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(54) **ALUMINUM ALLOY, CAST ARTICLE OF ALUMINUM ALLOY, AND METHOD FOR PRODUCING CAST ARTICLE OF ALUMINUM ALLOY**

(57) An aluminum alloy according to the present invention includes from 4.0 to 6.0% Mg, from 0.3 to 0.6% Mn, from 0.5 to 0.9% Fe, and the balance of Al and inevitable impurities when the entirety is taken as 100% by mass.

By appropriately selecting the composition range of

Mg, Mn and Fe, it has been possible to micro-finely crystallize Al(Mn, Fe) compounds while inhibiting the growth of primary-crystal Al. As a result, the resulting aluminum alloy is good in terms of the castability, and shows high strength as well as high ductility.

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DescriptionTechnical Field

[0001] The present invention relates to an aluminum alloy, and a process for producing a cast product made of an aluminum alloy. More particularly, it relates to an aluminum alloy which shows castability suitable for even producing thin-thickness cast products and the like, and high strength as well as good ductility even as cast, and a process for producing cast products comprising the aluminum alloy.

Background Art

[0002] Recently, it has been required to lightweight various products, conventional cast-iron products are about to give way to light aluminum alloy products rapidly. For example, in the case of automobiles, it is possible to expect mileage improvement by lightweighting, and the lightweighting is effective in environmental improvement as well.

[0003] By the way, high strength and high ductility have come to be required even for thin-thickness cast products (die-cast products especially), to which the requirements for strength and ductility have been moderate relatively. As a method for producing high-strength and high-ductility thin-thickness cast products, it has been proposed such a method that the resulting cast products are heat treated after casting while vacuuming the inside of dies, or after casting while filling the inside of dies with oxygen contrarily, for example. However, in such a method, heat treatments are needed to result in the increment of production costs. Moreover, the thinner and larger cast products are, the more the heat treatments cause strains of the cast products (swelling, deformations, and the like), and accordingly it takes more costs for the correction.

[0004] Hence, in order to solve such problems, the development of aluminum alloys which reveal high strength and high ductility even as cast has been carried out extensively. For example, in ① Japanese Unexamined Patent Publication (KOKAI) No. 9-3582, ② Japanese Unexamined Patent Publication (KOKAI) No. 11-293375, ③ Japanese Unexamined Patent Publication (KOKAI) No. 11-193434, and ④ Japanese Unexamined Patent Publication (KOKAI) No. 9-268340, Japanese Unexamined Patent Publication (KOKAI) No. 9-316581 and Japanese Unexamined Patent Publication (KOKAI) No. 11-80872, and the like, there are disclosures on such aluminum alloys. Hereinafter, the aluminum alloys set forth in the respective publications will be described in detail.

[0005] In ① Japanese Unexamined Patent Publication (KOKAI) No. 9-3582, an aluminum alloy cast product is disclosed which contains Mg: 3.0-5.5% (% by mass: being the same hereinafter), Zn: 1.0-2.0% (Mg/Zn: 1.5-5.5), Mn: 0.05-1.0%, Cu: 0.05-0.8%, and Fe: 0.1-0.8%. This Al-Mg-Mn-Zn-Cu system alloy contains Zn and Cu falling in a pre-determined range as essential elements.

[0006] When the present inventors tested and studied cast products made of this alloy, intermediate phases, such as $MgZn_2$ and $Mg_{32}(Al, Zn)_{49}$, are precipitated in the cast products, strength characteristic change by natural aging, and stress corrosion cracks appeared. Moreover, it was also understood that this alloy was such that hot tearing is likely to occur so that it was not suitable for casing thin-thickness members.

[0007] In ② Japanese Unexamined Patent Publication (KOKAI) No. 11-293375, a highly ductile aluminum alloy die cast is disclosed which is characterized in that it comprises Mg: 2.5-7.0%, Mn: 0.2-1.0%, and Ti: 0.05-0.2%, and Fe in an amount of 0.3% and Si in an amount of 0.5% or less, a porosity is 0.5% or less at a heavy-thickness part ranging from 1 to 5 mm, the average circle-equivalent diameter of crystallized substances is 1.1 μm or less, and the areal ratio of crystallized substances is 5% or less. This Al-Mg-Mn-Ti system alloy is such that Fe is treated as an inevitable impurity and the content is limited to less than 0.3%.

[0008] When the present inventors tested and studied thin-thickness die-cast products using this alloy, they were such that hot tearing was likely to occur. Moreover, when the Mg content increased, shrinkage cavities were likely to occur at the heavy-thickness center. The occurrence of hot tearing and shrinkage cavities is not preferable, because it enlarges the fluctuation of strength characteristic and elongation.

[0009] In ③ Japanese Unexamined Patent Publication (KOKAI) No. 11-193434, an aluminum alloy for high-toughness die-cast products is disclosed, aluminum alloy which comprises Mg: 3.0-5.5%, Mn: 1.5-2.0%, and Ni: 0.5-0.9%.

[0010] In this Al-Mg-Mn-Ni system alloy, Ni is an essential constituent element, and the toughness of die-cast products are improved by adjusting the content appropriately. Moreover, since the Mn content is much, the crystallized amount of its compounds is so much that the elongation is 10% approximately as indicated by the examples.

[0011] In ④ Japanese Unexamined Patent Publication (KOKAI) No. 9-268340, a highly ductile aluminum alloy is disclosed which comprises Mg: 0.01 to 1.2%, Mn: 0.5 to 2.5%; and Fe: 0.1-1.5%.

[0012] In this Al-Mg-Mn-Fe system alloy, defects such as hot tearing and shrinkage cavities, are inhibited from occurring by decreasing the Mg content so as to merely improve the castability and elongation. Accordingly, it is seen from the examples as well that the alloys are not satisfactory in view of the strength because the tensile strength is even less than 190 MPa. Note that the aluminum alloys, disclosed in Japanese Unexamined Patent Publication (KOKAI)

No. 9-316581 and Japanese Unexamined Patent Publication (KOKAI) No. 11-80872, are as poor as this alloy.

