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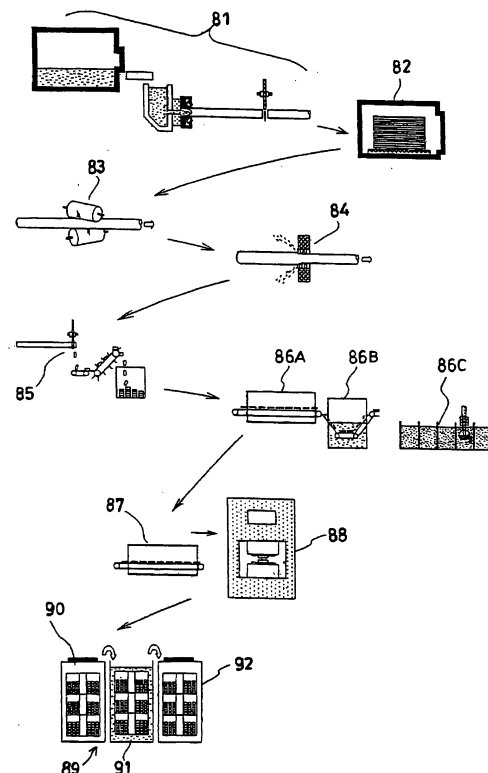
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(54) **PROCESS FOR PRODUCTION OF ALUMINUM ALLOY FORMINGS, ALUMINUM ALLOY FORMINGS AND PRODUCTION SYSTEM**

(57) The present invention are to provide a method for producing an aluminum-alloy shaped product that exhibits high-temperature mechanical strength superior to that of a conventional aluminum-alloy forged product.

The present invention provides a method for producing an aluminum-alloy shaped product, comprising a step of forging a continuously cast rod of aluminum-alloy serving as a forging material, in which the aluminum-alloy contains Si in an amount of 10.5 to 13.5 mass %, Cu in an amount of 2.5 to 6 mass %, Mg in an amount of 0.3 to 1.5 mass % and Ni in an amount of 0.8 to 4%, and satisfies a relational expression of "Ni (% by mass) $\geq (-0.68 \times \text{Cu}(\% \text{ by mass}) + 4.2(\% \text{ by mass}))$ ", and heat treatment and heating steps including a step of subjecting the forging material to pre-heat treatment (82), a step (87) of heating the forging material during a course of forging of the forging material and a step of subjecting an aluminum-alloy shaped product to post-heat treatment (89), said pre-heat treatment(82) including treatment of maintaining the forging material at a temperature of -10 to 480°C for two to six hours.

FIG.1



Description

Technical Field

[0001] The present invention relates to a method for producing an aluminum-alloy shaped product, which method includes a step of forging a continuously cast aluminum-alloy rod serving as a forging material, to an aluminum-alloy shaped product and to a production system for the shaped product.

Background Art

[0002] In recent years, in vehicles such as four-wheel-drive automobiles and two-wheel-drive automobiles (hereinafter such a vehicle will be referred to simply as an "automobile"), attempts have been made to employ an aluminum-alloy forged product in an internal combustion engine piston in order to attain high performance or to cope with environmental regulations. This is because, when such an aluminum-alloy forged product is employed, the weight of driving parts (e.g., a piston) for an internal combustion engine can be reduced, leading to reduction of a load upon operation of the internal combustion engine, enhancement of output, or reduction of fuel consumption. Conventionally, most internal combustion engine pistons have been produced from an aluminum-alloy cast product. However, in the case of such a cast product, difficulty is encountered in reducing internal defects generated during the course of casting, and excess material must be provided on the cast product so as to ensure safety design in terms of strength. Therefore, when such a cast product is employed in an internal combustion engine piston, reducing the weight of the piston is difficult.

[0003] In view of the foregoing, attempts have been made to reduce the weight of such a piston by producing the piston from an aluminum-alloy forged product, in which generation of internal defects can be suppressed.

[0004] A conventional method for producing an aluminum-alloy forging material includes a step of preparing molten aluminum-alloy by means of a typical smelting technique, a step of subjecting the molten aluminum-alloy to any continuous casting technique, such as continuous casting, semi-continuous casting (DC casting) or hot top casting, to thereby produce an aluminum-alloy cast ingot and a step of subjecting the cast ingot to homogenization heat treatment to thereby homogenize aluminum-alloy crystals. The thus produced aluminum-alloy forging material (cast ingot) is subjected to forging and then to a T6 treatment of JIS (Japanese Industrial Standard) to thereby produce an aluminum-alloy forged product.

[0005] JP-A 2002-294383 (Patent Document 1) discloses a method for producing a 6000-series-alloy cast product, in which the homogenization treatment temperature is lowered or the homogenization treatment is omitted.

[0006] However, high-temperature mechanical characteristics of the cast product are not examined in Patent Document 1.

[0007] Meanwhile, the following Japanese Patent Application Publication No. 2005-290545 (Patent Document 2), which is objected to produce an aluminum-alloy shaped product that exhibits high-temperature mechanical strength superior to that of a conventional aluminum-alloy forged product, discloses a method for producing an aluminum-alloy shaped product, comprising a step of forging a continuously cast rod of aluminum-alloy serving as a forging material, in which the aluminum-alloy contains Si in an amount of 10.5 to 13.5 mass %, Fe in an amount of 0.15 to 0.65 mass %, Cu in an amount of 2.5 to 5.5 mass % and Mg in an amount of 0.3 to 1.5 mass %, and heat treatment and heating steps including a step of subjecting the forging material to pre-heat treatment, a step of heating the forging material during a course of forging of the forging material and a step of subjecting a shaped product to post-heat treatment, the pre-heat treatment including treatment of maintaining the forging material at a temperature of -10 to 480°C for two to six hours.

[0008] In recent years, there has been increasing demand for an internal combustion engine of high efficiency and high output, and accordingly, parts employed in the engine have been further required to exhibit high-temperature mechanical strength.

[0009] Therefore, in view of the fact that an aluminum-alloy forged product enables further reduction of the weight, demand has arisen for a method for producing an aluminum-alloy shaped product exhibiting high-temperature (for example, fatigue strength at a temperature of 350°C) mechanical strength superior to that of a conventional aluminum-alloy forged product.

[0010] In view of the foregoing, objects of the present invention are to provide a method for producing an aluminum-alloy shaped product that exhibits high-temperature mechanical strength superior to that of a conventional aluminum-alloy forged product, to provide an aluminum-alloy shaped product and to provide a production system for the shaped product.

Disclosure of the Invention

[0011]

(1) In order to achieve the object, according to a first invention of the present invention, the present invention provides a method for producing an aluminum-alloy shaped product, comprising a step of forging a continuously cast rod of aluminum-alloy serving as a forging material, in which the aluminum-alloy contains Si in an amount of 10.5 to 13.5 mass %, Cu in an amount of 2.5 to 6 mass %, Mg in an amount of 0.3 to 1.5 mass % and Ni in an amount of 0.8 to 4%, and satisfies a relational expression of " $\text{Ni}(\% \text{ by mass}) \geq (-0.68 \times \text{Cu}(\% \text{ by mass}) + 4.2(\% \text{ by mass}))$ ", and heat treatment and heating steps including a step of subjecting the forging material to pre-heat treatment, a step of preliminary heating the forging material before a course of forging of the forging material and a step of subjecting a shaped product to post-heat treatment, said pre-heat treatment including treatment of maintaining the forging material at a temperature of -10 to 480°C for two to six hours.

(2) According to a second invention of the present invention, in the first mentioned method, the pre-heat treatment is performed at a temperature of at least 200°C and 370°C or lower.

(3) According to a third invention of the present invention, in the first mentioned method, the pre-heat treatment is performed at a temperature of at least -10°C and less than 200°C.

(4) According to a fourth invention of the present invention, in the first mentioned method, the pre-heat treatment is performed at a temperature of at least 370°C and 480°C or lower.

(5) According to a fifth invention of the present invention, in the method according to any one of the first to fourth mentioned methods, wherein the post-heat treatment is performed at 170 to 230°C for one to 10 hours without performing solid solution treatment.

(6) According to a sixth invention of the present invention, in the method according to any one of the first to fifth mentioned methods, the aluminum-alloy further contains Fe in an amount of 0.15 to 0.65 mass %.

(7) According to a seventh invention of the present invention, in the method according to any one of the first to sixth mentioned methods, the aluminum-alloy further contains P in an amount of 0.003 to 0.02 mass %.

(8) According to an eighth invention of the present invention, in the method according to any one of the first to seventh mentioned methods, the aluminum-alloy further contains at least one species selected from among Sr in an amount of 0.003 to 0.03 mass %, Sb in an amount of 0.1 to 0.35 mass %, Na in an amount of 0.0005 to 0.015 mass % and Ca in an amount of 0.001 to 0.02 mass %.

(9) According to a ninth invention of the present invention, in the method according to any one of the first to eighth mentioned methods, the aluminum-alloy further contains at least one species selected from among Mn in an amount of 0.1 to 1.0 mass %, Cr in an amount of 0.05 to 0.5 mass %, Zr in an amount of 0.04 to 0.3 mass %, V in an amount of 0.01 to 0.15 mass % and Ti in an amount of 0.01 to 0.2 mass %.

(10) According to a tenth invention of the present invention, in the method according to any one of the first to ninth mentioned methods, during the forging step, a percent reduction of a portion of the forging material that requires high-temperature fatigue strength resistance is regulated to 90% or less.

(11) According to an eleventh invention of the present invention, in the method according to any one of the first to tenth mentioned methods, the preliminary heating step is performed at a temperature of 380 to 480°C.

(12) According to a twelfth invention of the present invention, in the method according to any one of the first to eleventh mentioned methods, the continuously cast rod is produced through continuous casting of a molten alloy having an average temperature which falls within a range of a liquidus temperature +40°C to the liquidus temperature +230°C at a casting speed of 80 to 2,000 mm/minute.

(13) According to a thirteenth invention of the present invention, the present invention further provides an aluminum-alloy shaped product produced through the method according to any one of claims 1 to 12 and having a metallographic structure in which crystallization product networks, acicular crystallization products or crystallization product aggregates that have been formed during a course of continuous casting remain partially even after forging and heat treatment steps.

(14) According to a fourteenth invention of the present invention, the present invention also provides an aluminum-alloy shaped product produced through the method according to any one of claims 1 to 12 and having a eutectic Si area share of 8% or more, an average eutectic Si particle diameter of 5 μm or less, 25% or more of eutectic Si having an acicular eutectic Si ratio of 1.4 or more, an intermetallic compound area share of 1.2% or more, an average intermetallic compound particle diameter of 1.5 μm or more and 30% or more of intermetallic compounds or intermetallic compound aggregates having an intermetallic compound length or intermetallic compound aggregate length of 3 μm or more.

(15) According to a fifteenth invention of the present invention, in the aluminum-alloy shaped product produced through the method according to the thirteenth or fourteenth, an engine piston is made of the aluminum-alloy and includes a top surface portion and a skirt portion and the high-temperature fatigue strength of the top surface portion is 50 MPa or more.

(16) According to a sixteenth invention of the present invention, The present invention also provides a production system comprising a continuous line for performing a series of steps for producing an aluminum-alloy shaped product from a molten aluminum-alloy, wherein the series of steps includes at least the steps of the method of any one of

the first to thirteenth mentioned methods.

[0012] According to the first invention described in (1), since the aluminum-alloy includes Si, Cu, Mg, and Ni, it is possible to obtain shaped products that have excellent high-temperature fatigue strength, forgeability, ductility, and toughness. Further, since the composition of Ni and Cu satisfies a relational expression of $\text{Ni}(\% \text{ by mass}) \geq [-0.68 \times \text{Cu}(\% \text{ by mass}) + 4.2(\% \text{ by mass})]$, it is possible to improve fatigue strength characteristics at higher temperature.

[0013] Meanwhile, conventionally, shaped products made of multilevel alloys should be experimentally produced by changing the alloy composition, or complicated facilities and much time were required for the evaluation of the high-temperature fatigue strength. Accordingly, it was particularly difficult to design an alloy that has fatigue strength at high temperature.

[0014] However, it is possible to easily obtain an alloy, which has fatigue strength characteristics at higher temperature by designing alloy composition through using the aforementioned relational expression of the present invention as an index. Further, even though temperature is higher than 350°C, it is possible to obtain aluminum-alloy shaped products that have excellent mechanical strength.

[0015] More specifically, for example, after aluminum-alloy shaped products are retained at a temperature of 350°C for 100 hours, the fatigue strength thereof at a temperature of 350°C becomes 33 MPa or more. These characteristics are characteristics required for a top surface portion of a piston of an internal combustion engine that comes in contact with a high temperature atmosphere. Accordingly, it is possible to further reduce the thickness of a piston of a conventional internal combustion engine by using the aluminum-alloy shaped product according to the present invention and to reduce the weight of a piston of an internal combustion engine. Further, it is possible to realize to satisfy weight reduction required from the market, to reduce fuel consumption of an internal combustion engine, and to improve output.

[0016] According to the second invention described in (2), since the heat treatment temperature of the pre-heat treatment step is in the range of 200°C to 370°C, high-temperature fatigue strength, forgeability, ductility, and toughness further become excellent, so that it is possible to obtain better shaped products.

[0017] According to the third invention described in (3), since the heat treatment temperature of the pre-heat treatment step is in the range of -10°C to 200°C, it is possible to obtain a shaped product having more excellent high-temperature fatigue strength. However, forgeability, ductility, and toughness deteriorate as compared to when the heat treatment temperature is in the range of 200°C to 370°C.

