

METHOD FOR PRODUCING NEAR-NET-SHAPE MATERIAL

FOR ENGINE PISTON

TECHNICAL FIELD

[0001] The present invention relates to a method of producing a near-net-shape material for an engine piston of aluminum alloy excellent in wear resistance and high temperature characteristics, and also relates to the near-net-shape material for an engine piston.

BACKGROUND TECHNIQUE

[0002] An engine piston used in an engine to be mounted on a vehicle such as an automobile is required to have lightness to reduce the inertia force as much as possible, high temperature strength at the raised highest temperature, durability at the raised highest temperature, low thermal expansibility to reduce clearance variations due to thermal expansion, and wear resistance to reduce wear of ring grooves due to slide contact of a piston ring and wear due to the contact of a skirt portion with a cylinder surface.

[0003] For this reason, in an engine piston produced by forging, as the aluminum alloy constituting the piston, when wear resistance is given greater importance, an alloy in which the additive amount of Si is the same as or above the eutectic point has been used (see, for example, Patent Document 1). On the other hand, when high

temperature strength or high temperature fatigue strength is given greater importance, an alloy in which the additive amount of Si is the same as or below the eutectic point has been used (see, for example, Patent Document 2).

PRIOR ARTS

PATENT DOCUMENTS

[0004]

Patent Document 1: Japanese Unexamined Laid-open Patent Application Publication No.H06-279904

Patent Document 2: Japanese Unexamined Laid-open Patent Application Publication No. 2001-181769

PROBLEMS TO BE SOLVED BY THE INVENTION

[0005] In the engine piston of aluminum alloy, however, in order to enhance the efficiency of the engine, it is preferable to enhance the high temperature strength and high temperature fatigue strength while maintaining the wear resistance.

[0006] The invention was made in view of the aforementioned technical background, and its purpose is to provide a method of producing a near-net-shape material for an engine piston of aluminum alloy excellent in wear resistance and high temperature characteristics and to provide the near-net-shape material for an engine piston.

[0007] Other objects and advantages of the present invention

will be apparent from the following preferable embodiments.

MEANS FOR SOLVING THE PROBLEMS

[0008] The present invention has the following means.

[0009] [1] A method of producing a near-net-shape material for an engine piston, the method including the steps of:

a continuous casting step of continuously casting a melt having a composition consisting of Si: 11.0 to 13.0 mass%, Fe: 0.6 to 1.0 mass%, Cu: 3.5 to 4.5 mass%, Mn: 0.25 mass% or less, Mg: 0.4 to 0.6 mass%, Cr: 0.15 mass% or less, Ni: 0.6 to $\{(-4/6) \times [\text{Cu mass\%}] + 5\}$ mass%, Zr: 0.07 to 0.15 mass%, P: 0.005 to 0.010 mass%, Ca: 0.002 mass% or less, and the balance being Al and inevitable impurities by setting a melt temperature before pouring the melt into a continuous casting mold to 720 °C or above to thereby obtain a cast rod having a diameter of 85 mm or less; and

a forging step of forging a forging material obtained by homogenizing the cast rod at a temperature of 300 to 500 °C to obtain a near-net-shape material for an engine piston.

[0010] [2] The method of producing a near-net-shape material for an engine piston as recited in claim 1, wherein an additive amount of P in the composition of the melt satisfies the following formula (1):

$$0.0025 \times \text{an additive amount of Si} - 0.025 \leq \text{an additive amount of P} \leq 0.0025 \times \text{the additive amount of Si} - 0.02 \quad \dots \text{Formula (1)}$$

where a unit of the additive amount of P and a unit of the

additive amount of Si are "mass%", respectively.

[0011] [3] A near-net-shape material for an engine piston produced by the method of producing a near-net-shape material for an engine piston as recited in the aforementioned Item [1] or [2], wherein there exists primary Si at least in a portion of the near-net-shape material corresponding to a skirt portion and a portion of the near-net-shape material corresponding to a piston ring groove portion, and wherein there exists no primary Si having a maximum diameter of 50 μm or more and no Al-Fe-Cr-Mn series gigantic crystal having a maximum diameter of 50 μm or more.