Disclosure of Invention

[0013] The present invention has been done in view of such circumstances. Namely, it is an object to provide an aluminum alloy in which the occurrence and the like of hot tearing and micro porosity is less and accordingly which is good in terms of the castability. In particular, it is an object to provide an aluminum alloy from which cast products of high strength and good ductility can be obtained even as cast. Moreover, it is an object to provide an aluminum alloy whose cast products suffer the time change of mechanical characteristics and so forth less.

[0014] In addition, it is an object to provide a process for producing cast products, process in which this aluminum alloy is used.

[0015] Hence, the present inventors have been studying earnestly in order to solve this assignment, and have been repeated various systematic experiments, as a result, have discovered an aluminum alloy, which is good in terms of the castability, and moreover from which cast products of high strength and high ductility can be obtained even as cast, by appropriately controlling the composition proportion of Mg, Mn and Fe, and have arrived at completing the present invention.

(Aluminum Alloy)

[0016] Namely, an aluminum alloy according to the present invention comprises: from 4.0 to 6.0% magnesium (Mg); from 0.3 to 0.6% manganese (Mn); from 0.5 to 0.9% iron (Fe); and the balance of aluminum (Al) and inevitable impurities when the entirety is taken as 100% by mass.

[0017] Since the present aluminum alloy (Al-Mg-Mn-Fe alloy) contains Mg, Mn and Fe with an appropriate composition proportion, the castability is improved, and high strength as well as high ductility are revealed. Hereinafter, the reasons conceivable at present and how to arrive at the above-described composition will be described.

[0018] It has been known that the strength of aluminum alloys is improved by solving Mg or Mn in Al matrices, however, when producing thin-thickness die-cast products with Al-Mg-Mn alloys, hot tearing, porosity and the like, accompanied by solidification shrinkage, occur so that the castability is poor. Moreover, correlating therewith, the fluctuation of elongation enlarges.

[0019] Hence, in order to obtain an aluminum alloy which is good in terms of the castability and which is of high strength and high ductility, the present inventors focused on the relationship between the crystallization form of crystallized substances in the solidification process and the castability or mechanical properties. And, they ascertained that the hot tearing of cast products made of aluminum alloys occurs often in brittle liquid phase portions which reside between primary-crystal Al dendrites growing in the solidification process. This is believed to be as follows: upon the solidification shrinkage, shrinkage stresses act on cast products when the cast products are constricted by dies in a temperature range (semi-solidus temperature range) in which the cast products are shaped and begin to have strength in the process in which the cast products are being formed by the development and combination of primary-crystal dendrites; and the stresses concentrate on the brittle liquid phase portions which reside between the dendrites so as to cause the hot tearing frequently.

[0020] Hence, the present inventors thought of adding Fe to Al-Mg-Mn alloys, and changed the crystallization behavior in the solid-liquid coexisting zone by adjusting the Mn and Fe contents according to the Mg content so that they succeeded in obtaining good hot tearing resistance. Specifically, the crystallization temperature zone of primary-crystal Al was narrowed so that Al-Mn-Fe eutectics were crystallized between the network isthmuses of primary-crystal Al, which had finished crystallizing, without growing the dendrites of primary-crystal Al greatly. And, since the connection between respective solid phases developed rapidly under the circumstance, it is believed that the hot tearing was less likely to occur.

[0021] Moreover, in accordance with the present aluminum alloy, since Al(Mn, Fe) compounds crystallize micro-finely after micro-fine Al crystallizes out of the liquid phases as primary crystals, there are less coarse crystallized substances which result in lowering the ductility, and accordingly it is believed that it comes to reveal good ductility while even sustaining high strength.

[0022] Especially, when the present aluminum alloy can comprise primary-crystal aluminum and compounds which are dispersed uniformly, the primary-crystal aluminum having a dendritic cell size of 10 μm or less, the compounds having a grain diameter of 5 μm or less, it is more suitable in view of the strength and ductility. Moreover, it is more preferable when the dendritic cell size of said primary-crystal aluminum can be 5 μm or less and the grain diameter of said compounds can be 3 μm or less.

[0023] Here, the size of the dendritic cells (dendrite) is a length when measured in the longitudinal direction, and is an average value of the measured values for 100 pieces of the cells. Moreover, the grain diameter of the compounds is assessed in the longitudinal direction (the maximum length), and is an average value of measured values on 10

view fields of a structural photograph (view field area, $70 \times 100 \mu\text{m}$) which is taken with a magnification of 100 times by using an image processor.

[0024] Thus, in accordance with the present aluminum alloy, even when thin-thickness die-cast products are produced, for example, it is possible to obtain cast products provided with sufficient strength and good ductility without hardly causing porosity such as hot tearing and shrinkage cavities. For instance, it is possible to obtain an aluminum alloy which exhibits a 0.2% proof stress of 130 MPa or more and a fracture elongation of 13% or more as cast being free from being subjected to a heat treatment after casting.

[0025] Moreover, the aluminum alloy solution-strengthened by Mg and Mn falling in the aforementioned composition range is provided with an advantage that the change of mechanical properties with time is less without scarcely causing the hardness change by natural aging.

(Production Process for Cast Product Made of Aluminum Alloy)

[0026] A cast product comprising the above-described present aluminum alloy can be obtained by the following production process, for example.

[0027] Namely, a process according to the present invention for producing a cast product made of an aluminum alloy comprises the steps of: pouring an aluminum alloy molten metal into a die, the aluminum alloy molten metal comprising: from 4.0 to 6.0% Mg; from 0.3 to 0.6% Mn; from 0.5 to 0.9% Fe; and the balance of Al and inevitable impurities when the entirety is taken as 100% by mass; and solidifying the aluminum alloy molten metal by cooling it after the pouring step.

[0028] And, it is suitable that said solidifying step can be a step being solidified by cooling at a cooling rate of $20^\circ\text{C}/\text{sec.}$ or more.

[0029] It is because, with this arrangement, cast products made of an aluminum alloy can be obtained securely, cast products in which the above-described micro-fine primary-crystal aluminum and compounds are dispersed uniformly. It is further preferable that the cooling rate can be $50^\circ\text{C}/\text{sec.}$ or more.