[0018] According to the fourth invention described in (4), since the heat treatment temperature of the pre-heat treatment step is in the range of 370°C to 480°C, it is possible to obtain a shaped product having more excellent forgeability, ductility, and toughness. However, high-temperature fatigue strength deteriorates as compared to when the heat treatment temperature is in the range of 200°C to 370°C.

[0019] According to the fifth invention described in (5), the forging material is retained at a temperature of 170°C to 230°C for 1 to 10 hours, without performing a solid solution treatment at a post-heat treatment step. Accordingly, it is possible to obtain a shaped product having more excellent high-temperature fatigue strength. However, ductility and toughness deteriorate as compared to when a solution treatment is performed and the forging material is retained at a temperature of 170°C to 230°C for 1 to 10 hours.

[0020] According to the sixth invention described in (6), since the aluminum-alloy includes 0.15 to 0.65% by mass of Fe, Al-Fe, Al-Fe-Si, or Al-Ni-Fe based particles are crystallized, thereby improving high-temperature mechanical strength. Further, the content of 0.15 to 0.65% by mass of Fe suppresses the increase of the large crystallization products and improves forgeability, high-temperature fatigue strength, and toughness.

[0021] According to the seventh invention described in (7), the aluminum-alloy includes 0.003 to 0.02% by mass of P. Since generating primary Si crystals, P is preferable when wear resistance is a priority. In addition, P has an effect of micronizing primary Si crystals, and acts by suppressing the decrease of forgeability, ductility, or high-temperature fatigue strength that is caused by primary Si crystals generated. Further, the content of 0.003 to 0.02% by mass of P suppresses the increase of large primary Si crystals, thereby improving forgeability, high-temperature fatigue strength, and toughness.

[0022] According to the eighth invention described in (8), the aluminum-alloy may include one or the combination of two or more of 0.003 to 0.03% by mass of Sr, 0.1 to 0.35% by mass of Sb, 0.0005 to 0.015% by mass of Na, and 0.001 to 0.02% by mass of Ca. Accordingly, it is possible to suppress the generation of primary Si crystals and this is preferable when forgeability, ductility, and toughness are priorities. Further, the contents of Sr, Sb, Na, and Ca in this range suppress the generation of primary Si crystals, and improve forgeability, toughness, and high-temperature fatigue strength.

[0023] According to the ninth invention described in (9), the aluminum-alloy may include one or the combination of two or more of 0.1 to 1.0% by mass of Mn, 0.05 to 0.5% by mass of Cr, 0.04 to 0.3% by mass of Zr, 0.01 to 0.15% by mass of V, and 0.01 to 0.2% by mass of Ti. Accordingly, Al-Mn, Al-Fe-Mn-Si, Al-Cr, Al-Fe-Cr-Si, Al-Zr, Al-V, and Al-Ti based compounds are crystallized or precipitated, thereby improving high-temperature mechanical strength of the aluminum-alloy. Further, the contents of Mn, Cr, Zr, V, and Ti in this range suppress the increase of large crystallization

products, and improve forgeability, high-temperature fatigue strength, and toughness.

[0024] According to the tenth invention described in (10), since a percent reduction of a portion requiring high-temperature fatigue resistant strength is 90% or less in the forging step, the networks, acicular crystallization products, or aggregates of the crystallization products are appropriately divided and remain. Therefore, it is possible to obtain shaped products that have excellent ductility, toughness, and high-temperature fatigue strength.

[0025] According to the eleventh invention described in (11), since a preliminary heating temperature before processing is in the range of 380°C to 480°C in the forging step, it is possible to obtain shaped products that have excellent high-temperature fatigue strength, forgeability, ductility, and toughness.

[0026] According to the twelfth invention described in (12), the continuously cast rod is obtained by casting an aluminum-alloy, of which an average temperature of the molten alloy corresponds to a liquidus line of +40°C to +230°C, at a casting speed of 80 (mm/min) to 2000 (mm/min) by a continuous casting method. Accordingly, it is possible to obtain the networks, acicular crystallization products, or aggregates of the uniform and fine crystallization products, and to obtain shaped products that have excellent high-temperature fatigue strength, forgeability, ductility, and toughness.

[0027] According to the thirteenth invention described in (13), networks of crystallization products, acicular crystallization products, or aggregates of crystallization products formed during continuous casting partially remain in the structure even after forming and a heat treatment. Accordingly, it is possible to obtain shaped products that have excellent high-temperature fatigue strength, forgeability, ductility, and toughness.

[0028] According to the fourteenth invention described in (14), a sample having an area occupation ratio of eutectic Si of 8% or more, an average grain size of eutectic Si of 5 μm or less, and an acicular eutectic Si ratio of eutectic Si of 1.4 or more corresponds to 25% or more; and a sample having an area occupation ratio of an intermetallic compound of 1.2% or more, an average grain size of an intermetallic compound of 1.5 μm or more, and a length of an intermetallic compound or a length of an aggregate of a contacted intermetallic compound is 3 μm or more corresponds 30% or more. Accordingly, it is possible to reliably obtain shaped products that have excellent high-temperature fatigue strength, forgeability, ductility, and toughness.

[0029] According to the fifteenth invention disclosed in (15), since the high-temperature fatigue strength of the top surface portion is 50 MPa or more, the shaped products have sufficient high-temperature fatigue strength and may be suitably used for a top surface portion, and the like, of a piston of an internal combustion engine.

[0030] According to the sixteenth invention described in (16), a series of steps between molten metal and the aluminum-alloy shaped product are built up as a continuous line, and any one of the above-mentioned methods for production of aluminum-alloy shaped product is necessarily included in the series of steps. Accordingly, it is possible to improve fatigue strength characteristics at higher temperature.

[0031] Meanwhile, conventionally, shaped products made of multilevel alloys should be experimentally produced by changing the alloy composition, or complicated facilities and much time were required for the evaluation of the high-temperature fatigue strength. Accordingly, it was difficult to design an alloy that has fatigue strength at particularly high temperature.

[0032] However, it is possible to easily obtain an alloy, which has fatigue strength characteristics at higher temperature by designing alloy composition by using the relational expression of the present invention as an index. Further, even though temperature is higher than 350°C, it is possible to obtain aluminum-alloy shaped products that have excellent mechanical strength.

[0033] More specifically, for example, after aluminum-alloy shaped products are retained at a temperature of 350°C for 100 hours, the fatigue strength thereof at a temperature of 350°C becomes 33 MPa or more. These characteristics are, for example, characteristics required for a top surface portion of a piston of an internal combustion engine that comes in contact with a high temperature atmosphere. Accordingly, it is possible to further reduce the thickness of a piston of a conventional internal combustion engine by using the aluminum-alloy shaped product according to the present invention and to reduce the weight of a piston of an internal combustion engine. Further, it is possible to satisfy weight reduction required from the market, and realize to reduce fuel consumption of an internal combustion engine, and to improve output.

Brief Description of the Drawings

[0034]

Fig. 1 is a view showing a forging production system that is an example of a production line for realizing production method according to the present invention;

Fig. 2 is a view showing an example of a portion near a mold of a continuous casting apparatus that is used in the present invention;

Fig. 3 is a view showing another example of the portion near the mold of the continuous casting apparatus that is used in the present invention;

Fig. 4 is a view showing the effective mold length of the continuous casting apparatus that is used in the present invention;

Fig. 5 is a view showing another example of the continuous casting apparatus that is used in the present invention;

Fig. 6 is a view illustrating a relationship between contents of Ni and Cu that are in an aluminum-alloy;

Fig. 7A is a plan view of a piston having the shape of Examples 17 and 18 of the present invention and Comparative Examples 11 to 13;

Fig. 7B is a front view of the piston shown in Fig. 7A; and

Fig. 8 is a cross-sectional view taken along line VIII-VIII of Fig. 7A.

Best Mode for Carrying Out the Invention

[0035] The alloy composition of the shaped product according to the present invention will be described.

[0036] A molten aluminum-alloy used in the present invention includes 10.5 to 13.5% by mass (preferably, 11.5 to 13% by mass) of Si, 2.5 to 6% by mass (preferably, 3.5 to 5.5% by mass) of Cu, 0.3 to 1.5% by mass (preferably, 0.5 to 1.3% by mass) of Mg, and 0.8 to 4% by mass (preferably, 1.8 to 3.5% by mass) of Ni, and is adjusted to have composition that satisfies a relational expression of $\text{Ni}(\% \text{ by mass}) \geq [-0.68 \times \text{Cu}(\% \text{ by mass}) + \text{AA}(\% \text{ by mass})]$ (wherein, AA is a constant and $\text{AA} \geq 4.2$ preferably $\text{AA} \geq 4.7$).

[0037] Si increases high-temperature mechanical strength and wear resistance by the distribution of eutectic Si, and coexists with Mg and precipitates Mg_2Si particles, thereby improving high-temperature mechanical strength. If Si content is less than 10.5% by mass, the above-mentioned effects are small. If Si content exceeds 13.5% by mass, a large amount of primary Si crystals is crystallized, so that high-temperature fatigue strength, ductility, and toughness are decreased.

[0038] Ni generates Al-Ni based and Al-Ni-Cu based crystallization products, and improves high-temperature mechanical strength by using the crystallization products. If Ni content is less than 0.8% by mass, the above-mentioned effects are small. If Ni content exceeds 4% by mass, the amount of large crystallization products is increased, so that forgeability or high-temperature fatigue strength, ductility, and toughness are decreased.

[0039] Cu precipitates CuAl_2 particles, and generates Al-Cu based and Al-Ni-Cu based crystallization products, thereby improving high-temperature mechanical strength. If Cu content is less than 2.5% by mass, the above-mentioned effects are small. If Cu content exceeds 6% by mass, the amount of large Al-Cu based crystallization products is increased, so that forgeability or high-temperature fatigue strength, ductility, and toughness are decreased.

[0040] Mg coexists with Si and precipitates Mg_2Si particles, thereby improving high-temperature mechanical strength. If Mg content is less than 0.3% by mass, the above-mentioned effects are small. If Mg content exceeds 1.5% by mass, the amount of large Mg_2Si crystallization products is increased, so that forgeability or high-temperature fatigue strength, ductility, and toughness are decreased.

[0041] Further, in the present invention, the composition of Ni and Cu needs to satisfy a relational expression of $\text{Ni}(\% \text{ by mass}) \geq [-0.68 \times \text{Cu}(\% \text{ by mass}) + \text{AA}(\% \text{ by mass})]$ (wherein, AA is a constant and $\text{AA} \geq 4.2$ preferably $\text{AA} \geq 4.7$). The reason for this is that a fatigue strength characteristic at higher temperature is improved if Ni and Cu satisfy this relational expression. Meanwhile, since having a large amount of a generated network-like or acicular intermetallic compounds that contribute to high-temperature strength, the aluminum-alloy shaped product that are prepared to have a constant AA equal to or larger than 4.7 are preferable.

[0042] The mechanism of the improvement of the fatigue strength characteristic is not clear, but may be estimated as follows. It is considered that Al-Ni based crystallization products, Al-Ni-Cu based crystallization products, Al-Cu based crystallization products, and Cu dissolved in an aluminum matrix under high-temperature environment contribute most to the improvement of high-temperature mechanical strength. A relationship between Cu content and Ni content where high-temperature mechanical strength is effectively improved by these crystallization products and the solid solution of Cu has been deduced from the above-mentioned relational expression.

[0043] The fatigue strength of the shaped product using the aluminum-alloy at a temperature of 350°C is equal to or higher than 33 MPa that is a preferable value, more preferably, 43 MPa. Further, the fatigue strength of the shaped product using the aluminum-alloy at a temperature of 300°C is equal to or higher than 55 MPa.

[0044] It is preferable that the molten alloy contain one or two or more of 0.1 to 1% by mass (preferably, 0.2 to 0.5% by mass) of Mn, 0.05 to 0.5% by mass (preferably, 0.1 to 0.3% by mass) of Cr, 0.04 to 0.3% by mass (preferably, 0.1 to 0.2% by mass) of Zr, and 0.01 to 0.15% by mass (preferably, 0.05 to 0.1% by mass) of V, and 0.01 to 0.2% by mass (preferably, 0.02% to 0.1% by mass) of Ti. The reason why Mn, Cr, Zr, V, and Ti is contained is to crystallize or precipitate Al-Mn or Al-Fe-Mn-Si based compounds, Al-Cr or Al-Fe-Cr-Si based compounds, Al-Zr based compounds, Al-V based compounds, and Al-Ti based compounds, and to improve the high-temperature mechanical strength of the aluminum-alloy. If Mn content is less than 0.1% by mass, Cr content is less than 0.05% by mass, Zr content is less than 0.04% by mass, V content is less than 0.01% by mass, and Ti content is less than 0.01% by mass, the above-mentioned effects are small. If Mn content exceeds 1.0% by mass, Cr content exceeds 0.5% by mass, Zr content exceeds 0.3% by mass, V content exceeds 0.15% by mass, and Ti content exceeds 0.2% by mass, the amount of large crystallization products

is increased, so that forgeability, high-temperature fatigue strength, and toughness are decreased.

[0045] Further, it is preferable that the molten alloy include 0.15 to 0.65% by mass (preferably, 0.3 to 0.5% by mass) of Fe, and Al-Fe, Al-Fe-Si, or Al-Ni-Fe based particles are crystallized, thereby improving high-temperature mechanical strength. If Fe content is less than 0.15% by mass, the above-mentioned effects are small. If Fe content exceeds 0.65% by mass, the amount of Al-Fe, Al-Fe-Si, or Al-Ni-Fe based large crystallization products is increased, so that forgeability or high-temperature fatigue strength, ductility, and toughness are decreased.