[0012] [4] A near-net-shape material for an engine piston produced by forging, wherein the near-net-shape material has a composition consisting of: Si: 11.0 to 13.0 mass%, Fe: 0.6 to 1.0 mass%, Cu: 3.5 to 4.5 mass%, Mn: 0.25 mass% or less, Mg: 0.4 to 0.6 mass%, Cr: 0.15 mass% or less, Ni: 0.6 to $\{(-4/6) \times [\text{Cu mass\%}] + 5\}$ mass%, Zr: 0.07 to 0.15 mass%, P: 0.005 to 0.010 mass%, Ca: 0.002 mass% or less, and the balance being Al and inevitable impurities.

[0013] [5] The near-net-shape material for an engine piston as recited in claim 4, wherein an additive amount of P in the composition of the near-net-shape material satisfies the following formula (1):

$$0.0025 \times \text{an addition amount of Si} - 0.025 \leq \text{an additive amount of P} \leq 0.0025 \times \text{the additive amount of Si} - 0.02 \quad \dots \text{Formula (1)}$$

where a unit of the additive amount of P and a unit of the

additive amount of Si are "mass%", respectively.

[0014] [6] The near-net-shape material for an engine piston as recited in the aforementioned Item [4] or [5], wherein there exists primary Si at least in a portion of the near-net-shape material corresponding to a skirt portion and a portion of the near-net-shape material corresponding to a piston ring groove portion, and wherein there exists no primary Si having a maximum diameter of 50 μm or more and no Al-Fe-Cr-Mn series gigantic crystal having a maximum diameter of 50 μm or more.

EFFECTS OF THE INVENTION

[0015] According to the present invention, by adjusting the additive amount of compositional elements of the melt so as to fall within a predetermined range and producing a near-net-shape material for an engine piston according to the production method of the present invention, a near-net-shape material for an engine piston of aluminum alloy excellent in wear resistance and high temperature characteristics can be obtained. Accordingly, in the engine piston produced from the near-net-shape material, it becomes possible to improve the performance efficiency of the engine and reduce a fuel usage in an automobile or a motorcycle.

[0016] Furthermore, in the near-net-shape material, since there exists primary Si at least at a skirt portion corresponding portion of the near-net-shape material or at a piston ring groove portion corresponding portion of the near-net-shape material, at

least these portions are excellent in wear resistance. Accordingly, in the engine piston produced by the near-net-shape material, wear resistance can be controlled at least at the skirt portion and the piston ring groove portion.

BRIEF EXPLANATION OF THE DRAWINGS

[0017]

[Fig. 1] Fig. 1 is a bottom view showing a near-net-shape material for an engine piston according to an embodiment of the present invention.

[Fig. 2] Fig. 2 is a front view of the near-net-shape material.

[Fig. 3] Fig. 3 is a cross-sectional view taken along the line X-X in Fig. 2.

[Fig. 4] Fig. 4 is a front view of an engine piston produced from the near-net-shape material.

[Fig. 5] Fig. 5 is a schematic cross-sectional view of a horizontal continuous casting device.

[Fig. 6] Fig. 6 is a schematic cross-sectional view of a hot-top continuous casting device.

[Fig. 7] Fig. 7 is a cross-sectional view of a mold constituting a forging device showing one example of a step of forging a forging material using the forging device.

[Fig. 8] Fig. 8 is a cross-sectional view of a mold constituting a forging device showing another example of a step of forging a forging material using the forging device.

[Fig. 9] Fig. 9 is a perspective view of an analysis sample of a melt of aluminum alloy.

[Fig. 10] Fig. 10 is a structure image of Example 1 photographed by microstructure observation.

[Fig. 11] Fig. 11 is a structure image of Comparative Example 3 photographed by microstructure observation.

[Fig. 12] Fig. 12 is a diagram showing a relation between the additive amount of P and the additive amount of Si in Examples 9-12 and Comparative Examples 17-24.

EMBODIMENTS FOR CARRYING OUT THE INVENTION

[0018] Next, the embodiment of the present invention will be detailed with reference to figures.