[0030] By the way, the "aluminum alloy" set forth in the present invention not only involves aluminum alloys as a raw material for casting but also cast products (manufactured goods) made of aluminum alloys after casting.

[0031] Namely, the present invention can be grasped as a cast product made of an aluminum alloy, the cast product comprising: from 4.0 to 6.0% Mg; from 0.3 to 0.6% Mn; from 0.5 to 0.9% Fe; and the balance of Al and inevitable impurities when the entirety is taken as 100% by mass.

[0032] Moreover, the "castability" set forth in the present specification is a concept which involves not only the molten metal fluidity, the releasability and the like but also the occurrence rate and so forth of hot tearing and shrinkage cavities (porosity).

Brief Description of the Drawings

[0033] Fig. 1 is a cross-sectional view for illustrating a vertical die-casting machine equipped with a die for assessing hot tearing, die which is capable of varying the constriction length.

[0034] Fig. 2 is a cross-sectional view taken along the line "A-A" in Fig. 1.

[0035] Fig. 3 is a bar graph for illustrating the relationship between the constriction length and castability on each test sample.

[0036] Fig. 4 is a graph for illustrating the relationship between the hot tearing characteristics and the Fe content.

Best Mode for Carrying out the Invention

A. Mode for Carrying Out

[0037] Next, the present invention will be described in more detail while naming embodiment modes.

(1) Alloy Composition

① Mg

[0038] Mg is an element which solves in the matrix of aluminum to improve the mechanical strength (for example, the tensile strength) of aluminum alloys. Moreover, Mg is an element which exerts influences on the ductility and castability of aluminum alloys as well.

[0039] When Mg is comprised less than 4.0% (percentage by mass, being the same hereinafter), the improvement of mechanical strength is not sufficient, especially, it is difficult to secure a proof stress (a 0.2% proof stress, being the

same hereinafter) of 130 MPa or more. Moreover, when Mg is comprised in excess of 6.0%, the oxidation of molten metals is significant. In addition, since the composition of Mn and Fe whose coarse crystallized substances start crystallizing as primary crystals according to the Mg content increment moves to a lower concentration side, the ductility is deteriorated by the crystallization of the coarse crystallized substances when the Mg content exceeds 6% in the case where Mn and Fe fall in the aforementioned composition range.

[0040] Therefore, it is preferable that Mg can be comprised from 4.0 to 6.0%, and it is further preferable that it can be comprised from 4.0 to 5.0%, when the entirety is taken as 100% by mass.

② Mn

[0041] Mn is an element which improves the mechanical strength of aluminum alloys by solving in the matrix of aluminum similarly to Mg, or by generating compounds with aluminum to precipitate them micro-finely in the matrix. Moreover, it also produces an effect of improving the anti-seisurability to dies.

[0042] When Mn is comprised less than 0.3%, the improvement of mechanical strength is not sufficient, and when it is comprised in excess of 0.6%, it is not preferable because coarse crystallized substances crystallize to result in lowering the ductility.

[0043] Therefore, it is preferable that Mn can be comprised from 0.3 to 0.6%, and it is further preferable that it can be comprised from 0.3 to 0.5%, when the entirety is taken as 100% by mass.

③ Fe

[0044] Fe is an element which changes the crystallization process in solidification to inhibit hot tearing resulting from solidification shrinkage. Moreover, Fe also produces an effect of improving the anti-seisurability to dies when die-casting is carried out.

[0045] When Fe is comprised less than 0.5%, it is insufficient to change the crystallization process greatly, and the effect of inhibiting hot tearing is less. On the other hand, when Fe is comprised in excess of 0.9%, it is not preferable because coarse crystallized substances crystallize to lower the ductility. Therefore, it is preferable that Fe can be comprised from 0.5 to 0.9% when the entirety is taken as 100% by mass.

[0046] According to a further study by the present inventors, it became apparent that it is further preferable that Fe can be comprised from 0.5 to 0.8% or from 0.5 to 0.7%.

④ Cr

[0047] Cr is an element which improves the mechanical strength of aluminum alloys by solving in the matrix of aluminum similarly to Mg and Mn.

[0048] When Cr is comprised less than 0.1%, the improvement of mechanical strength is not sufficient, and when it is comprised in excess of 0.7%, it is not preferable because coarse crystallized substances crystallize to result in lowering the ductility.

[0049] Therefore, it is preferable that Cr can be comprised from 0.1 to 0.7%, and it is further preferable that it can be comprised from 0.2 to 0.5%, when the entirety is taken as 100% by mass.

⑤ Ti and B

[0050] Ti and B become the nucleation site of primary-crystal Al. Accordingly, when those elements are added to increase, the respective crystalline grain diameters of primary-crystal Al diminish. As a result, a solid-liquid fluidic state is maintained to a higher solid-phase ratio side, and consequently the timing of stress occurrence by solidification shrinkage is put off on a lower temperature side so that it is believed that the resistance against hot tearing is improved. Specifically, it is believed as follows.

[0051] Ti becomes the nucleation site of α -Al, constitutes micro-fine structures, and reveals the effects of inhibiting hot tearing as well as improving the ductility, moreover, can improve the proof stress of aluminum alloys as well.

[0052] Hence, it is suitable that 0.01-0.3% Ti can be included when the entirety is taken as 100% by mass. It results from the fact that, when Ti is comprised less than 0.01%, no micro-fine structure can be obtained; and when Ti is comprised in excess of 0.3%, coarse crystallized substances (Al_3Ti and the like) crystallize to result in lowering the ductility. It is more preferable that Ti can be comprised from 0.1 to 0.2%.

[0053] B reveals a great effect of micro-finishing crystalline grains, especially when it coexists with Ti.

[0054] When B is comprised less than 0.01%, no micro-fine structure can be obtained, and when it is comprised in excess of 0.05%, it is not economical because the variation of crystalline grain diameters is less. Therefore, in the coexistence with Ti, it is suitable that 0.01-0.05% boron (B) can be included when the entirety is taken as 100% by

mass. It is more suitable that it can be comprised from 0.03 to 0.05%. Note that it is economical that B can be added as titanium boride such as TiB_2 in addition to the case where it is added as a simple substance.