[0046] Furthermore, it is preferable that the molten alloy includes 0.003 to 0.02% by mass (preferably, 0.007 to 0.016% by mass) of P. Since generating primary Si crystals, P is preferable when wear resistance is a priority. In addition, P has an effect of micronizing primary Si crystals, and suppresses the decrease of forgeability, ductility, or high-temperature fatigue strength that is caused by primary Si crystals generated. If P content is less than 0.003% by mass, the effect of micronizing primary Si crystals is small, large primary Si crystals is generated at the center of an ingot, and forgeability or high-temperature fatigue strength, ductility, and toughness are decreased. If P content exceeds 0.02% by mass, the amount of generated primary Si crystals is increased, and forgeability or high-temperature fatigue strength, ductility, and toughness are decreased.

[0047] In addition, the molten alloy contains one or two or more of 0.003 to 0.03% by mass (preferably, 0.01 to 0.02% by mass) of Sr, 0.1 to 0.35% by mass (preferably, 0.15 to 0.25% by mass) of Sb, 0.0005 to 0.015% by mass (preferably, 0.001 to 0.01% by mass) of Na, and 0.001 to 0.02% by mass (preferably, 0.005 to 0.01% by mass) of Ca, which is preferable because there is an effect of micronizing primary Si crystals. If Sr content is less than 0.003% by mass, Sb content is less than 0.1% by mass, Na content is less than 0.0005% by mass, and Ca content is less than 0.001% by mass, the above-mentioned effects are small. If Sr content exceeds 0.03% by mass, Sb content exceeds 0.35% by mass, Na content exceeds 0.015% by mass, and Ca content exceeds 0.02% by mass, the amount of large crystallization products is increased or casting defects are generated, so that forgeability, high-temperature fatigue strength, and toughness are decreased.

[0048] The composition ratios of the aluminum-alloy shaped product and an alloy ingredient of an ingot can be confirmed by a method using, for example, an optical emission spectrometer (e.g., PDA-5500, product of Shimadzu Corporation), which is based on photoelectric that is disclosed in JIS H1305.

[0049] An embodiment of the present invention will be described in detail below with reference to drawings.

[0050] Fig. 1 is a view showing a production system that is an example of a production line for realizing production method according to the present invention. In Fig. 1, a forging production system configures a continuous casting apparatus 81 that horizontally casts a continuously cast rod from molten metal and cuts the continuously cast rod to a predetermined length; a pre-heat treatment apparatus 82 for performing a heat treatment on the continuously cast rod that is cast by the continuous casting apparatus 81; a correction apparatus 83 for correcting the bend of the continuously cast rod if the continuously cast rod heat-treated by the pre-heat treatment apparatus 82 is bent; a peeling apparatus 84 for removing the outer peripheral portion of the continuously cast rod of which the bent is corrected by the correction apparatus 83; a cutting apparatus 85 for cutting the continuously cast rod of which the outer peripheral portion is removed by the peeling apparatus 84 into cut pieces that have a length required for the forging of the shaped product; an upsetting apparatus (not shown) that preliminarily heats the cut pieces cut by the cutting apparatus 85 and upsets the cut pieces; lubrication apparatuses 86A and 86B for applying a graphite lubricant to the preliminarily heated forging material, for immersing the preliminarily heated forging material in a graphite lubricant, or for coating the preliminarily heated forging material with a graphite lubricant in order to coat the forging material which is upset by the upsetting apparatus with a lubricant; a forging apparatus 88 for forging the product (preform) from the forging material that is further heated by the preliminary heating apparatus 87 and coated with a lubricant; and a post-heat treatment apparatus 89 for performing a post-heat treatment on the forged products (product) that are forged by the forging apparatus 88.

[0051] For example, the post-heat treatment apparatus 89 may configure a solid solution treatment apparatus 90 that performs a solution treatment on the forged products, a quenching apparatus 91 that quenches the product heated by the solid solution treatment apparatus 90, and an aging treatment apparatus 92 that performs an aging treatment on the product quenched by the quenching apparatus 91. If the solution treatment is omitted, it is preferable that the aging treatment apparatus 92 be provided behind the forging apparatus 88 without providing the solid solution treatment apparatus 90 and the quenching apparatus 91.

[0052] Meanwhile, the peeling apparatus 84 and the upsetting apparatus may be omitted. Further, the conveyance between the apparatus may be achieved by automatic conveying apparatuses. Further, a lubricant coating treatment of the lubrication apparatuses 86A and 86B may be substituted with an apparatus 86C for bonde treatment (phosphoric-acid-salt coating treatment).

[0053] In this case, the pre-heat treatment apparatus 82 has a function to retain the temperature of the forging material in the range of -10°C to 480°C for 2 to 6 hours. The preliminary heating apparatus 87 has a function to make the temperature of the forging material in the range of 380°C to 480°C. The solid solution treatment apparatus 90 and the quenching apparatus 91 of the post-heat treatment apparatus 89 have functions to make the temperature of the forged products (shaped products) for the solution be in the range of 480°C to 520°C and then to quench the forged products.

The aging treatment apparatus 92 of the post-heat treatment apparatus 89 has a function to retain the temperature of the forged products (shaped products) in the range of 170°C to 230°C.

[0054] A method for production used in the production system according to the present invention includes a step of performing a pre-heat treatment on the round rod that is obtained by casting an aluminum-alloy by a continuous casting method, a step of forming the preform from pre-heat treated materials as forging material by hot plastic forming, and a step of performing a post-heat treatment after the plastic forming. The temperature of the pre-heat treatment is in the range of -10°C to 480°C, and the temperature of the forging material during the hot plastic forming is in the range of 380°C to 480°C. In the post-heat treatment step, solution heating is performed so that the temperature of the preform is in the range of 480°C to 520°C, or temperature is directly managed so as to satisfy a temperature condition of 170°C to 230°C without performing the solution treatment. Accordingly, shaped products are consistently produced by performing steps that include from the casting step to each of all heat treatment steps. As a result, it is possible to stably produce shaped products having preferred mechanical strength.

[0055] Forging may be mentioned to be used as the above-mentioned plastic forming. However, as long as the temperature of the pre-heat treatment, the conditions of the temperature of the forging material during the hot plastic forming, and the temperature of the post-heat treatment are satisfied, the combination of rolling working and extruding working may be used as the method for production according to the present invention. The reason for this is that it is possible to obtain an effect of the present invention in controlling the network of the structure or crystallization products in either case.

[0056] The aluminum-alloy shaped product according to the present invention may be suitably used as parts that require mechanical strength at high temperature. Accordingly, the shaped product having the shapes of, for example, an engine piston, a valve lifter, a valve retainer, a cylinder liner, and the like, may be produced according to the present invention; and the shaped product may be formed in desired shapes by further performing machining on the shaped product with a lathe, a machining center, and the like, if necessary, so as to be used as parts for various products.

[0057] Any one of a known hot top continuous casting, a known vertical continuous casting, a known horizontal continuous casting, and a known DC casting may be used in a part of a basic solidification method of the method for production that is used in the present invention. For example, the method may be a horizontal continuous casting that supplies one or two or more fluids, which are selected from a gas lubricant and a liquid lubricant, and the gas obtained through thermal decomposition of the liquid thereof, onto the inner wall surfaces of a tubular mold that has forced cooling and is held so as to have a central axis parallel to a horizontal direction; supplies a molten aluminum-alloy containing Si to one end of the tubular mold so as to form columnar molten alloy; and draws an ingot which is formed by solidifying the columnar molten alloy in the tubular mold from the other end of the tubular mold. A case where the present invention is applied to a horizontal continuous casting will be described below.

[0058] Fig. 2 is a view showing an example of a portion near the mold of the continuous casting apparatus that is used in the present invention. A tundish 250, a refractory plate-like body 210, and a tubular mold 201 are disposed so that an molten alloy 255 stored in the tundish 250 is supplied to the tubular mold 201 through the refractory plate-like body 210. The tubular mold 201 is held so that a center axis 220 of the mold is substantially parallel to a horizontal direction. A means for forcedly cooling the mold is disposed in the tubular mold 201 and a means for forcedly cooling the mold for a cast ingot 216 is disposed at an outlet of the tubular mold 201 so that the molten alloy 255 becomes the cast ingot 216. In Fig. 2, a cooling water showering apparatus 205 is provided as an example of a means for forcedly cooling the cast ingot 216. A drive apparatus (not shown) is disposed near the outlet of the tubular mold 201 so that the forcedly cooled and cast ingot 216 is drawn at a constant speed and continuously cast. Further, a synchronized cutting machine (not shown), which cuts the drawn and cast rod to a predetermined length, is provided.

[0059] Another example of the portion near the mold of the continuous casting apparatus, which is used in the present invention, will be described with reference to Fig. 3. Fig. 3 is a schematic cross-sectional view of an example of a DC casting apparatus. In the DC casting apparatus, a molten aluminum-alloy 1 is introduced into a stationary water-cooling mold 5, which is made of an aluminum-alloy or copper, through a trough 2, a dip tube 3, and a floating distributor 4. The water-cooling mold 5 is cooled by cooling water 5A. A molten aluminum-alloy 6 introduced into the water-cooling mold 5 forms a solidification shell 7 at a portion thereof, which comes in contact with the water-cooling mold 5, and is constructed. A solidified aluminum-alloy ingot 7A is drawn downward from the water-cooling mold 5 by a lower mold 9. In this case, the aluminum-alloy ingot 7A is further cooled by cooling water jet 8 that is supplied from the water-cooling mold 5, thereby being completely solidified. If the lower mold 9 reaches a lower end where the lower mold 9 can be moved, the aluminum-alloy ingot 7A is cut at a predetermined position and withdrawn.

[0060] Referring to Fig. 2, the tubular mold 201 is held so that the center axis 220 of the mold is substantially parallel to a horizontal direction. The tubular mold 201 includes a means for forcedly cooling the tubular mold 201. This means for forcedly cooling the mold 201 cools the wall surfaces of the mold by cooling water 202 that is stored in a mold's cooling water cavity 204; removes the heat of the columnar molten alloy 215, which is filled in the tubular mold 201, from the surfaces of the molten metal that comes in contact with the inner wall of the mold 201; and forms a solidification shell on the surface of the molten metal. The tubular mold 201 further includes a means for forcedly cooling the mold.

This means for forcedly cooling the mold discharges cooling water from the cooling water showering apparatus 205 so that cooling water comes in direct contact with the cast ingot 216 at the end of the outlet of the tubular mold 201, thereby solidifying the columnar molten alloy 215 stored in the tubular mold 210. In addition, an end of the tubular mold 201, which is positioned opposite to nozzles of the cooling water showering apparatus 205, is connected to the tundish 250 through the refractory plate-like body 210.

[0061] In Fig. 2, cooling water that is used to forcedly cool the tubular mold 201, and cooling water that is used to forcedly cool the cast ingot 216 are supplied through a cooling water feed tube 203. However, the cooling water may be separately supplied.

[0062] A distance from a position, where the extension line of the central axis of the nozzle of the cooling water showering apparatus 205 intersects the surface of the cast ingot 216, to the contact surface between the tubular mold 201 and the refractory plate-like body 210 is referred to as an effective mold length (see reference numeral L of Fig. 4). It is preferable that the effective mold length be in the range of 15 to 70 mm. If the effective mold length is less than 15 mm, such as a good film is not formed, so that casting cannot be performed. If the effective mold length exceeds 70 mm, forced cooling is ineffective and the solidification caused by the inner wall of the mold is dominant. Accordingly, the contact resistance between the tubular mold 201 and the columnar molten alloy 215 or the solidification shell is increased, so that cracks are generated on the casting surface or the tubular mold 201 is torn off therein, and the like. Therefore, this is not preferable due to unstable casting.

[0063] It is preferable that a material of the tubular mold 201 be one or the combination of two or more selected from aluminum, copper, or alloys thereof. The combination of materials may be selected in consideration of thermal conductivity, heat resistance, and mechanical strength.

[0064] Further, it is preferable in the mold that a permeable porous member 222 having a self-lubricity be provided in a ring shape on the surface of the tubular mold 201 coming in contact with the columnar molten alloy 215. The ring shape means that the permeable porous member is provided on the entire inner wall 221 of the tubular mold 201 in a circumferential direction. The air permeability of the permeable porous member 222 may be in the range of 0.005 to 0.03 [L(liter)/(cm²/min)], more preferably, 0.07 to 0.02 [L/(cm²/min)]. The thickness of the permeable porous member 222 to be provided is not particularly limited, but is preferably in the range of 2 to 10 mm, more preferably, 3 to 8 mm. For example, graphite of which air permeability is in the range of 0.008 to 0.012 [L/(cm²/min)] may be used as the permeable porous member 222. In this case, the air permeability is obtained by measuring the amount of air, which has a pressure of 2 kg/cm² and is ventilated through a test piece having a thickness of 5 mm, per minute under.

[0065] It is preferable to use a tubular mold 201 in which a permeable porous member 222 is provided in the range of 5 to 15 mm within the range of the effective mold length. It is preferable that an O-ring 213 is provided on the matching surface of the tubular mold 201, the refractory plate-like body 210, and the permeable porous member 222.