[0019] In this embodiment, "excellent in high temperature characteristics" denotes that the strength at 250 °C is excellent. In other words, it denotes that, at 250 °C, the tensile strength (i.e., high temperature tensile strength) is 120 MPa or more and the fatigue strength (i.e., high temperature fatigue strength) is 60 MPa or more.

[0020] In Figs. 1 to 3, "11" denotes a near-net-shape material for an engine piston of aluminum alloy according to an embodiment of the present invention.

[0021] In Fig. 4, "1" denotes an engine piston of aluminum alloy produced from the near-net-shape material 11.

[0022] In the following explanation, the explanation will be

made with the understanding that the direction from one of the upper and lower edges of the paper depicting Fig. 1 to the other is defined as a "fore-and-aft direction," the direction from one of the right and left edge of the paper depicting Fig. 1 to the other is defined as a "right-and-left direction," and the direction from one of the upper and lower edges of the paper depicting Figs. 2 and 3 is defined as an "up-and-down direction."

[0023] As shown in Fig. 4, the engine piston 1 is integrally provided with a crown face portion 2 circular in a plan view, a land portion 3 formed below the crown face portion, a pair of skirt portions 4 arranged below the land portion in an opposed manner, a pair of pin boss portions 5, and side wall portions 6. The land portion 3 has, at its outer peripheral surface, a plurality of piston ring groove portions 7 in which a plurality of piston rings (e.g., pressure rings, oil rings) are to be fitted.

[0024] As shown in Figs. 1 to 3, the near-net-shape material 11 for an engine piston is formed by forging, and, in the same manner as in the engine piston 1, is integrally provided with a portion corresponding to the crown face portion 2 (i.e., the crown face portion corresponding portion 12), a land portion corresponding portion 13 formed below the crown face portion corresponding portion, a pair of skirt portion corresponding portions 14 and 14 arranged below the land portion corresponding portion in an opposed manner, a pair of pin boss portion corresponding portions 15 and 15, and a side wall portion corresponding portions 16 and 16. The outer

peripheral surface of the land portion corresponding portion 13 and the inner side vicinity thereof is a portion in which a plurality of piston ring groove portions 7 are formed at the time of the final finish processing, i.e., a piston ring groove portion corresponding portion 17.

[0025] In this near-net-shape material 11, there exists primary Si at least at the skirt portion corresponding portion 14 and the piston ring groove portion corresponding portion 17. Furthermore, in the entire near-net-shape material, there exists no primary Si having a maximum diameter of 50 μm or more and no Al-Fe-Cr-Mn series gigantic crystal having a maximum diameter of 50 μm or more. In addition, in the entire near-net-shape material, there exists no segregation of primary Si.

[0026] In this embodiment, "there exists primary Si" specifically denotes that, for example, after mirror polishing of the material, when the mirror polished surface is subjected to microstructure observation under a metallograph, there exist gray-brown block-shaped crystals.

[0027] Here, the maximum diameter of primary Si is defined as a diameter measured at a portion where the primary Si becomes maximum in diameter. The maximum diameter of Al-Fe-Cr-Mn series gigantic crystal is defined as a diameter measured at a portion where the gigantic crystal becomes maximum in diameter.

[0028] A concrete method of measuring the maximum diameter of primary Si can be exemplified as follows. For example, after mirror

polishing of a test piece, when the mirror polished surface is subjected to a microstructure observation under a metallograph, recognizing a gray-brown block-shaped crystal as primary Si, the maximum length of the crystal is measured using an image analysis device to thereby obtain the maximum diameter of the primary Si. As the image analysis device, a product named LUZEX made by Nireco Corporation can be preferably used.

[0029] A concrete method of measuring the maximum diameter of Al-Fe-Cr-Mn series gigantic crystal can be exemplified as follows. For example, after mirror polishing of a test piece, when the mirror polished surface is subjected to a microstructure observation under a metallograph, recognizing a light gray color crystal as the Al-Fe-Cr-Mn series gigantic crystal, the maximum length of the gigantic crystal is measured using an image analysis device to thereby obtain the maximum diameter of the Al-Fe-Cr-Mn series gigantic crystal. As the image analysis device, a product named LUZEX made by Nireco Corporation can be preferably used.