⑥ Be

[0055] Be reveals an effect on the oxidation resistance even independently, and inhibits decrease of Mg resulting from oxidation when it dissolves.

[0056] Therefore, even being independent (without coexisting with Ti and the like), it is suitable that 0.001-0.01% beryllium (Be) can be included when the entirety is taken as 100% by mass. It is more suitable that it can be comprised from 0.005 to 0.01%. Of course, it is needless to say that Be can coexist with Ti and so forth.

⑦ Mo

[0057] Mo produces an effect of inhibiting the slag generation accompanied by the oxidation of Al-Mg alloy molten metals.

[0058] When Mo is comprised less than 0.05%, the oxidation inhibition effect is not sufficient, and when it is comprised in excess of 0.3%, it is not preferable because coarse crystallized substances crystallize to result in lowering the ductility.

[0059] Therefore, it is preferable that Mo can be comprised from 0.05 to 0.3%, and it is further preferable that it can be comprised from 0.1 to 0.2%, when the entirety is taken as 100% by mass.

⑧ Inevitable Impurities

[0060] As far as inevitable impurities do not exert an adverse effect on the characteristics of aluminum alloys, the types and contents are not limited, however, the present inventors found out that the castability of aluminum alloys, and the strength or ductility can be improved by controlling the content of Si and Cu, inevitable impurities.

[0061] Namely, it is suitable that Si, an inevitable impurity, can be comprised 0.5% or less, and that Cu can be comprised 0.3% or less.

[0062] Si is an inevitable impurity which is included in aluminum bare metal, and, when it is contained in excess of 0.5%, it is not preferable because Mg_2Si precipitates in the matrix by natural aging to change the mechanical characteristics of aluminum alloys with time.

[0063] Cu not only promotes hot tearing but also lowers corrosion resistance. Therefore, when an aluminum alloy according to the present invention is used as structural members, especially, it is preferable that it can be comprised 0.3% or less.

(2) Applications

[0064] The present aluminum alloy or process for producing a cast product can be utilized in a variety of cast products made of aluminum alloys.

[0065] For example, in the field of automobiles and two-wheeled vehicles, when the present aluminum alloy or process for producing the same is used in members for body structures, chassis members, wheels, space frames, steering wheels (armatures), seat frames, suspension members, engine blocks, transmission cases, pulleys, oil pans, shift levers, instrument panels, door impact panes, surge tanks for intake, pedal brackets, front shroud panels, and the like, it is possible to produce each of these members at a lower cost without subjecting them to heat treatments.

[0066] Note that, although the present aluminum alloy is of high strength and high ductility even as cast, it is naturally advisable to carry out cold working or heat treatments after casting.

B. Examples

[0067] Subsequently, while giving examples, the present invention will be described in more detail.

(Production and Testing of Test Samples)

(1) Example No. 1

[0068] Aluminum alloys were used which had an alloy composition of Sample Nos. 1 through 5 and Sample Nos. C1 through C7 set forth in Table 1, test samples were produced for each of the samples, test samples whose constriction length was changed variously, and each of the hot tearing characteristics was assessed. Note that Table 1 indicates them while Al, the major component, is abbreviated (being the same hereinafter).

[0069] To be more precise, as illustrated in Fig. 1, various test samples were produced by a vertical die-casting machine equipped with a die whose cavity had a cross-section of 7 mm in thickness and 10 mm in width and constriction length was changeable variously, and the hot tearing characteristics assessment was carried out.

[0070] The casting conditions were such that the melting temperature was 750 °C; the die temperature was from 50 to 100 °C; the casting pressure was 63.7 MPa; and the plunger speed was 0.6 m/s. After the respective molten metals were poured by pressurizing with the plunger (a pouring step), they were solidified at a cooling rate of 100 °C/sec. approximately (a solidifying step).

[0071] The assessment of the hot tearing resistance was examined by a constriction length at which a crack occurred. It indicates that the longer the constriction length is, the less likely an alloy is to cause hot tearing. The thus obtained test results of the respective test samples are illustrated in Fig. 3.

[0072] Note that this test was carried out while a 0.5 mm in thickness × 10 mm in height insulating sheet was bonded three-way around the aforementioned cavity in the middle in the direction of the constriction length in order to localize positions at which a hot tearing occurred. How this insulating sheet was bonded three-way is illustrated in Fig. 2, a cross-sectional view taken along the line "A-A" in Fig. 1.

(2) Example No. 2

[0073] Aluminum alloys were used which had an alloy composition of Sample Nos. 6 through 14 and Sample Nos. C8 through C10 set forth in Table 1, and plate-shaped cast products whose thickness was 2 mm, width was 50 mm and length was 70 mm were produced by the vertical die-casting machine.

[0074] The casting conditions were such that the melting temperature was 750 °C; the die temperature was from 50 to 100 °C; the casting pressure was 63.7 MPa; and the plunger speed was 1.4 m/s. Moreover, after the molten metals were poured by pressurizing with the plunger (a pouring step), they were solidified at a cooling rate of 100 °C/sec. approximately (a solidifying step).

[0075] From these as-cast plate-shaped cast products, plate-shaped tensile test samples were produced whose flat-surface portions were as-cast surfaces. The respective test samples were used to examine the tensile strength, 0.2% proof stress and fracture elongation. The results are set forth in Table 2. Note that the tensile test on the respective test samples was carried out with an autograph tensile testing machine made by SHIMAZU, and the aforementioned characteristics were found from the stress-strain diagram obtained for the respective test samples.

(3) Example No. 3

[0076] Aluminum alloys were used which had an alloy composition of Sample Nos. 15 through 19 and Sample Nos. C11 and C12 set forth in Table 1, and as-cast plate-shaped cast products were produced in the same manner as Example No. 2.

[0077] Here, in order to examine the influence of the mechanical characteristic change of the respective plate-shaped cast products with time (artificial aging), the as-cast plate-shaped cast products, and plate-shaped cast products, the same having been heated at 175 °C for 10 hours, were prepared, and the hardness (the Vickers hardness) of the respective plate-shaped cast products was examined. The results are set forth in Table 3.