[0066] The shape of the inner wall 221 of the radial cross-section of the tubular mold 201 may have a triangular shape, a rectangular shape, or an irregular shape having no symmetry axis nor symmetry plane, in addition to a circular shape. Alternatively, a core may be provided in the mold in order to form a hollow cast ingot. Further, the tubular mold 201 is a tubular mold of which both ends are opened. The molten alloy 255 is supplied into the tubular mold 201 from one end of the tubular mold 201 through a molten alloy inlet 211 that is formed through the refractory plate-like body 210, and the cast ingot 216 is extruded or drawn from the other end of the tubular mold 201.

[0067] The inner wall 221 of the tubular mold 201 is formed to have an elevation angle in the range of 0 to 3°, more preferably, 0 to 1° with respect to the center axis 220 of the mold in a direction where the cast ingot 216 is drawn. If the elevation angle is less than 0°, resistance is applied to the outlet of the tubular mold 201 when the cast ingot 216 is drawn from the tubular mold 201. For this reason, casting cannot be performed. Meanwhile, if the elevation angle exceeds 3°, the inner wall 221 of the tubular mold 201 comes in insufficient contact with the columnar molten alloy 215. Accordingly, an effect of removing heat that heat is removed from the columnar molten alloy 215 or the solidification shell to the tubular mold 201 deteriorates, so that solidification becomes insufficient. As a result, this is not preferable due to the increase of the possibility of casting troubles that re-melted surface is formed on the surface of the cast ingot 216 or the molten alloy 255, which is unsolidified, is discharged from the end of the tubular mold 201, and the like.

[0068] The tundish 250 configures a molten alloy receiving inlet 251 for receiving a molten aluminum-alloy that is adjusted to have prescribed alloy ingredients by an external melting furnace or the like, a molten alloy reservoir 252, and an outlet 253 that makes the molten metal to flow into the tubular mold 201. The tundish 250 maintains the level 254 of the molten alloy 255 at a position that is higher than the upper surface of the tubular mould 201, and stably distributes the molten alloy 255 to each tubular mold 201 in the case of multiple casting. The molten alloy 255 held in the molten alloy reservoir 252 of the tundish 250 is poured in the tubular mold 201 from the molten alloy inlet 211 that is provided through the refractory plate-like body 210.

[0069] The refractory plate-like body 210 is used to isolate the tundish 250 from the tubular mold 201, and can be produced from a material having refractory heat-insulating properties. For example, Lumiboard manufactured by NICH- IAS Corporation, INSURAL manufactured by FOSECO JAPAN, Ltd., or Fiber Blanket Board manufactured by IBIDEN CO., LTD. may be used as the refractory plate-like body. The refractory plate-like body 210 has the shape that can form

the molten alloy inlet 211. One or more pouring ports 211 may be formed at a portion of which the refractory plate-like body 210 protrudes inward from the inner wall 221 of the tubular mold 201.

[0070] Reference numeral 208 denotes a fluid feed-tube through a fluid is supplied. A lubrication fluid may be used as the fluid. The fluid may be one kind or two kinds or more selected from gaseous lubricants and liquid lubricants. It is preferable that supply pipes for a gaseous lubricant and a liquid lubricant be separately provided.

[0071] The fluid, which is pressurized and supplied from the fluid feed-tube 208, is supplied to a gap, which is formed between the tubular mold 201 and the refractory plate-like body 210, through a circular path 224. It is preferable that a gap of 200 μm or less be formed to the portion between the tubular mold 201 and the refractory plate-like body 210. The gap has a size so that the molten alloy 255 can not permeate through the gap and the fluid can flow to the inner wall 221 of the tubular mold 201. In the mode shown in Fig. 2, the circular path 224 is formed on the outer peripheral surface of the permeable porous member 222 that is provided on the tubular mold 201. The fluid permeates into the permeable porous member 222 due to applied pressure, is fed onto the entire surface of the permeable porous member 222 that comes in contact with the columnar molten alloy 215, and is supplied onto the inner wall 221 of the tubular mold 201. The liquid lubricant may be heated and changed into decomposed gas, and may be supplied onto the inner wall 221 of the tubular mold 201.

[0072] As a result, it is possible to improve the lubrication between the permeable porous surfaces of the tubular mold 201, and the periphery of the columnar molten alloy 215 and the periphery of the solidification shell. The permeable porous member 222 is provided in a ring shape, so that it is possible to obtain a better lubrication effect and to easily cast a continuously cast rod made of an aluminum-alloy.

[0073] A corner space 230 is formed by one or two or more selected from the supplied gases, the supplied liquid lubricant, and the gases decomposed from the liquid lubricant.

[0074] A casting step included in the method for production according to the present invention will be described.

[0075] In Fig. 2, the molten alloy 255 stored in the tundish 250 is supplied to the tubular mold 201, which is held so as to have a center axis 220 of the mold substantially parallel to a horizontal direction, through the refractory plate-like body 210. The molten alloy is forcibly cooled at the outlet of the tubular mold 201, and becomes the cast ingot 216. Since the cast ingot 216 is drawn at a constant speed by a drive apparatus that is provided near the outlet of the tubular mold 201, the molten alloy is continuously cast into a cast rod. The drawn cast rod is cut to a predetermined length by a synchronized cutting machine. That is, an aluminum-alloy, of which the average temperature of a molten alloy 255 corresponds to a liquidus line of $+40^{\circ}\text{C}$ to $+230^{\circ}\text{C}$, can be cast into the continuously cast rod at a casting speed of 300 (mm/min) to 2000 (mm/min) by a continuous casting method. Under this condition, it is possible to obtain shaped products where crystallization products are finely dispersed and forgeability and high-temperature mechanical strength are excellent. It is preferable that a casting speed be in the range of 80 (mm/min) to 400 (mm/min) in case of a hot top continuous casting, a vertical continuous casting, and a DC casting. Accordingly, it is preferable that a casting speed be in the range of 80 (mm/min) to 2000 (mm/min).

[0076] The composition of the molten aluminum-alloy 255 stored in the tundish 250 will be described.

[0077] The molten alloy 255 includes 10.5 to 13.5% by mass (preferably, 11.5 to 13% by mass) of Si, 2.5 to 6% by mass (preferably, 3.5 to 5.5% by mass) of Cu, 0.3 to 1.5% by mass (preferably, 0.5 to 1.3% by mass) of Mg, and 0.8 to 4% by mass (preferably, 1.8 to 3.5% by mass) of Ni, and is an aluminum-alloy that satisfies a relational expression of $\text{Ni}(\% \text{ by mass}) \geq [-0.68 \times \text{Cu}(\% \text{ by mass}) + \text{AA}(\% \text{ by mass})]$ (wherein, AA is a constant and $\text{AA} \geq 4.2$ preferably $\text{AA} \geq 4.7$ is satisfied.).

[0078] It is preferable that the molten alloy 255 contain one or two or more of 0.1 to 1% by mass (preferably, 0.2 to 0.5% by mass) of Mn, 0.05 to 0.5% by mass (preferably, 0.1 to 0.3% by mass) of Cr, 0.04 to 0.3% by mass (preferably, 0.1 to 0.2% by mass) of Zr, and 0.01 to 0.15% by mass (preferably, 0.05 to 0.1% by mass) of V, and 0.01 to 0.2% by mass (preferably, 0.02% to 0.1% by mass) of Ti.

[0079] Further, it is preferable that the molten alloy includes 0.15 to 0.65% by mass (preferably, 0.3 to 0.5% by mass) of Fe.

[0080] Furthermore, it is preferable that the molten alloy includes 0.003 to 0.02% by mass (preferably, 0.007 to 0.016% by mass) of P.

[0081] In addition, the molten alloy contains one or two or more of 0.003 to 0.03% by mass (preferably, 0.01 to 0.02% by mass) of Sr, 0.1 to 0.35% by mass (preferably, 0.15 to 0.25% by mass) of Sb, 0.0005 to 0.015% by mass (preferably, 0.001 to 0.01% by mass) of Na, and 0.001 to 0.02% by mass (preferably, 0.005 to 0.01% by mass) of Ca, which is preferable because there is an effect of micronizing eutectic Si crystals.

[0082] A difference between the height of the level 254 of the molten alloy 255 that is stored in the tundish 250, and the height of the upper surface of the inner wall 221 of the tubular mold 201 is set in the range of 0 to 250 mm, more preferably, 50 to 170 mm. If the difference is provided to both, the pressure of the molten alloy 255 supplied inside the tubular mold 201, liquid lubricant, and gas obtained from the vaporization of the liquid lubricant are suitably balanced with each other. The reason for this is that the castability is stabilized and it is possible to easily produce a continuously cast rod made of an aluminum-alloy. If level sensors, which are used to measure and monitor the height of the level 254

of the molten alloy 255, are provided to the tundish 250, it is possible to accurately manage the difference and maintain the difference at a predetermined value.

[0083] Vegetable oil, which is liquid lubricant, may be used as the liquid lubricant. For example, rapeseed oil, castor oil, and salad oil may be used as the liquid lubricant. Since hardly having an adverse effect on environment, these are preferable.

[0084] It is preferable that the amount of supplied liquid lubricant be in the range of 0.05 (mL/min) to 5 (mL/min) [more preferably, 0.1 (mL/min) to 1 (mL/min)]. If the amount of supplied liquid lubricant is excessively small, the breakout of an ingot is generated due to the lack of lubrication. If the amount of supplied liquid lubricant is excessively large, surplus oil will be mixed to the ingot. For this reason, there is a concern that the formation of crystal grains having a uniform size will deteriorate.

[0085] It is preferable that the casting speed, that is, a speed where the cast ingot 216 is drawn from the tubular mold 201, be in the range of 300 (mm/min) to 2000 (mm/min) [more preferably, 600 (mm/min) to 2000 (mm/min)]. This is preferable because the networks of the crystallization products formed by casting become uniform and fine and resistance against the deformation of an aluminum matrix at high temperature is increased, and high-temperature mechanical strength is improved. Of course, the effect of the present invention is not limited by the casting speed. However, if the casting speed is increased, the effect thereof becomes significant.

[0086] It is preferable that the amount of the cooling water discharged from the cooling water showering apparatus 205 be in the range of 5 (L/min) to 30 (L/min) [more preferably, 25 (L/min) to 30 (L/min)] per mold. If the amount of cooling water is excessively small, the breakout will be generated or the surface of the cast ingot 216 will be re-melted, so that non-uniform structure will be formed. For this reason, there is a concern that the formation of crystal grains having a uniform size will deteriorate. Meanwhile, if the amount of cooling water is excessively large, a very large amount of heat will be removed from the tubular mold 201, so that casting cannot be performed. Of course, the effect of the present invention is not limited by the amount of cooling water. However, if the cooling capacity is increased to increase a temperature gradient from a solidification interface to the interior of the tubular mold 201, the effect thereof becomes significant.

[0087] It is preferable that the average temperature of the molten alloy 255, which flows into the tubular mold 201 from the tundish 250, correspond to a liquidus line of +40°C to +230°C (more preferably, a liquidus line of +60 to +200°C). If the temperature of the molten alloy 255 is excessively low, large crystallization products will be formed in the tubular mold 201 and before that. For this reason, there is a concern that the formation of crystal grains having a uniform size deteriorates. Meanwhile, if the temperature of the molten alloy 255 is high, a large amount of hydrogen gas will be included in the molten alloy 255 and also include porosities in the cast ingot 216. For this reason, there is a concern that the formation of crystal grains having a uniform size will deteriorate.

[0088] In the present invention, these casting conditions are controlled so that eutectic Si of the structure of the castings or intermetallic compounds become the networks of the crystallization products, acicular crystallization products, or aggregates of crystallization products formed during the continuous casting, with few spherical aggregates. Accordingly, the effect of each of subsequent heat treatments becomes effective, which is preferable.

[0089] In the present invention, as a pre-heat treatment, it is important that a cast rod after having been cast is retained in the temperature range of -10°C to 480°C (preferably, -10°C to 370°C) for 2 to 6 hours before being provided to a forging step as forging material. It is more preferable that the temperature condition corresponds to room temperature. However, even though the temperature is equal to or lower than the room temperature, it is possible to obtain the effect thereof.

[0090] If a pre-heat treatment is performed as described above, the aluminum shaped product where the networks of the crystallization products, acicular crystallization products, or the aggregates of crystallization products formed during the continuous casting partially remain in the structure even after forming and a heat treatment. The crystallization products having these shapes resist against the deformation of an aluminum matrix under high temperature. As a result, mechanical strength is obtained under high temperature in the range of 250°C to 400°C. That is, since the networks of the crystallization products, acicular crystallization products, or the aggregates of crystallization products resist against deformation under high temperature where the aluminum matrix is softened, aluminum shaped products have excellent high-temperature mechanical strength. Meanwhile, if a pre-heat treatment temperature is high and a percent reduction of the forging material is high, the networks of the crystallization products, acicular crystallization products, or the aggregates of crystallization products are divided and aggregated in a granular shape, and the aggregates in a granular shape are uniformly dispersed state in the aluminum matrix softening under high temperature. For this reason, the resistance of the crystallization products against the deformation of the aluminum matrix under high temperature deteriorates, and high-temperature mechanical strength is also not increased.

[0091] According to the present invention, under the above-mentioned alloy composition, the aluminum matrix is softened, and the network or acicular crystallization products of crystallization products, or aggregates, which resist against the deformation of the aluminum matrix, partially remain in a high-temperature range higher than the range of 250°C to 400°C where deformation occurs very easily, thereby increasing high-temperature mechanical strength.