[0030] In this embodiment, an Al-Fe-Cr-Mn series crystal having a maximum diameter of 50 μm or more among Al-Fe-Cr-Mn series crystals having various sizes will be specifically referred to as an Al-Fe-Cr-Mn series gigantic crystal. An Al-Fe-Cr-Mn series gigantic crystal is also called an Al-Fe-Cr-Mn series gigantic intermetallic compound (giant compound).

[0031] In the present invention, the criteria for determination on whether or not there exists segregation of primary

Si is not specifically limited. In this embodiment, however, as to the criteria for determination, in cases where there exists primary Si aggregation formed by 5 or more (preferably 3 or more) primary Si gathered and having at least one of the distance between the adjacent primary Si which is shorter than a diameter of the primary Si particle, it is determined that there exists primary Si. In cases where there exists no such primary Si aggregation, it is determined that there exists no segregation of primary Si.

[0032] Next, as a production method of a near-net-shape material for an engine piston according to one embodiment of the present invention, a production method of the aforementioned near-net-shape material 11 will be explained.

[0033] The production method of the near-net-shape material 11 includes a continuous casting step of continuously casting a melt of a predetermined composition to obtain a cast rod and a forging step of forging a forging material obtained by homogenizing the cast rod to obtain a near-net-shape material.

[0034] At the continuous casting step, it is required to continuously cast the melt by setting a melt temperature before pouring the melt into a continuous casting mold to 720 °C or above. Furthermore, the diameter of the cast rod to be obtained at this continuous casting step should be 85 mm or less.

[0035] The composition of the melt includes Si: 11.0 to 13.0 mass%, Fe: 0.6 to 1.0 mass%, Cu: 3.5 to 4.5 mass%, Mn: 0.25 mass% or less, Mg: 0.4 to 0.6 mass%, Cr: 0.15 mass% or less, Ni: 0.6 to

$\{(-4/6) \times [\text{Cu mass\%}] + 5\} \text{mass\%}$, Zr: 0.07 to 0.15 mass%, P: 0.005 to 0.010 mass%, Ca: 0.002 mass% or less, and the balance being Al and inevitable impurities.

[0036] At the forging step, the forging material should be a material obtained by homogenizing the cast rod at a temperature of 300 to 500 °C.

[0037] Hereinafter, the reasons for adding the composition elements of the aluminum alloy melt, the reasons for limiting the additive amount (concentration) thereof, and the reasons for limiting the production conditions of the near-net-shape material 11 will be explained.

[0038] <About Si: 11.0 to 13.0 mass%>

Si is an element for reducing the thermal expansion of the aluminum alloy and enhancing the wear resistance thereof. In other words, the wear resistance can be enhanced by controlling the crystallization of primary Si in an appropriate status.

[0039] The appropriate thermal expansion coefficient is determined by the material of the opposite member of the engine piston 1, i.e., the material (iron, or aluminum) of the cylinder block. However, since the cylinder block partially reaches a high temperature, but does not entirely reach a high temperature (or takes a time to reach a high temperature), and therefore it is preferable that the thermal expansion coefficient is as small as possible. In general, in designing the engine piston 1 and selecting a piston ring, they are designed or selected to have a

size when they reached a high temperature. For this reason, if the thermal expansion is excessively large, the skirt portion 4 becomes small in diameter when the temperature is low, which readily causes yawing of the engine piston 1 at the time of the engine start. Therefore, it is preferable that the additive amount of Si is as much as possible from the view point of reducing the thermal expansion. The preferable thermal expansion coefficient is $19 \times 10^{-6} / \text{K}$ to $21 \times 10^{-6} / \text{K}$ at the range of 25 to 250 °C, and the additive amount of Si to obtain such thermal expansion coefficient is 11.0 to 13.0 mass%.