[0078] Note that the Vickers hardness was such that a hardness meter made by AKASHI was used; a load of 5 kg was loaded for 30 seconds; and the hardness was determined by converting the size of the indentation made in this instance.

(4) Example No. 4

[0079] Moreover, the relationship between the hot tearing resistance and Fe content of Al alloy cast products was examined in detail. Namely, test samples were produced in the same manner as Example No. 1, test samples which comprised the alloy composition of Sample Nos. 20 through 26 set forth in Table 4 and had various constriction lengths. The respective samples were such that the Fe content was varied mainly while the Mg, Mn and Ti contents were made equal approximately. Assessing the hot tearing resistance by the constriction length at which a crack occurred was the same as the case of Example No. 1 as well. The thus obtained test results of the respective test samples are illustrated in Fig. 4.

(5) Example No. 5

[0080] The influence of the alloy composition exerting on the oxidation resistance of Al alloy molten metals was examined. First, Al alloy molten metals were prepared which comprised the alloy composition of Sample No. 27 and Sample No. 28. The respective molten metals were measured for the weight in advance. These molten metals were

put in a crucible made of alumina, and were held at 750 °C for 5 hours in an aerial atmosphere.

[0081] After cooling the molten metals, the weight of the solidified Al alloys was measured. And, the weight gain of the Al alloys was found from the weight difference before and after holding them in said heating. The results are set forth in Table 5 altogether. Note that, in Table 5, there are recited the oxidation increment proportions (oxidation increment rates) with respect to the weight of the molten metals before holding them in said heating.

(Assessment)

(1) Castability

[0082] It is seen from Fig. 3 that all of the aluminum alloys of Sample Nos. 1 through 5 falling within the present composition range had a sufficiently longer constriction length, at which a crack occurred, than those of Sample Nos. C1 through C7. Specifically, no crack occurred up to a constriction length of 50 mm for Sample No. 1, a constriction length of 70 mm for Sample Nos. 2 and 3, and a constriction length of 80 mm for Sample Nos. 4 and 5.

[0083] From these, when a proper amount of the Fe content was added while the Mn content was controlled, it was understood that the hot tearing resistance is improved remarkably. Moreover, when Ti making the nucleation sites was added while Mg, Mn and Fe had fallen in the present composition ranges, it was also appreciated that the hot tearing resistance was further improved.

[0084] In particular, as can be apparent from Table 4 and Fig. 4, the Al alloy cast products of Sample Nos. 22 through 24, in which the Fe content was contained from 0.5 to 0.8% while having Mg, Mn and Fe fallen within the present suitable composition ranges, were such that the hot tearing resistance was furthermore improved.

(2) Strength and Ductility

[0085] ① All of Sample Nos. 6 through 14 were aluminum alloys falling within the present composition range. And, as can be understood from Table 2, all of those aluminum alloys exhibited a tensile strength of 250 MPa or more, a 0.2% proof stress of 130 MPa or more, and in addition an elongation of 15% or more. Therefore, even as cast, it was appreciated that the aluminum alloy according to the present invention reveals good ductility while maintaining sufficient strength. Especially, there also exist those which exhibited a tensile strength of 300 MPa or more, a 0.2% proof stress of 150 MPa or more, and an elongation in excess of 20%.

[0086] Moreover, Sample No. 7, an aluminum alloy of Sample No. 6 with Ti contained, was such that the crystal grains were more micro-fined so that the ductility was further improved.

[0087] ② On the other hand, the aluminum alloys of Sample Nos. C8 through C10 falling outside the composition range according to the present invention could not make the strength and ductility compatible. For example, since Sample No. C8 was such that the Mn content exceeded 0.6% by mass, the elongation was less than 10% so that it was of low ductility, though the tensile strength and 0.2% proof stress were high. On the contrarily, Sample No. C9 which comprised less than 0.3% by mass Mn, and Sample No. C10 which comprised less than 4.0% by mass Mg were such that the strength was insufficient, though they were of high ductility.

(3) Influence of Aging

[0088] All of Sample Nos. 15 through 19 were aluminum alloys falling within the present composition range. As can be understood from Table 3, these aluminum alloys were such that the hardness variation was insignificant between as cast and after being heated at 175 °C for 10 hours.

[0089] On the other hand, since the aluminum alloys of Sample Nos. C11 and C12 included Si abundantly beyond the level of inevitable impurities, the hardness variation was significant between as cast and after being heated at 175 °C for 10 hours. That is, age hardening occurred, and accordingly there arise a fear that the characteristics are changed by natural aging in aluminum alloys with such a composition.

(4) Oxidation Resistance

[0090] As indicated by Sample Nos. 27 and 28 of Table 5, when Mo was further comprised from 0.1 to 0.2% while having Mg, Mn, Ti and Fe fallen within the present suitable composition ranges, it become apparent that the Al alloy molten metals show much better oxidation resistance.

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TABLE 1

Sample No.	Aluminum Alloy Composition (% by Mass)						
	Mg	Mn	Fe	Si	Cu	Ti	Cr
1	4.98	0.31	0.75	Less than 0.1	Less than 0.01	-	-
2	5.68	0.60	0.80	↑	↑	0.15	-
3	4.98	0.32	0.50	↑	↑	↑	-
4	4.98	0.32	0.76	↑	↑	↑	-
5	4.31	0.30	0.76	↑	↑	↑	-
6	4.30	0.30	0.75	↑	↑	-	-
7	4.31	0.30	0.76	↑	↑	0.15	-
8	5.68	0.60	0.80	↑	↑	↑	-
9	5.62	0.32	0.76	↑	↑	↑	-
10	4.79	0.52	0.85	↑	↑	0.16	-
11	4.98	0.32	0.76	↑	↑	0.15	-
12	4.01	0.53	0.76	↑	↑	↑	-
13	4.02	0.31	0.75	↑	↑	0.16	-
14	4.30	0.30	0.75	↑	↑	-	0.21
15	5.68	0.60	0.80	↑	↑	0.15	-
16	4.79	0.52	0.85	↑	↑	0.16	-
17	4.01	0.53	0.76	↑	↑	0.15	-
18	4.31	0.30	0.76	↑	↑	↑	-
19	4.00	0.50	0.75	0.25	↑	↑	-
C1	5.01	0.80	0.75	Less than 0.1	↑	-	-
C2	4.99	1.20	0.15	↑	↑	-	-
C3	5.00	1.20	0.15	↑	↑	0.15	-
C4	3.50	0.80	0.15	↑	↑	-	-
C5	3.50	0.80	0.15	↑	↑	0.15	-
C6	2.88	0.97	0.96	0.09	↑	-	-
C7	3.38	0.81	0.74	0.06	0.25	-	-
C8	4.79	1.05	0.91	↑	↑	-	-
C9	4.00	0.10	0.75	↑	↑	-	-
C10	3.00	0.50	0.75	↑	↑	-	-
C11	4.26	-	0.15	1.98	↑	-	-
C12	4.00	0.50	0.75	0.75	↑	0.16	-