[0092] When a homogenization treatment is suppressed or omitted on a 6000 series alloy or the like that is a dilute alloy where the amount of crystallization products is relatively small and the network or acicular crystallization products of the crystallization products do not so appear, the suppression or omission of the homogenization treatment facilitates the suppression of recrystallization or the simplification of steps. This is different from the present invention that facilitates high-temperature improvement by maintaining preferably the network or acicular crystallization products contained in a high-Si-content alloy forging material where the amount of crystallization products is large and the network or acicular crystallization products appears during casting.

[0093] As described in the Background Art, the disclosure of Patent Document 1 (Japanese Patent Application Publication No. 2002-294383) relates to a 6000 series alloy, and the suppression or omission of the temperature of the homogenization treatment is performed not to obtain high-temperature characteristics of the alloy but to improve mechanical characteristics at normal temperature by suppressing recrystallization. The network or acicular crystallization products of the crystallization products does not so appear in the dilute alloy where the alloy system is also different and the amount of crystallization products is relatively small. Al-Mn and Al-Cr based compounds, which suppress the recrystallization, are finely precipitated by lowering and suppressing the temperature of the homogenization treatment. This is different from the present invention that facilitates high-temperature improvement by maintaining preferably the network or acicular crystallization products in a high-Si-content alloy forging material where the amount of crystallization products is large and the network and acicular crystallization products appear during casting.

[0094] In particular, in order to increase the high-temperature mechanical strength and improve the forgeability of the forging material, it is preferable that the retention temperature of the pre-heat treatment be in the range of 200°C to 370°C. If the retention temperature is set in this temperature range, it is possible to form an aluminum shaped product where the eutectic Si or intermetallic compounds at the time of the pre-heat treatment are hardly aggregated in a spherical shape, and the networks of the crystallization products, acicular crystallization products, or the aggregates of crystallization products formed during the continuous casting partially remain even after forging and a post-heat treatment, so that the aluminum shaped product has excellent high-temperature mechanical strength excellent.

[0095] In particular, in order to further increase the high-temperature mechanical strength of the forging material, it is preferable that the retention temperature of the pre-heat treatment is in the range of -10°C to 200°C. If the retention temperature is set in this temperature range, it is possible to form an aluminum shaped product where the eutectic Si or intermetallic compounds at the time of the pre-heat treatment are not almost aggregated in a spherical shape, and the networks of the crystallization products, acicular crystallization products, or the aggregates of crystallization products formed during the continuous casting partially remain even after forging and a post-heat treatment, so that the aluminum shaped product has excellent high-temperature mechanical strength.

[0096] Further, in order to further increase the forgeability of the forging material, it is preferable that the retention temperature of the pre-heat treatment be in the range of the 370°C to 480°C. If the retention temperature is set in this temperature range, it is possible to form an aluminum shaped product where some eutectic Si or intermetallic compounds at the time of the pre-heat treatment are aggregated in a spherical shape and the resistance against the deformation is decreased during the casting, so that the aluminum shaped product has excellent forgeability. Furthermore, in this temperature range, it is possible to form an aluminum shaped product where the networks of the crystallization products, acicular crystallization products, or the aggregates of crystallization products formed during the continuous forging partially remain even after the forging and a post-heat treatment, so that the aluminum shaped product has excellent high-temperature mechanical characteristics.

[0097] The pre-heat treatment step may be provided between after the casting and the forging step. For example, the pre-heat treatment step may be performed within one day after the casting, or the forging material may be provided to the forging step within one week after the pre-heat treatment step. Correction treatment and peeling treatment may be performed during this period.

[0098] Next, an example of the forging step included in the present invention will be described. A method for production includes 1) a step of cutting the continuously cast round rod to a predetermined length, 2) a step of preliminarily heating and upsetting the cut forging material, 3) a step of lubricating the upset forging material, 4) a step of providing the forging material into a mold so as to forge the forging material, and 5) a step of extracting product from the mold by a knock-out mechanism.

[0099] A lubricant may be applied to the forging material to be forged, and may be heated before being provided to the upsetting treatment. Meanwhile, the upsetting step may be omitted.

[0100] A lubricant treatment may be the application of a water-soluble lubricant or a bonde treatment. For example, it is preferable that the forging material be preliminarily heated at a temperature of 380°C to 480°C and provided to a forging apparatus after the bonde treatment is performed on the forging material. If the forging material is preliminarily heated at a temperature of 380°C to 480°C, the deformability of the forging material is improved and easily formed in a complicated shape.

[0101] It is preferable that an aqueous lubricant be used as the lubricant, and it is more preferable that a water-soluble graphite lubricant is used as the lubricant. The reason for this is that graphite is easily seized on the forging material. In

this case, for example, it is preferable that the forging material is heated at a temperature of 380°C to 480°C and provided to a forging apparatus after a lubricant is applied to the forging material corresponding to a temperature of 70°C to 350°C and then the forging material is cooled at normal temperature (for example, the forging material is retained for 2 to 4 hours). It is preferable that an aqueous lubricant be used as the lubricant, and it is more preferable that a water-soluble

graphite lubricant be used as the lubricant. The reason for this is that graphite is easily seized on the forging material. [0102] Before the forging material is provided, a lubricant is applied to the surface of the mold. The amount of the lubricant may be further appropriately set in a state so as to correspond to the combination of an upper mold and dies by adjusting a spraying time. It is preferable that an oil-based lubricant be used as the lubricant. For example, mineral oil may be used as the lubricant. The reason for this is that the temperature of the mold may be lowered in the case of aqueous liquid lubricant but the lowering of the temperature can be suppressed. Since a lubrication effect is improved if an oil-based lubricant is a mixture of graphite and mineral oil, it is more preferable that the oil-based lubricant be used.

[0103] It is preferable that the heating temperature of the mold be in the range of 150°C to 250°C. The reason for this is that a sufficient plastic flow can be obtained.

[0104] In the present invention, a percent reduction of a portion requiring high-temperature fatigue resistant strength is preferably 90% or less (preferably 70% or less) in the forging. If a percent reduction is equal to or less than this percent reduction, it is possible to form a shaped product where the division of the networks of the crystallization products, acicular crystallization products, or the aggregates of crystallization products is suppressed, so that the aluminum shaped product has excellent high-temperature mechanical strength.

[0105] Meanwhile, the portions of the shaped product, which requires high-temperature mechanical strength, may satisfy this percent reduction.

[0106] Meanwhile, if plastic forming step such as an upsetting step is performed before forging, it is preferable that a percent reduction be considered as a total of the percent reductions of those plastic forming steps. For example, in case of the shaped product that have complicated shapes, a percent reduction per processing is preferably in the range of 10 to 80% (more preferably 10 to 50%) and processing is preferably performed several times (more preferably twice). For example, a percent reduction of the first processing is preferably in the range of 10 to 50% (more preferably 10 to 30%).

[0107] Herein, a percent reduction is defined as follows.

$$\text{Percent reduction} = (\text{thickness before plastic forming} - \text{thickness after plastic forming}) / (\text{thickness before plastic forming}) \times 100\%$$

[0108] A post-heat treatment is performed on the resultant forged products. The combination of a solution treatment and an aging treatment may be used as the post-heat treatment. The post-heat treatment may be performed within one week after the forging treatment.

[0109] Specifically, it is possible to perform a solution treatment on the forged products under conditions where the forged products are retained at a temperature of, for example, 480°C to 520°C (preferably 490°C to 510°C) for 3 hours.

[0110] A T5 treatment or a T6 treatment of JIS standards may be performed on the forged products as the post-heat treatment other than the above-mentioned post-heat treatment.

[0111] In the present invention, it is preferable that the product taken out of the forging apparatus is retained at a temperature of 170°C to 230°C (more preferably 190°C to 220°C) for 1 to 10 hours as an aging treatment without the solution treatment or quenching. It is possible to form a shaped product where the division and aggregation of the networks of the crystallization products, acicular crystallization products, or the aggregates of crystallization products can be suppressed, which makes high-temperature mechanical strength excellent. Therefore, this is preferable.

[0112] The alloy structure of the shaped product produced by the above-mentioned method corresponds to aluminum the shaped product where the eutectic Si or intermetallic compounds are hardly aggregated in a spherical shape, and the networks of the crystallization products, acicular crystallization products, or the aggregates of crystallization products formed during the continuous casting partially remain even after the forging and a post-heat treatment, so that the shaped products has excellent high-temperature mechanical strength.

[0113] Further, the alloy composition contains 10.5 to 13.5% by mass (preferably, 11.5 to 13% by mass) of Si, 2.5 to 6% by mass (preferably, 3.5 to 5.5% by mass) of Cu, 0.3 to 1.5% by mass (preferably, 0.5 to 1.3% by mass) of Mg, and 0.8 to 4% by mass (preferably, 1.8 to 3.5% by mass) of Ni, and corresponds to an aluminum-alloy that satisfies a relational expression of $\text{Ni} (\% \text{ by mass}) \geq [-0.68 \times \text{Cu} (\% \text{ by mass}) + \text{AA} (\% \text{ by mass})]$ (wherein, AA is a constant and $\text{AA} \geq 4.2$ preferably $\text{AA} \geq 4.7$).

[0114] It is preferable that the alloy composition contain one or two or more of 0.1 to 1% by mass (preferably, 0.2 to

0.5% by mass) of Mn, 0.05 to 0.5% by mass (preferably, 0.1 to 0.3% by mass) of Cr, 0.04 to 0.3% by mass (preferably, 0.1 to 0.2% by mass) of Zr, 0.01 to 0.15% by mass (preferably, 0.05 to 0.1% by mass) of V, and 0.01 to 0.2% by mass (preferably, 0.02% to 0.1% by mass) of Ti.

[0115] Further, it is preferable that the alloy composition includes 0.15 to 0.65% by mass (preferably, 0.3 to 0.5% by mass) of Fe.

[0116] Furthermore, it is preferable that the alloy composition includes 0.003 to 0.02% by mass (preferably, 0.007 to 0.016% by mass) of P.

[0117] In addition, the alloy composition contains one or two or more of 0.003 to 0.03% by mass (preferably, 0.01 to 0.02% by mass) of Sr, 0.1 to 0.35% by mass (preferably, 0.15 to 0.25% by mass) of Sb, 0.0005 to 0.015% by mass (preferably, 0.001 to 0.01% by mass) of Na, and 0.001 to 0.02% by mass (preferably, 0.005 to 0.01% by mass) of Ca, which is preferable because there is an effect of micronizing primary Si crystals.

(Examples)

[0118] The present invention will be specifically described below by using examples. However, the present invention is not limited to these examples.

(Examples 1 to 16)

[Manufacturing conditions]

[0119] The aluminum-alloy shaped product of Examples 1 to 16 shown in Table 1 and Comparative Examples 1 to 10 shown in Table 2 were produced by a production system shown in Fig. 1.

(Table 1)

	Temperature of Homogenization Treatment (°C)	Percent reduction during the course of upsetting	Post-Heat Treatment (T6, T5)	Composition of Aluminum-alloy (% by mass)									Fatigur Strength Stress (Unit MPa)		Value of AA
				Si	Fe	Cu	Mn	Mg	Ni	Ti	P	Sr	Temperature Condition 300 °C	Temperature Condition 350 °C	
Example 1	370	50%	T6	10.5	0.25	2.7	-	0.95	3.8	-	-	0.015	60	45	5.64
Example 2	370	50%	T6	10.5	0.25	2.7	-	0.95	3.8	-	0.015	-	59	44	5.64
Example 3	370	50%	T6	12.8	0.48	3.0	0.23	0.95	3.0	0.075	0.018	-	59	43	5.04
Example 4	370	50%	T5	12.8	0.48	3.0	0.23	0.95	3.0	0.075	0.018	-	62	44	5.04
Example 5	370	50%	T6	11.8	0.33	3.2	-	0.72	2.2	-	0.005	-	54	39	4.38
Example 6	370	50%	T6	12.8	0.25	3.8	-	0.95	1.8	-	0.018	-	53	38	4.38
Example 7	370	50%	T6	13.4	0.25	4.1	-	1.10	2.2	-	0.018	-	57	43	4.99
Example 8	370	50%	T6	13.4	0.61	4.1	0.32	1.21	2.2	-	0.010	-	58	43	4.99
Example 9	not over 200	50%	T6	13.4	0.61	4.1	0.32	1.21	2.2	-	0.010	-	59	44	4.99
Example 10	370	50%	T6	12.8	0.48	4.5	0.23	0.95	1.5	0.075	0.018	-	55	40	4.56
Example 11	370	50%	T6	12.5	0.28	5.1	0.21	1.14	1.1	-	0.007	-	55	39	4.57
Example 12	370	50%	T6	12.8	0.25	5.5	-	0.95	1.0	-	0.018	-	57	43	4.74
Example 13	370	50%	T6	12.8	0.48	5.5	0.23	0.95	1.0	0.075	0.018	-	58	44	4.74

(continued)

	Temperature of Homogenization Treatment (°C)	Percent reduction during the course of upsetting	Post-Heat Treatment (T6, T5)	Composition of Aluminum-alloy (% by mass)									Fatigur Strength Stress (Unit MPa)		Value of AA
				Si	Fe	Cu	Mn	Mg	Ni	Ti	P	Sr	Temperature Condition 300°C	Temperature Condition 350°C	
Example 14	370	50%	T6	10.5	0.25	5.7	-	0.95	3.5	-	0.010	-	62	47	7.38
Example 15	370	88%	T6	12.8	0.48	3.0	0.23	0.95	3.0	0.075	0.018	-	58	41	5.04
Example 16	470	50%	T6	12.8	0.48	3.0	0.23	0.95	3.0	0.075	0.018	-	58	41	5.04