[0040] On the other hand, such additive amount of Si conventionally caused unstable crystallization of primary Si due to continuous casting as follows. In detail, since the eutectic point of Al-Si alloy is normally 11.7 mass%, no primary Si will be crystallized at 11.0 mass%. For this reason, in cases where Si is added by an amount in the vicinity of the eutectic point, continuous casting could not be performed so that the primary Si crystallization status becomes stable. In other words, if the additive amount of Si fell within the range of, for example, 11.7 ± 0.5 mass%, the crystallization of primary Si due to continuous casting was conventionally unstable.

[0041] The present inventor, however, has found specific alloy compositions and production conditions capable of obtaining excellent high temperature strength and high temperature fatigue strength while maintaining wear resistance even in cases where Si

is added by an amount in the vicinity of the eutectic point.

[0042] That is, according to the composition of the melt of the present invention, by adding Ca or P, primary Si will be crystallized stably due to the mutual actions with them even in cases where Si is added by an amount in the vicinity of the eutectic point, which enables to improve the wear resistance. It is more preferable that the additive amount of Si exceeds 12.0 mass%.

[0043] If the additive amount of Si is less than 11.0 mass%, the thermal expansion becomes large and that crystallization of primary Si is restrained, resulting in poor wear resistance, which is not preferable.

[0044] If the additive amount of Si exceeds 13 mass%, the crystallized primary Si is aggregated to cause a starting point of fatigue breaking, deteriorating high temperature fatigue strength, which is not preferable.

[0045] Especially when forging a forging material obtained by homogenizing the cast rod at a predetermined temperature into a near-net-shape material for an engine piston, it is preferable that, at the outer peripheral portions of the cast rod corresponding to the skirt portion 4 and the piston ring groove portion 7 of the engine piston 1, the distribution state of the primary Si is even and the size of the primary Si is minute.

[0046] <About Fe: 0.6 to 1.0 mass%>

Fe is crystallized together with Cr and Mn into an Al-Fe-Cr-Mn series intermetallic compound, and the crystal becomes a dispersion

strengthening phase which is stable even at high temperatures, which contributes to improvement of the high temperature strength.

[0047] If the additive amount of Fe is less than 0.6 mass%, the amount of dispersion strengthening phase is small, resulting in less improvement of the high temperature strength, which is not preferable.

[0048] On the other hand, if the additive amount of Fe exceeds 1.0 mass%, needle-like Al-Fe-Cr-Mn series gigantic crystals will be generated to cause a starting point of fatigue breaking, deteriorating high temperature fatigue strength, which is not preferable.

[0049] In general, if Fe, Cr, and Mn are added in large amount, there is a possibility that an Al-Fe-Cr-Mn series gigantic crystal is generated to deteriorate high temperature fatigue strength. Considering it, in the present invention, in cases where the total amount of Fe, Cr and Mn is large, it is especially preferable that Cr and Mn are added so that the total additive amount of Cr and Mn is controlled to be 40% or less with respect to the additive amount of Fe. By doing so, even if the additive amount of Fe is large, it is possible to restrain crystallization of gigantic crystals.

[0050] Further, Fe will be crystallized into an Al-Fe-Ni-Cu series intermetallic compound stable even at high temperatures together with Al, Fe and Ni, which contributes to improvement of high temperature strength.

[0051] Therefore, it is specifically preferable to add Fe within a range in which no Al-Fe-Cr-Mn series gigantic crystal is generated.

[0052] <About Cr: 3.5 to 4.5 mass%>

 Cu will be crystallized into an Al-Cu(-Mg) series intermetallic compound, and the presence thereof enhances strength and fatigue strength at 150 °C or less (hereinafter referred to as normal temperature strength and normal temperature fatigue strength, respectively).

[0053] Further, Cu will be crystallized together with Al, Fe, and Ni into an Al-Fe-Ni-Cu series intermetallic compound which is stable even at high temperatures, which contributes to enhancement of high temperature strength.

[0054] If the additive amount of Cu is less than 3.5 mass%, the amount of deposit of an Al-Cu(-Mg) series intermetallic compound is small, and the amount of crystal of an Al-Fe-Ni-Cu series intermetallic compound is small, which is not preferable.