TABLE 2

Sample No.	Tensile Strength (MPa)	0.2% Proof Stress (MPa)	Fracture Elongation (%)
6	290	139	20.0
7	324	165	15.0

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TABLE 2 (continued)

Sample No.	Tensile Strength (MPa)	0.2% Proof Stress (MPa)	Fracture Elongation (%)
8	321	160.3	17.7
9	310	154	18.3
10	304	146	21.5
11	284	140	19.6
12	270	135	19.8
13	290	140	23.0
14	298	149	19.0
C8	309	167	9.0
C9	265	120	22.0
C10	260	112	22.6

TABLE 3

Sample No.	Hardness (HV)	
	As Cast	After Heat Treatment (175 °C × 10 hr.)
15	79.1	82
16	73.7	76
17	67.3	68
18	70.1	72
19	68	69.2
C11	83.5	107.5
C12	68	78.2

TABLE 4

Sample No.	Aluminum Alloy Composition (% by Mass)					
	Mg	Mn	Ti	Fe	Si	Cu
20	4.46	0.39	0.14	0.12	Less than 0.1	Less than 0.01
21	4.46	0.36	0.15	0.36	↑	↑
22	4.32	0.37	0.14	0.50	↑	↑
23	4.31	0.30	0.15	0.76	↑	↑
24	4.62	0.32	0.14	0.80	↑	↑
25	4.55	0.39	0.14	0.88	↑	↑
26	4.36	0.34	0.12	0.98	↑	↑

TABLE 5

Sample No.	Aluminum Alloy Composition (% by Mass)							Oxidation Increment Rate (%)
	Mg	Mn	Ti	Fe	Mo	Si	Cu	
27	4.46	0.39	0.14	0.12	0.18	Less than 0.1	Less than 0.01	0.0063

TABLE 5 (continued)

Sample No.	Aluminum Alloy Composition (% by Mass)							Oxidation Increment Rate (%)
	Mg	Mn	Ti	Fe	Mo	Si	Cu	
28	4.46	0.36	0.15	0.36	-	↑	↑	0.0081

Claims**1.** An aluminum alloy, comprising:

from 4.0 to 6.0% magnesium (Mg);
 from 0.3 to 0.6% manganese (Mn);
 from 0.5 to 0.9% iron (Fe); and
 the balance of aluminum (Al) and inevitable impurities when the entirety is taken as 100% by mass (mass percentage).

2. The aluminum alloy set forth in claim 1 further comprising from 0.1 to 0.7% chromium (Cr) when the entirety is taken as 100% by mass.

3. The aluminum alloy set forth in claim 1 further comprising from 0.01 to 0.3% titanium (Ti) when the entirety is taken as 100% by mass.

4. The aluminum alloy set forth in claim 1 further comprising from 0.01 to 0.05% boron (B) when the entirety is taken as 100% by mass.

5. The aluminum alloy set forth in claim 1 further comprising from 0.001 to 0.01% beryllium (Be) when the entirety is taken as 100% by mass.

6. The aluminum alloy set forth in claim 1 further comprising from 0.05 to 0.3% molybdenum (Mo) when the entirety is taken as 100% by mass.

7. The aluminum alloy set forth in claim 1, wherein said inevitable impurities comprise 0.5% or less silicon (Si) and 0.3% or less copper (Cu) when the entirety is taken as 100% by mass.

8. The aluminum alloy set forth in claim 1 wherein said Fe is from 0.5 to 0.8% by mass.

9. The aluminum alloy set forth in either one of claims 1 through 8, comprising primary-crystal aluminum and compounds which are dispersed uniformly, the primary-crystal aluminum having a dendritic cell size of 10 μ m or less, the compounds having a grain diameter of 5 μ m or less.

10. The aluminum alloy set forth in either one of claims 1 through 8, exhibiting a tensile strength of 250 MPa or more as cast being free from being subjected to a heat treatment after casting.

11. The aluminum alloy set forth in either one of claims 1 through 8, exhibiting a 0.2% proof stress of 130 MPa or more as cast being free from being subjected to a heat treatment after casting.

12. The aluminum alloy set forth in either one of claims 1 through 8, exhibiting a fracture elongation of 13% or more as cast being free from being subjected to a heat treatment after casting.

13. A cast product made of an aluminum alloy, the cast product comprising:

from 4.0 to 6.0% Mg;
 from 0.3 to 0.6% Mn;
 from 0.5 to 0.9% Fe; and
 the balance of Al and inevitable impurities when the entirety is taken as 100% by mass.

14. A process for producing a cast product made of an aluminum alloy, the process comprising the steps of:

pouring an aluminum alloy molten metal into a die, the aluminum alloy molten metal comprising:

5 from 4.0 to 6.0% Mg;
 from 0.3 to 0.6% Mn;
 from 0.5 to 0.9% Fe; and
 the balance of Al and inevitable impurities when the entirety is taken as 100% by mass; and

10 solidifying the aluminum alloy molten metal by cooling it after the pouring step.

15. The process for producing a cast product made of an aluminum alloy set forth in claim 14, wherein said solidifying step is a step being solidified by cooling at a cooling rate of 20 °C/sec. or more.