(Table 2)

	Temperature of Homogenization Treatment (°C)	Percent reduction during the course of upsetting	Post-Heat Treatment (T6, T5)	Composition of Aluminum-alloy (% by mass)								Fatigur Strength Stress (Unit MPa)		Value of AA	
				Si	Fe	Cu	Mn	Mg	Ni	Ti	P	Sr	Temperature Condition 300°C		Temperature Condition 350°C
Comparative Example 1	370	50%	T6	11.0	0.25	3.0	0.10	0.40	1.8	-	0.010	-	45	30	3.84
Comparative Example 2	370	50%	T6	12.3	0.3	3.3	0.15	0.85	1.8	0.05	0.005	-	47	32	4.04
Comparative Example 3	470	50%	T6	12.3	0.3	3.3	0.15	0.85	1.8	0.05	0.005	-	45	30	4.04
Comparative Example 4	370	50%	T6	12.8	0.48	4.0	-	0.95	1.2	-	0.010	-	46	31	3.92
Comparative Example 5	370	50%	T6	12.8	0.48	5.0	-	0.95	0.5	-	0.010	-	46	32	3.90
Comparative Example 6	500	50%	T6	13.4	0.61	4.1	0.32	1.21	2.2	-	0.010	-	48	35	4.99
Comparative Example 7	370	50%	T6	12.3	0.3	5.7	0.16	0.98	0.5	-	0.010	-	49	36	4.38
Comparative Example 8	370	50%	T6	12.4	0.3	6.3	0.17	0.97	0.6	-	0.010	-	*1	*1	4.88
Comparative Example 9	370	50%	T6	12.3	0.32	2.3	0.16	0.94	3.7	0.05	0.010	-	49	35	5.26
Comparative Example 10	370	50%	T6	12.4	0.36	2.3	0.15	0.99	4.3	-	0.010	-	*1	*1	5.86

[0120] Continuously cast round rods, which each have a diameter of $\phi 85$ (mm) and are made of aluminum-alloys of Examples 1 to 16 having a composition shown in Table 1 and Comparative Examples 1 to 10 shown in Table 2, were cast by using a hot top continuous casting apparatus shown in Fig. 5 as the continuous casting apparatus 81 configuring the production system. The hot top continuous casting apparatus is a caster using a gas pressurization hot top casting method, and is configured so that gas and liquid lubricant are introduced into a clearance between a header and a mold and the pressure of the molten alloy supplied to the mold, liquid lubricant, and gas obtained from the vaporization of the liquid lubricant are preferably balanced with each other. Since an area where the molten aluminum comes in contact with the mold is small due to this configuration, it is possible to rapidly cool and solidify a molten alloy by cooling water and to stably cast a continuously cast rod made of an aluminum-alloy.

[0121] After that, as the pre-heat treatment step, a homogenization treatment was performed on each of the continuously cast round rods at temperatures shown in Tables 1 and 2. Each of the continuously cast round rods was cut at a thickness of 20 or 80 mm and was used as a forging material to be forged. Then, after forging materials to be forged were preliminarily heated at a temperature of 420°C, each upsetting step was performed at predetermined percent reductions during the course of upsetting shown in Tables 1 and 2 and plastic forming was performed in a predetermined shape.

[0122] Meanwhile, when an upsetting step was performed at a percent reduction during the course of upsetting of 55% on Examples 5 to 7 and 10 to 13, a crack rate was evaluated. The evaluation results are shown in Table 3. In Table 3, an O mark indicated that a crack rate caused by an upsetting step was less than 1%, and a Δ mark indicated that a crack rate caused by an upsetting step was equal to or larger than 1%.

(Table 3)

	Temperature of Homogenization Treatment (°C)	Percent reduction during the course of upsetting	Content in Aluminum-alloy (wt%)		Value of AA	Crack Rate
			Cu	Ni		
Example 5	370	55%	3.2	2.2	4.38	Δ
Example 6	370	55%	3.8	1.8	4.38	O
Example 7	370	55%	4.1	2.2	4.99	Δ
Example 10	370	55%	4.5	1.5	4.56	O
Example 11	370	55%	5.1	1.1	4.57	O
Example 12	370	55%	5.5	1.0	4.74	O
Example 13	370	55%	5.5	1.0	4.74	O

[0123] After that, each of Examples and Comparative Examples was produced by performing a predetermined post-heat treatment step shown in Tables 1 and 2 on the forging material on which plastic forming has been performed.

[0124] Meanwhile, the post-heat treatment step was performed by any one of a T5 treatment that quenched plastic worked articles with water and retained the plastic worked articles at a temperature of 210°C for 6 hours; and a T6 treatment that retained plastic worked articles at a temperature of 500°C for 2.5 hours, quenched the plastic worked articles with water, and retained the plastic worked articles at a temperature of 210°C for 6 hours.

[Evaluation of fatigue strength]

[0125] The fatigue strength of each of Examples and Comparative Examples was evaluated by the following method.

[0126] Test pieces were fabricated from each of Examples and Comparative Examples, and the fatigue strength of each of the test pieces was evaluated under environment of 300°C and 350°C by an Ono-type rotary bending fatigue testing machine after the test pieces were preliminarily heated at a temperature of 300°C or 350°C for 100 hours. Repeated stress was applied 10, 000, 000 times, and stress where the test piece was not broken was measured.

[0127] Tables 1 and 2 show the composition, the heat treatment condition, the percent reduction during the course of upsetting, and the evaluation result of fatigue strength of each of Examples and Comparative Examples, and a constant AA that satisfies a relational expression defined by $Ni(\% \text{ by mass}) = [-0.68 \times Cu(\% \text{ by mass}) + AA(\% \text{ by mass})]$. Further, Fig. 6 shows a relationship between the percentage contents of Ni and Cu in the composition of each of Examples and Comparative Examples. Meanwhile, in Fig. 6, the respective values of AA of Examples 1 to 14 were represented by reference characters S1 to S14, respectively, and the respective values of AA of Comparative Examples 1 to 10 (excluding

Comparative Example 6) were represented by reference characters C1 to C10, respectively.

[0128] All Examples 1 to 16 were produced by the method for production according to the present invention, and have fatigue strength of 33 MPa or more at a temperature of 350°C as appreciated from Table 1. Since having target fatigue strength as described above, Examples 1 to 16 produced by the method for production according to the present invention may be preferably used for parts that require mechanical strength at high temperature.

[0129] It is essential for the aluminum-alloy, which is used in the method for production according to the present invention, to have the composition where Ni content and Cu content are included in a region surrounded by A-B-C-D-E-A of Fig. 6.

[0130] All Examples 10 to 13 and Example 6, of which Ni content and Cu content are included in a region surrounded by D-E-H-I-D, can be processed over an percent reduction during the course of upsetting of 55% as shown in Table 3. Thus, in the present invention, it is more preferable to use an aluminum-alloy containing Cu content so that Ni content is equal to or less than 2.0 wt% and $AA \geq 4.2$ is satisfied.

[0131] In contrast, Comparative Examples 1 to 5 and 7 to 10, which have composition out of the range of the alloy composition defined in the method for production according to the present invention, did not have target fatigue strength as shown in Table 2. Comparative Examples 8 and 10 had poor plastic workability and generated cracks during upsetting. "*" shown in Table 2 indicates a case that a test piece of Comparative Example cannot have been sampled. Meanwhile, the values of AA of Comparative Examples 1 to 4 were less than 4.2. Further, Comparative Example 6, on which a pre-heat treatment step was performed at a temperature out of the temperature range defined in the method for production according to the present invention, also did not have target fatigue strength.

[Evaluation of metal structure]

[0132] Samples of which structure to be observed were cut out from a center portion of a vertical cross section of each of Examples of Table 1 and Comparative Examples of Table 2, and the samples were micro-polished. Then, the networks of the crystallization products of the samples were observed from microphotographs of the samples in order to evaluate the metal structure of each of Examples and Comparative Examples.

[0133] It could be confirmed that the networks of the crystallization products, acicular crystallization products, or the aggregates of crystallization products formed during the continuous casting partially remain in the structure of Examples even after forming and a heat treatment.

[0134] Further, as for each of the Examples, an area occupation ratio of eutectic Si is 8% or more, an average grain size of the eutectic Si is 5 μm or less, and the eutectic Si of an acicular ratio of 1.4 or more is 25% or more; and an area occupation ratio of an intermetallic compound is 1.2% or more, an average grain size of an intermetallic compound of 1.5 μm or more. And a length of an intermetallic compound or a length of an aggregate of a contacted intermetallic compound of 30% or more is 3 μm or more.

[0135] In particular, as shown in Table 4, all Examples 10 and 13, which contain Ni and Cu at preferred concentration, have average grain sizes of eutectic Si of 2.5 μm or less. It is appreciated that both Examples 10 and 13 have about 80% eutectic Si of which acicular ratios are 1.4 or more, and have about 90% or more aggregates of intermetallic compounds of which length is 3 μm or more.

[0136] Further, according to the results of Tables 1 and 4, it is appreciated that Example 13 having a constant AA larger than 4.7 has a larger amount of network-like or acicular intermetallic compounds contributing to high-temperature strength, and higher fatigue strength as compared to Example 10 having a constant AA less than 4.7. As described above, in the present invention, the aluminum-alloy shaped product prepared a constant AA of 4.7 or more are preferable.

[0137] In contrast, each of Comparative Examples had a smaller percentage content of eutectic Si having an acicular ratio of 1.4 or more, and a smaller length of an intermetallic compound or a smaller length of an aggregate of a contacted intermetallic compound, as compared to Examples. For example, as shown in Table 4, Comparative Example 6 included only about 22% eutectic Si of which acicular ratio is 1.4 or more. And an intermetallic compound or an aggregate of a contacted intermetallic compound of which length is 3 μm or more is only about 28% in Comparative Example 6.

(Table 4)

	Eutectic Si			Intermetallic Compound		
	Area Occupation Ratio (%)	Average Grain Size	Acicular Ratio of 1.4 or More	Area Occupation Ratio (%)	Average Grain Size	Acicular Ratio of 1.4 or More
Example 10	8.6%	2.4 μm	78%	7.4%	2.6 μm	88%
Example 13	8.5%	2.5 μm	80%	7.8%	2.7 μm	89%

(continued)

	Eutectic Si			Intermetallic Compound		
	Area Occupation Ratio (%)	Average Grain Size	Acicular Ratio of 1.4 or More	Area Occupation Ratio (%)	Average Grain Size	Acicular Ratio of 1.4 or More
Comparative Example 6	8.5%	2.0 μm	22%	7.2%	1.9 μm	28%

(Examples 17 and 18)

[Manufacturing conditions]

[0138] Examples 17 and 18 and Comparative Examples 11 and 12, respectively, were produced under the composition and manufacturing conditions shown in Table 5 by the same method for production as Examples 1 to 16 and Comparative Examples 1 to 10.

[0139] Meanwhile, Comparative Example 13 was made of a powdery extruded-cast material, and was produced by the same method for production as Comparative Examples 11 and 12 except that Comparative Example 13 was not formed from a continuously cast round rod made of an aluminum-alloy and a homogenization treatment was not performed. All Examples 17 and 18 and Comparative Examples 11 to 13 were formed as the aluminum-alloy shaped product having the shape of a piston 1 that had a diameter of 80 mm and a top surface 10 having a thickness of 8 mm as shown in Figs. 7A to 7C.

[Evaluation of fatigue strength]

[0140] The fatigue strength of each of Examples 17 and 18 and Comparative Examples 11 to 13 was evaluated by the following method.

[0141] First, after the piston 1 of each of Examples and Comparative Examples was preliminarily heated at a temperature of 300°C or 350°C for 100 hours, a test piece 11 was cut out from a center portion of the top surface 10 of each of Examples and Comparative Examples. The fatigue strength of each of the test pieces 11 was evaluated by a pulsating tensile fatigue test under temperature environment corresponding to the preliminary heating temperature. In the fatigue test, a stress ratio R was -0.1, and the maximum stress where the test piece was not broken against the application of stress 10,000,000 times was referred to as fatigue strength. Table 5 shows the evaluation results of the fatigue strength of Examples 17 and 18 and Comparative Examples 11 to 13.

[0142] As appreciated from Table 5, the fatigue strength of Examples 17 and 18 at a temperature of 350°C exceeds 43 MPa that is preferable for a part requiring mechanical strength at high temperature, and the fatigue strength thereof at a temperature of 300°C exceeds 55 MPa. Further, since Examples 17 and 18 correspond to Examples 10 and 13 where the same manufacturing conditions as Examples 17 and 18 except for shapes are used, it is appreciated that Examples 17 and 18 have stable mechanical strength at high temperature despite an evaluation method.

(Table 5)

		Forging material	Temperature of Homogenization Treatment (°C)	Post-Heat Treatment (T6, T5)	Composition of Aluminum-alloy (% by mass)								Fatigur Strength Stress (Unit: MPa)		Value of AA
					Si	Fe	Cu	Mn	Mg	Ni	Ti	P	Temperature Condition 300°C	Temperature Condition 350°C	
Comparative Example 11		Continuously Cast Rod	370	T6	12.3	0.3	3.3	0.15	0.85	1.8	0.05	0.005	64	45	4.04
Comparative Example 12		Continuously Cast Rod	370	T6	12.4	0.3	1.0	-	1.04	1.0	-	0.010	45	33	1.66
Comparative Example 13		Powdery Extruded-Cast Material	-	T6	11.7	5.3	2.5	-	1.1	-	-	-	80	59	1.70
Example 17		Continuously Cast Rod	370	T6	12.8	0.48	4.5	0.23	0.95	1.5	0.075	0.018	70	52	4.56
Example 18		Continuously Cast Rod	370	T6	12.8	0.48	5.5	0.23	0.95	1.0	0.075	0.018	73	54	4.74

[0143] In contrast, a value of AA of Comparative Example 11 is less than 4.2, and corresponds to Comparative Example 2 where the same manufacturing conditions as Comparative Example 11 except for shapes are used. From the evaluation results of the fatigue strength of Comparative Example 2 of Table 2 and Comparative Example 11 of Table 5, it is considered that the reliability of the mechanical strength of Comparative Example 11 lacks at high temperature.