[0055] Cu is a heavy element, and therefore if the additive amount of Cu is large, the lightweight properties inherent in aluminum alloy will be deteriorated. Although the solid solubility limit of Cu is 5.65 mass%, even if Cu is added so as to exceed 4.5 mass%, less effect of enhancing normal temperature strength and normal temperature fatigue strength can be expected. Therefore, the upper limit of the additive amount of Cu is set to 4.5 mass%.

[0056] <About Mn: 0.25 mass% or less>

Mn is an element which will be crystallized together with Fe and/or Cr into an intermetallic compound, resulting in a dispersion strengthening phase to contribute to enhancement of high temperature strength. However, Mn readily creates an Al-Fe-Cr-Mn series gigantic crystal as compared with Fe. For this reason, the additive amount of Mn is set to 0.25 mass% or less. The additive amount of Mn is preferably as small as possible, more preferably less than detection limits. The most preferable additive amount of Mn is 0 mass%.

[0057] <About Mg: 0.4 to 0.6 mass%>

Mg is an element which enhances normal temperature strength and normal temperature fatigue strength when existed together with Si and/or Cu. If the additive amount of Mg is less than 0.4 mass%, the aforementioned effects become less effective, which is not preferable. Even if Mg is added so as to exceed 0.6 mass%, the aforementioned effect will be saturated. Therefore, the additive amount of Mg is set to 0.4 to 0.6 mass%.

[0058] <About Cr: 0.15 mass% or less>

Cr is an element which will be crystallized together with Fe and/or Mn into an intermetallic compound, resulting in a dispersion strengthening phase to contribute to enhancement of high temperature strength. However, Cr readily creates an Al-Fe-Cr-Mn series gigantic crystal as compared with Fe. For this reason, the additive amount of Cr is set to 0.15 mass% or less. The additive amount of Cr is preferably as small as possible, more preferably

less than detection limits. The most preferable additive amount of Cr is 0 mass%.

[0059] <About Ni: 0.6 to $\{(-4/6) \times [\text{Cu mass\%}] + 5\}\text{mass\%}$ >

As mentioned above, Ni will be crystallized together with Cu into an Al-Fe-Ni-Cu series intermetallic compound which is stable even at high temperatures and enhances high temperature strength and high temperature fatigue strength. Such crystal are preferably as much as possible. However, if the additive amount of Ni is less than 0.6 mass%, the aforementioned effect becomes less effective. Therefore, the additive amount of Ni is set to 0.6 mass% or more. On the other hand, if the additive amount of Ni exceeds $\{(-4/6) \times [\text{Cu mass\%}] + 5\}\text{mass\%}$, cracks will be generated during the forging step, and therefore it is not preferable. For this reason, the upper limit of the additive amount of Ni is set to $\{(-4/6) \times [\text{Cu mass\%}] + 5\}\text{mass\%}$. Therefore, if the additive amount of Cu is 3.5 mass% which is the lower limit, the upper limit of the additive amount of Ni is 2.7 mass%. Furthermore, if the additive amount of Cu is 4.5 mass% which is the upper limit, the upper limit of the additive amount of Ni is 2.0 mass%.

[0060] <About Zr: 0.07 to 0.15 mass%>

Zr is an element which will be crystallized at a temperature of 350 °C or more into an Al-Zr series intermetallic compound to enhance high temperature strength of an alloy material. If the additive amount of Zr is less than 0.07 mass%, the aforementioned effect becomes less effective. If the additive amount of Zr exceeds

0.15 mass%, the aforementioned effect will be saturated. For this reason, the additive amount of Zr is set to 0.07 to 0.15 mass%.

[0061] <About P: 0.005 to 0.010 mass%>

P is an element which moves the lower limit of the additive amount of Si at which primary Si is crystallized toward the lower amount of Si and miniaturizes the particle diameter of the crystal of primary Si. In cases where the additive amount of Si is relatively high, no addition of P causes rough primary Si. If the additive amount of P is less than 0.005 mass%, the aforementioned effect is less effective, and therefore it is not preferable. On the other hand, if the additive amount of P exceeds 0.010 mass%, the aforementioned effect is saturated, and needle-shaping of eutectic Si will be enhanced, resulting deteriorated toughness, which is not preferable. Therefore, the additive amount of P is set to 0.005 to .0010 mass%. By setting so, the maximum diameter of the primary Si can be controlled to 50 μm or less.