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Fig.1

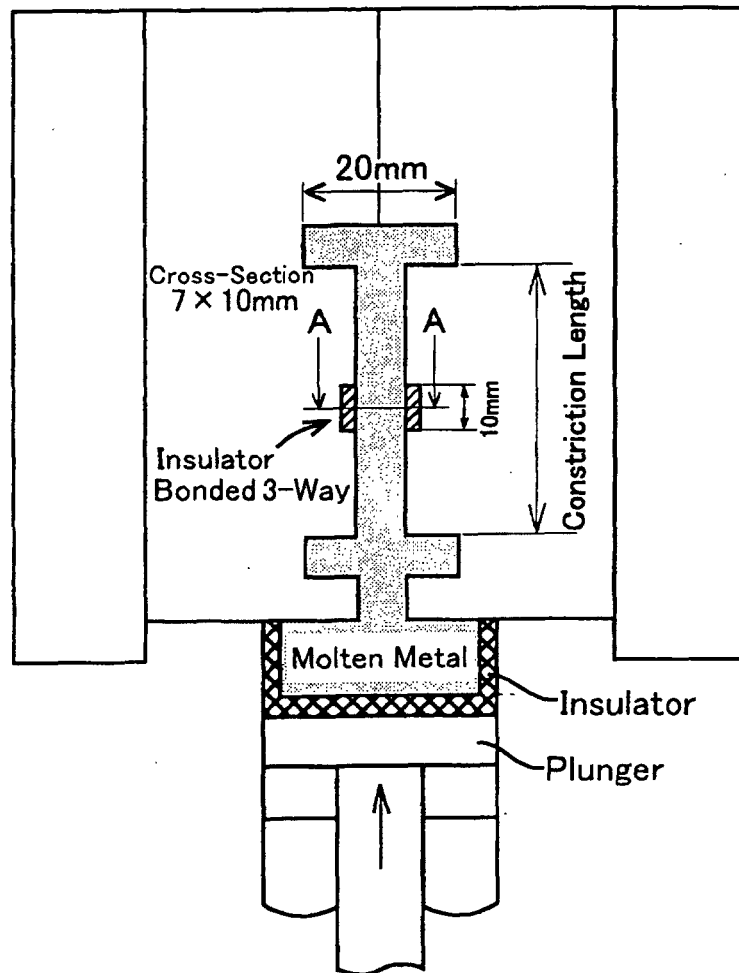
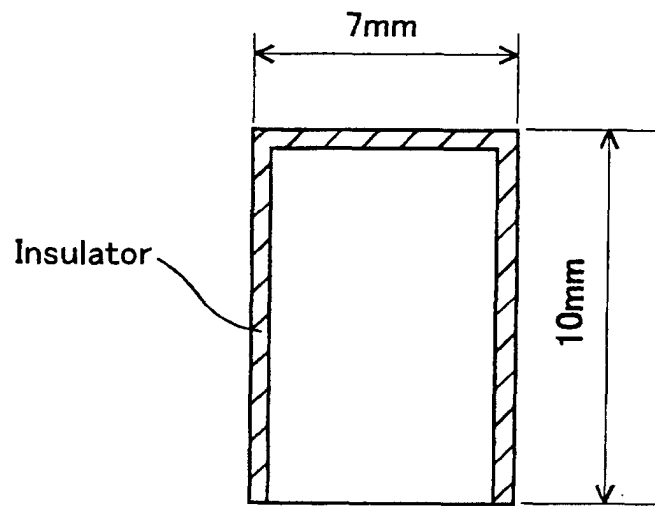