[0144] Further, AA of Comparative Example 12 is 1.68, and the fatigue strength thereof at a temperature of 350°C is significantly lower than 43 MPa.

[0145] Meanwhile, Comparative Example 13 made of a powdery extruded-cast material has fatigue strength higher than the fatigue strength of Examples 17 and 18, regardless of a fact that AA is 1.7. However, there is a drawback in that a fine portion, for example, a skirt portion 12 of a sample formed by packing is apt to become brittle. Thus, the shaped product using the powdery extruded-cast material have poorer ductility and toughness as compared to the aluminum-alloy shaped products that include a forging step using a continuously cast rod made of an aluminum-alloy as forging material.

[0146] Since having excellent ductility, toughness, and fatigue strength, the aluminum-alloy shaped product, which are produced by the method for production according to the present invention, may be preferably used for top surfaces or the like of a piston of an internal combustion engine.

Industrial Applicability

[0147] As described above, the present invention provides a method for production of aluminum-alloy shaped product that includes a forging step using a continuously cast rod made of an aluminum-alloy as forging material. The aluminum-alloy contains Si, Cu, Mg, and Ni. Accordingly, according to the present invention, it is possible to obtain a shaped product that has excellent high-temperature fatigue strength, forgeability, ductility, and toughness. Further, in Ni and Cu, since a relational expression of " $\text{Ni (\% by mass)} \geq [-0.68 \times \text{Cu (\% by mass)} + 4.2 (\% \text{ by mass})]$ " is satisfied, it is possible to further improve fatigue strength characteristics at high temperature.

[0148] It is possible to further reduce the thickness of a piston of a conventional internal combustion engine by using the aluminum-alloy shaped product according to the present invention and to reduce the weight of a piston of an internal combustion engine. Further, it is possible to satisfy weight reduction required from the market, to reduce fuel consumption of an internal combustion engine, and to improve output.

Claims

1. A method for producing an aluminum-alloy shaped product, comprising:

a step of forging a continuously cast rod of aluminum-alloy serving as a forging material, in which the aluminum-alloy contains Si in an amount of 10.5 to 13.5 mass %, Cu in an amount of 2.5 to 6 mass %, Mg in an amount of 0.3 to 1.5 mass % and Ni in an amount of 0.8 to 4%, and satisfies a relational expression of " $\text{Ni (\% by mass)} \geq (-0.68 \times \text{Cu (\% by mass)} + 4.2 (\% \text{ by mass}))$ ", and heat treatment and heating steps including a step of subjecting the forging material to pre-heat treatment, a step of preliminary heating the forging material before a course of forging of the forging material and a step of subjecting a shaped product to post-heat treatment, said pre-heat treatment including treatment of maintaining the forging material at a temperature of -10 to 480°C for two to six hours.

2. The method according to claim 1, wherein the pre-heat treatment is performed at a temperature of at least 200°C and 370°C or lower.

3. The method according to claim 1, wherein the pre-heat treatment is performed at a temperature of at least -10°C and less than 200°C.

4. The method according to claim 1, wherein the pre-heat treatment is performed at a temperature of at least 370°C and 480°C or lower.

5. The method according to any one of claims 1 to 4, wherein the post-heat treatment is performed at 170 to 230°C for one to 10 hours without performing solid solution treatment.

6. The method according to any one of claims 1 to 5, wherein the aluminum-alloy further contains Fe in an amount of 0.15 to 0.65 mass %.

7. The method according to any one of claims 1 to 6, wherein the aluminum-alloy further contains P in an amount of 0.003 to 0.02 mass %.
8. The method according to any one of claims 1 to 7,
wherein the aluminum-alloy further contains at least one species selected from among Sr in an amount of 0.003 to 0.03 mass %, Sb in an amount of 0.1 to 0.35 mass %, Na in an amount of 0.0005 to 0.015 mass % and Ca in an amount of 0.001 to 0.02 mass %.
9. The method according to any one of claims 1 to 8,
wherein the aluminum-alloy further contains at least one species selected from among Mn in an amount of 0.1 to 1.0 mass %, Cr in an amount of 0.05 to 0.5 mass %, Zr in an amount of 0.04 to 0.3 mass %, V in an amount of 0.01 to 0.15 mass % and Ti in an amount of 0.01 to 0.2 mass %.
10. The method according to any one of claims 1 to 9,
wherein during the forging step, a percent reduction of a portion of the forging material that requires high-temperature fatigue strength resistance is regulated to 90% or less.
11. The method according to any one of claims 1 to 10, wherein in the forging step, the preliminary heating step is performed at a temperature of 380 to 480°C.
12. The method according to any one of claims 1 to 11,
wherein the continuously cast rod is produced through continuous casting of a molten aluminum-alloy having an average temperature which falls within a range of a liquidus temperature +40°C to the liquidus temperature +230°C at a casting speed of 80 to 2,000 mm/minute.
13. An aluminum-alloy shaped product produced through the method according to any one of claims 1 to 12 and having a metallographic structure in which crystallization product networks, acicular crystallization products or crystallization product aggregates that have been formed during a course of continuous casting remain partially even after forging and heat treatment steps.
14. An aluminum-alloy shaped product produced through the method according to any one of claims 1 to 12 and having a eutectic Si area share of 8% or more, an average eutectic Si particle diameter of 5 μm or less, 25% or more of eutectic Si having an acicular eutectic Si ratio of 1.4 or more, an intermetallic compound area share of 1.2% or more, an average intermetallic compound particle diameter of 1.5 μm or more and 30% or more of intermetallic compounds or intermetallic compound aggregates having an intermetallic compound length or intermetallic compound aggregate length of 3 μm or more.
15. An aluminum-alloy shaped product produced through the method according to claim 13 or 14,
wherein an engine piston is made of the aluminum-alloy and includes a top surface portion and a skirt portion and the high-temperature fatigue strength of the top surface portion is 50 MPa or more.
16. A production system comprising a continuous line for performing a series of steps for producing an aluminum-alloy shaped product from a molten aluminum-alloy, wherein the series of steps includes at least the steps of the method of any one of claims 1 to 12.

