metallic alloy to form a solid-enriched semi-solid structure of the alloy, wherein the step of removing includes the step of removing liquid phase until the solid-enriched semi-solid structure has from about 35 to about 55 weight percent solid phase; and forming the alloy having the solid-enriched semi-solid structure into a shape.

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