Fig.2



A-A Cross-Section

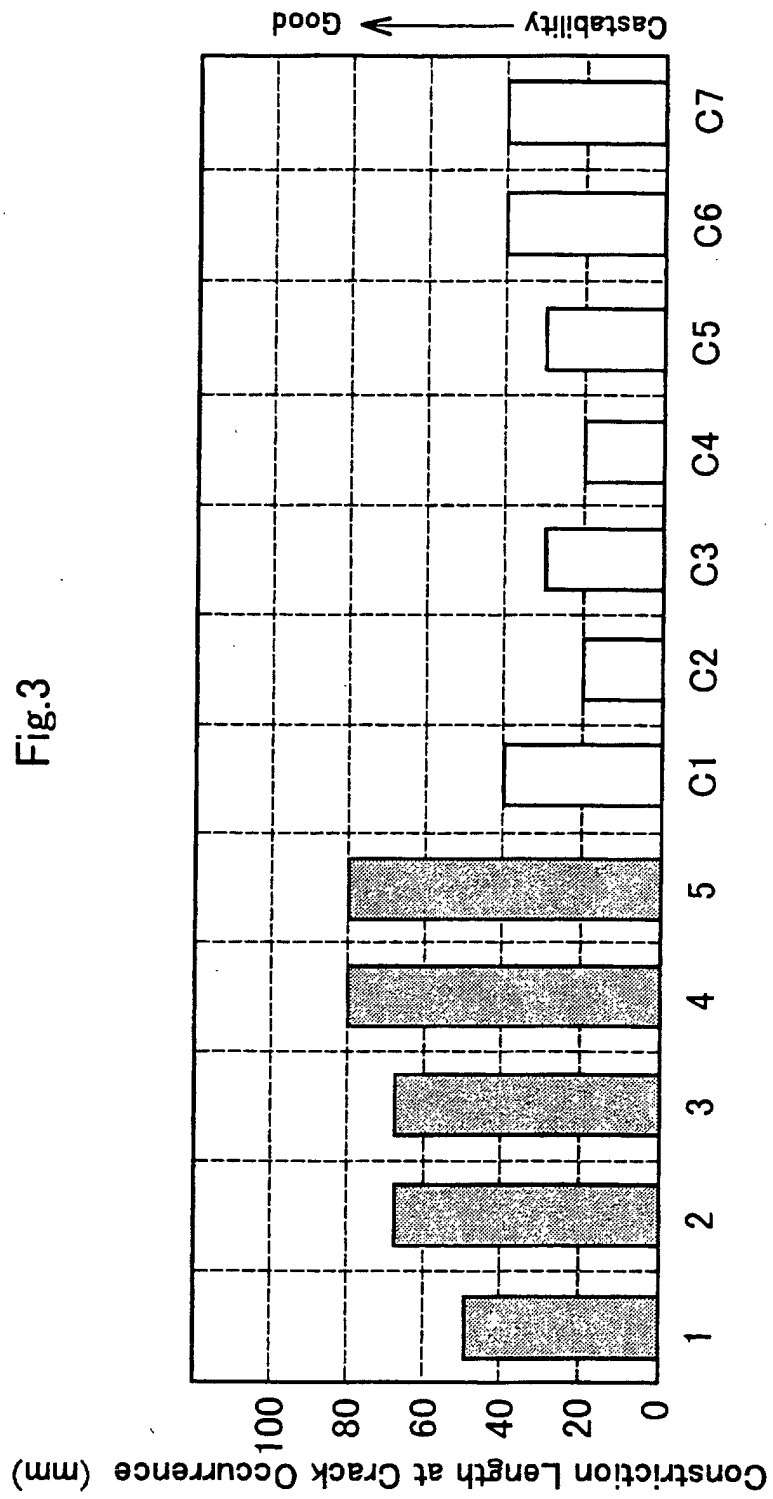
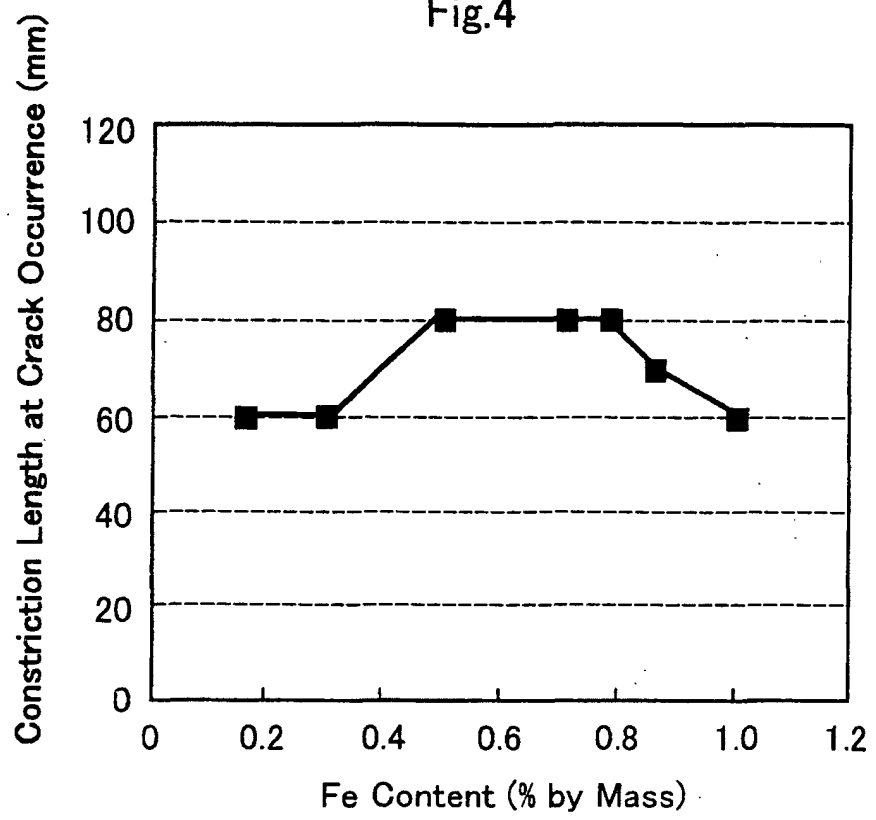


Fig.4



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP02/08854

A. CLASSIFICATION OF SUBJECT MATTER
Int.Cl⁷ C22C21/06

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
Int.Cl⁷ C22C21/00-21/18Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Jitsuyo Shinan Koho 1926-1996 Toroku Jitsuyo Shinan Koho 1994-2002
Kokai Jitsuyo Shinan Koho 1971-2002 Jitsuyo Shinan Toroku Koho 1996-2002

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 99/13118 A1 (Nippon Light Metal Co., Ltd.), 19 March, 1999 (19.03.99), Claims; page 13, line 12 to page 14, line 4; table 1 & JP 11-80873 A Claims; column 5, line 44 to column 6, line 6; table 1	1-5, 7, 8, 10-14 6, 9, 15
X	JP 62-243748 A (Kobe Steel, Ltd.), 24 October, 1987 (24.10.87), Claims; page 2, lower right column, lines 12 to 18; table 1 (Family: none)	1-5, 7, 8, 10-14 6, 9, 15
X	JP 4-218640 A (Kabushiki Kaisha Kasei Naoetsu), 10 August, 1992 (10.08.92), Claims; table 3 (Family: none)	1-5, 7, 8, 10-14 6, 9, 15

☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A" document defining the general state of the art which is not considered to be of particular relevance	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&" document member of the same patent family
"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search
30 September, 2002 (30.09.02)Date of mailing of the international search report
15 October, 2002 (15.10.02)Name and mailing address of the ISA/
Japanese Patent Office

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP02/08854

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 62-214163 A (Sky Aluminium Co., Ltd.), 19 September, 1987 (19.09.87),	1-5,7,8, 10-14
Y	Claims; page 4, upper right column, line 17 to lower right column, line 7; table 1 (Family: none)	6,9,15
X	JP 54-5810 A (Kubota, Ltd.), 17 January, 1979 (17.01.79),	1-5,7,8, 10-14
Y	Claims; tables 1, 3, 4; page 2, lower left column, lines 18 to 20 (Family: none)	6,9,15
Y	JP 46-36091 B1 (Tokyo Katen Oru Kogyo Kabushiki Kaisha), 22 October, 1971 (22.10.71), Column 2, line 28 to column 3, line 1 (Family: none)	6
Y	JP 5-5149 A (Sky Aluminium Co., Ltd.), 14 January, 1993 (14.01.93), Claims; column 7, line 44 to column 8, line 34 (Family: none)	9,15
P,A	JP 2002-129271 A (Toyota Central Research And Development Laboratories, Inc.), 09 May, 2002 (09.05.02), Claims (Family: none)	1-15

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