FIG. 1

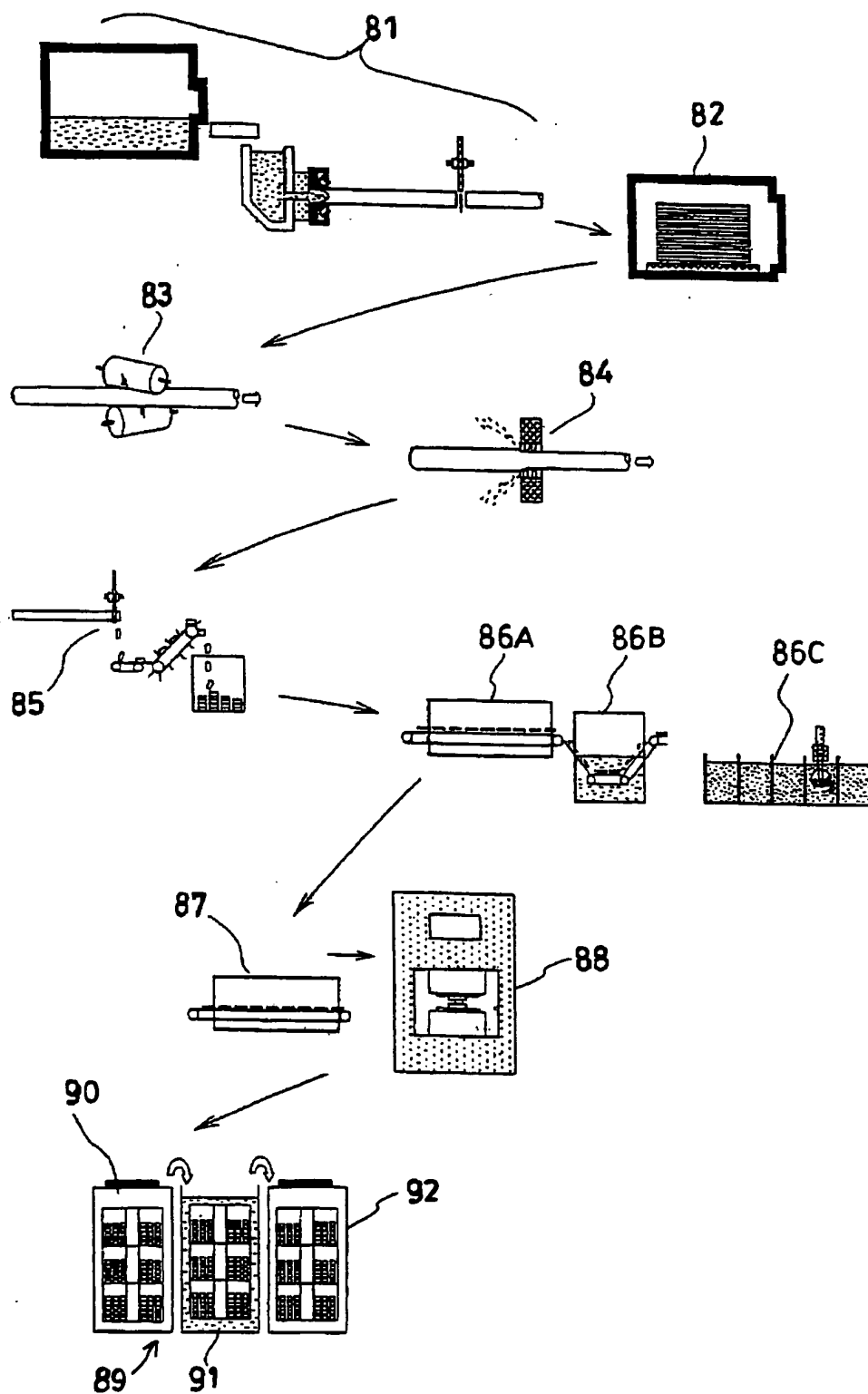


FIG. 2

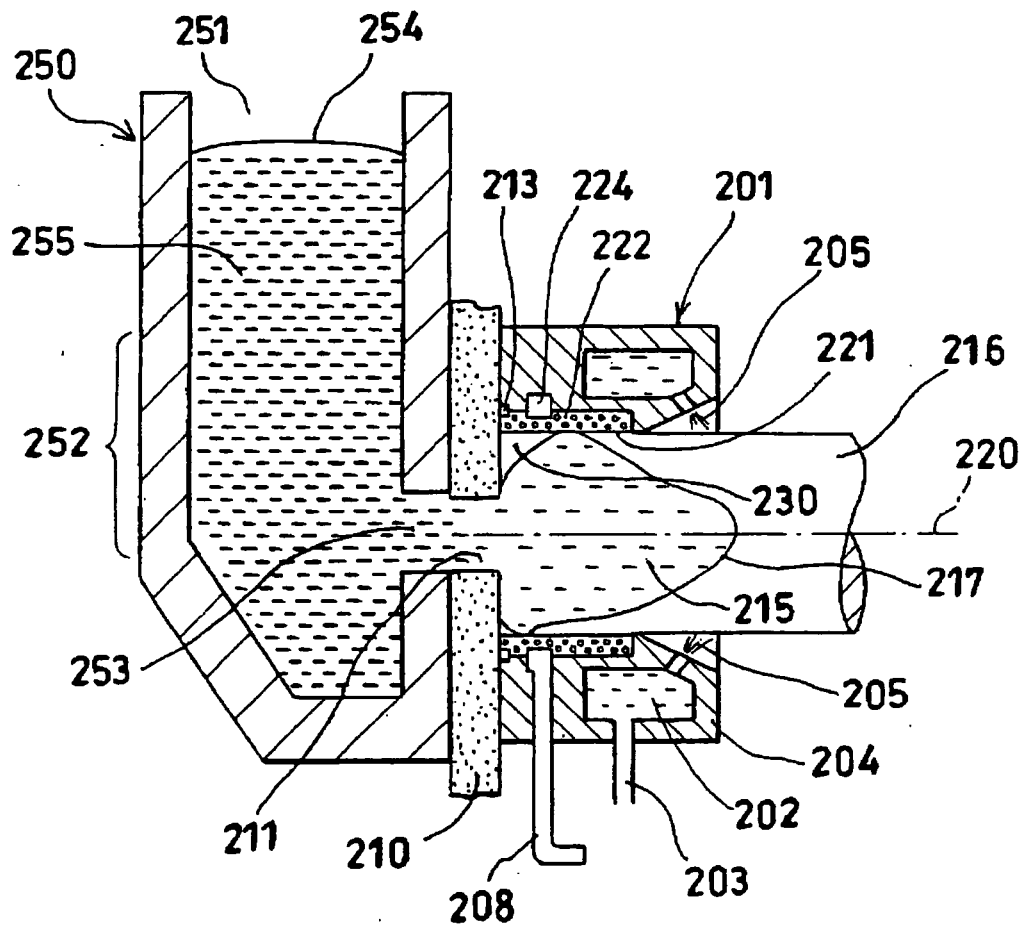


FIG. 3

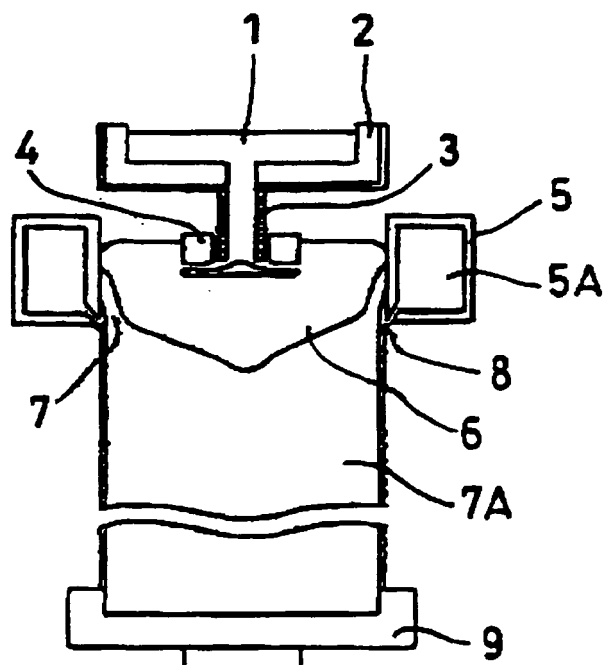


FIG. 4

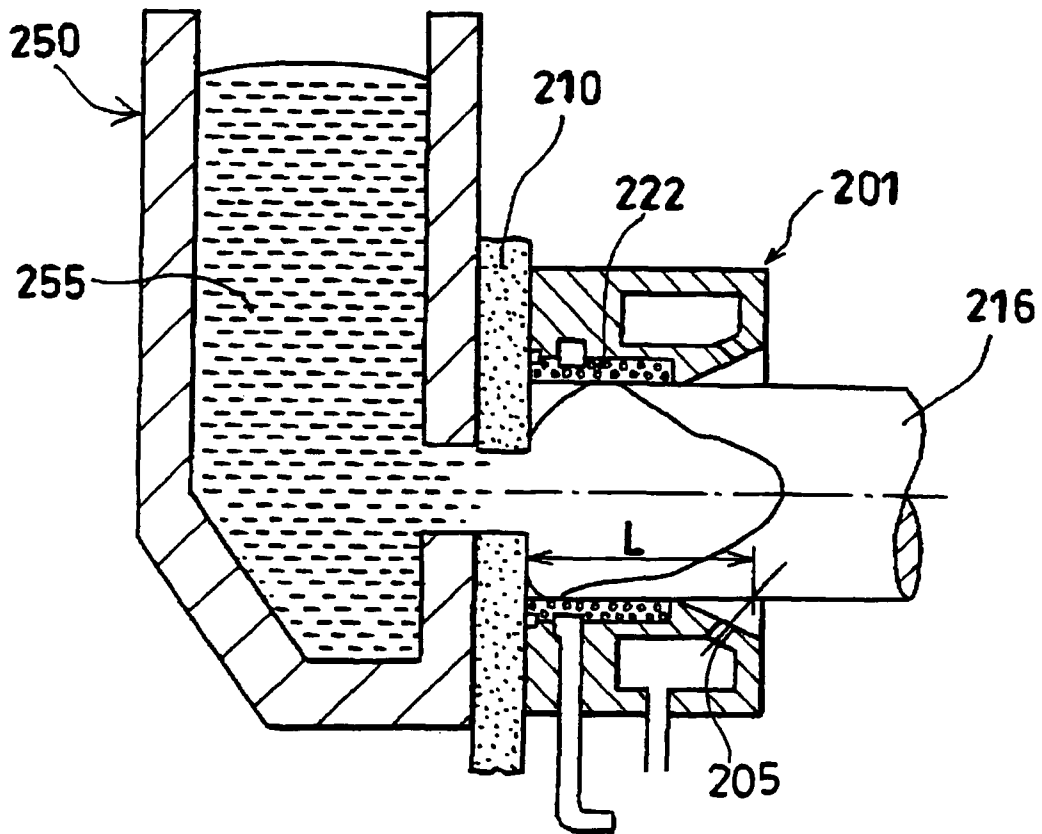


FIG.5

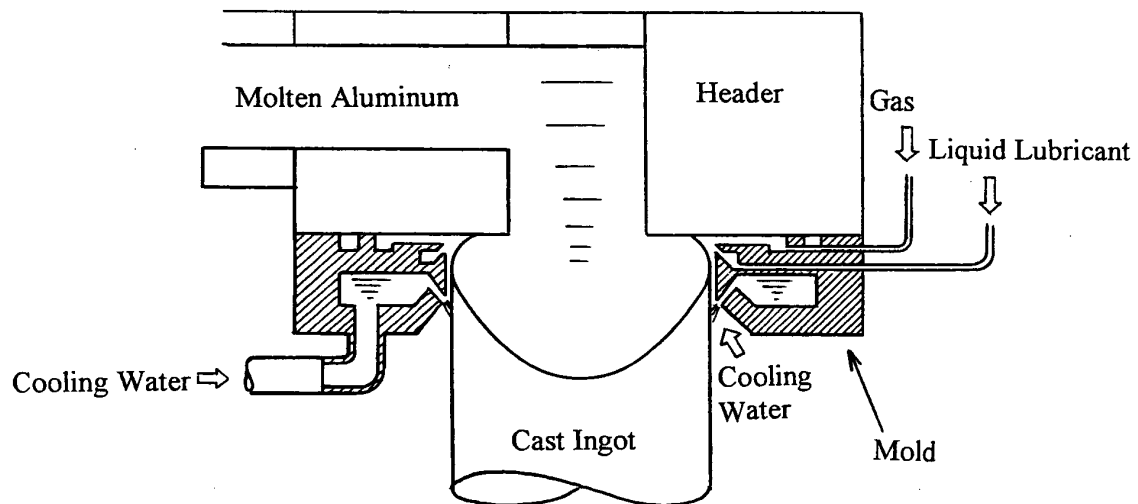


FIG. 6

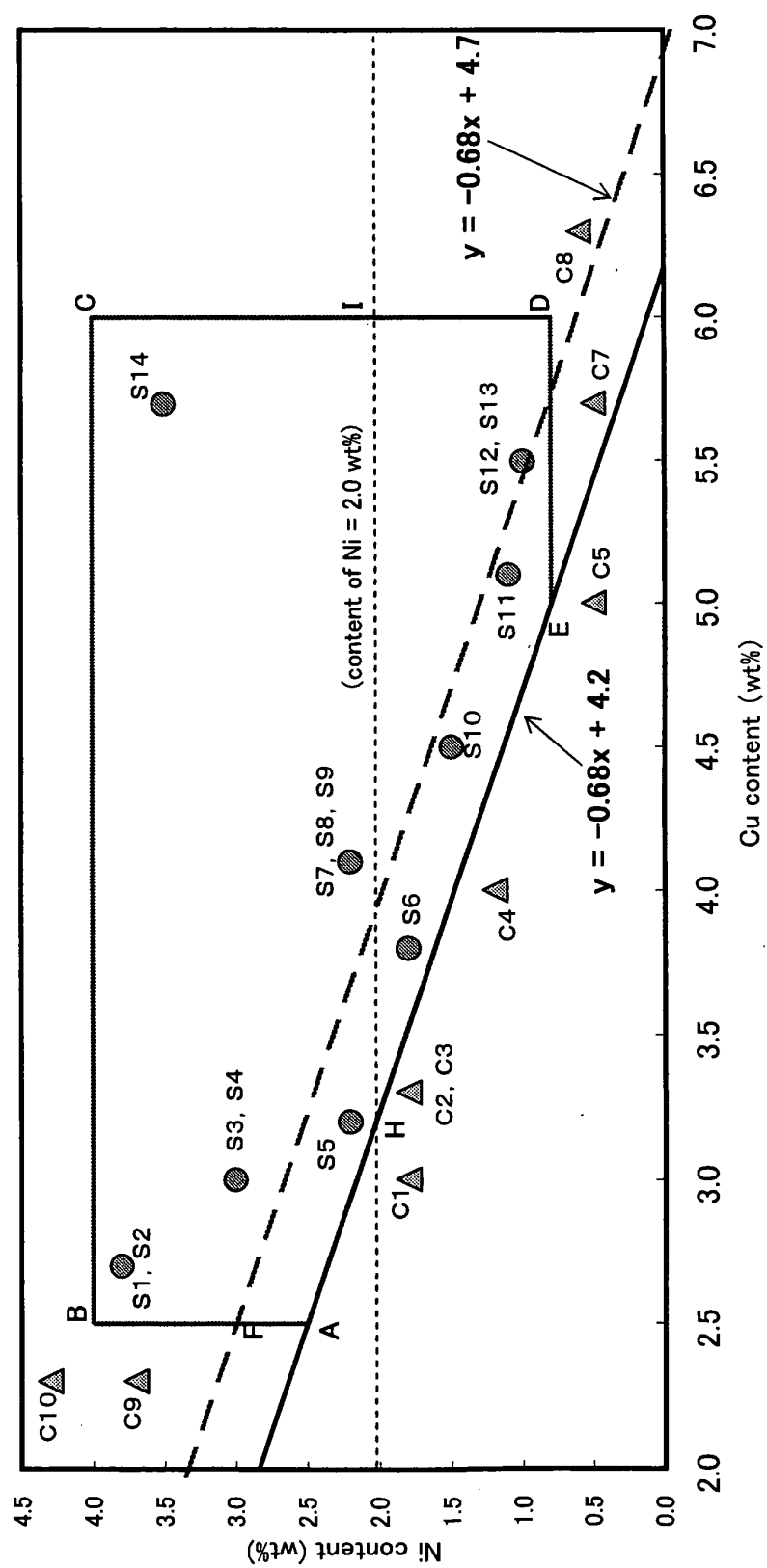


FIG. 7 (a)

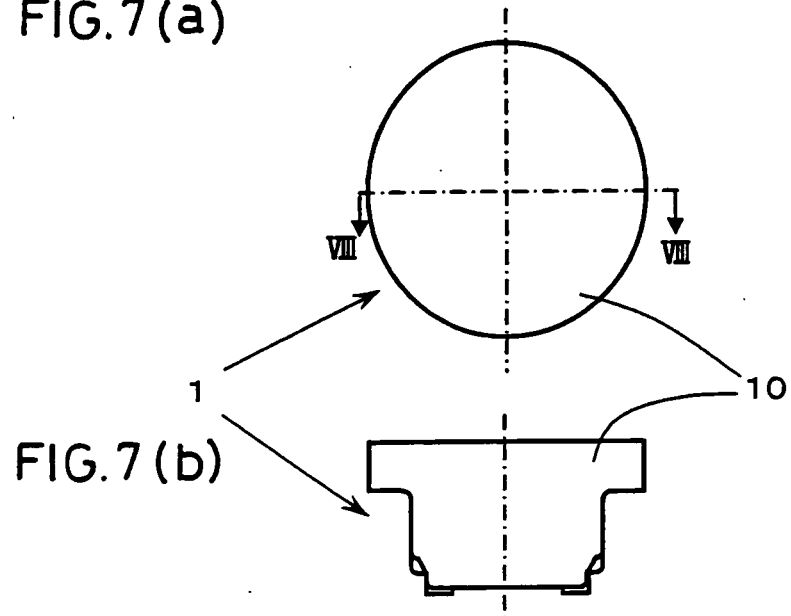
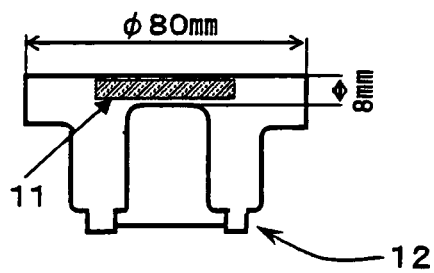


FIG. 8



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2007/065331

A. CLASSIFICATION OF SUBJECT MATTER

C22F1/043(2006.01)i, B21J5/00(2006.01)i, C22C21/02(2006.01)i, B22D11/00
(2006.01)n, B22D11/18(2006.01)n, B22D11/20(2006.01)n, C22F1/00(2006.01)n

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)

C22F1/04-1/057, B21J5/00, C22C21/00-21/18, B22D11/00, B22D11/18,
B22D11/20, C22F1/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Jitsuyo Shinan Koho 1922-1996 Jitsuyo Shinan Toroku Koho 1996-2007
Kokai Jitsuyo Shinan Koho 1971-2007 Toroku Jitsuyo Shinan Koho 1994-2007

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.
A	JP 2005-290545 A (Showa Denko Kabushiki Kaisha), 20 October, 2005 (20.10.05), Claims 1 to 16; tables 1 to 2 & WO 2005/059195 A1	1-16
A	JP 11-012674 A (Aisin Seiki Co., Ltd.), 19 January, 1999 (19.01.99), Claims 1, 3; Par. Nos. [0010] to [0016]; tables 1, 3 & US 5996471 A & DE 19829047 A1	1-16

☐ Further documents are listed in the continuation of Box C.

☐ See patent family annex.

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Date of the actual completion of the international search
22 October, 2007 (22.10.07)

Date of mailing of the international search report
30 October, 2007 (30.10.07)

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Patent documents cited in the description

- JP 2002294383 A [0005] [0093]
- JP 2005290545 A [0007]