[0062] Especially, it is preferable that the additive amount of P satisfies the following formula (1). With this, crystallization of the primary Si due to continuous casting can be assuredly stabilized. As a result, it becomes possible to realize that primary Si assuredly exists in the entire near-net-shape material and also possible to assuredly prevent segregation of primary Si. Furthermore, eutectic Si can be assuredly formed into a spherical shape. As a result, a near-net-shape material for an engine piston excellent in wear

resistance and high temperature characteristics can be assuredly obtained.

[0063] $0.0025 \times \text{an additive amount of Si} - 0.025 \leq \text{the additive amount of P} \leq 0.0025 \times \text{the additive amount of Si} - 0.02$...Formula (1)

where a unit of the additive amount of P and a unit of the additive amount of Si are "mass%", respectively.

[0064] P alone is small in melting amount into a melt (i.e., additive amount of P) and is hard to handle. In order to increase the additive amount of P and enable easy handling, it is preferable that P is added to a melt in the form of P-Cu alloy (8 mass% of P, 92 mass% Cu of mother alloy).

[0065] <About Ca: 0.002 mass% or less>

Ca is an element which inhibits miniaturization and hardening of primary Si due to P. Therefore, flux including magnesium chloride (MgCl_2) is added to a melt and mixing them to reduce the amount of Ca in the melt so that the additive amount of Ca becomes 0.002 mass% or less. More preferably, the additive amount of Ca and P (unit: mass%) is set to $P > 6 \times \text{Ca}$. In this case, even in cases where Si is added by an amount in the vicinity of the eutectic point, P will not be depleted by Ca. This results in creation of AlP and, and this AlP effectively behaves as a nucleus for creating heterogeneous nucleus of primary Si, which makes it possible to crystallize primary Si minutely and evenly. As a result, the wear resistance can be enhanced. The additive amount of Ca is preferably

as small as possible, more preferably less than detection limits.
The most preferable additive amount of Ca is 0 mass%.

[0066] At the continuous casting step, the reason that the melt temperature is set to 720 °C or above is as follows.

[0067] Casting the melt before start solidification while holding it in a high temperature situation controls creation of an Al-Fe-Cr-Mn series gigantic crystal during the solidification step, and also contributes to miniaturization and even distribution of primary Si which will be crystallized in the cast rod. Therefore, the casting temperature is set to 720 °C or above. This can be realized by setting the melt temperature before pouring into a continuous casting mold to 720 °C or above. The more preferable melt temperature is 740 °C or above. By setting the melt temperature to 720 °C or above, at the time of forging the forging material obtained by homogenizing the cast rod into a near-net-shape material of an engine piston, the crystallization status of primary Si can be made to be miniaturized and even at the outer peripheral portion of the cast rod corresponding the skirt portion 4 and the piston ring groove portions 7 of the engine piston 1. The upper limit of the melt temperature is not specifically limited, and can be, for example, 850 °C (preferably 750 °C).

[0068] At the continuous casting step, the reason that the diameter of the cast rod is set to 85 mm or less is as follows.

[0069] If the diameter (i.e., the casting diameter) of the cast rod becomes larger, the cooling rate at the center of the ingot

becomes slow, which readily creates an Al-Fe-Cr-Mn series gigantic crystal and inhibits miniaturization and even distribution of primary Si at the center portion of the cast rod. If the diameter of the cast rod is 85 mm or less, the difference between the cooling rate at the center of the cast rod and the cooling rate at the outer peripheral portion thereof can be kept small, preferably 200 °C/s or less. This controls creation of an Al-Fe-Cr-Mn series gigantic crystal. Therefore, the diameter of the cast rod is set to 85 mm or less. By setting so, at the time of forging the forging material obtained by homogenizing the cast rod into a near-net-shape material for an engine piston, at the center portion of the cast rod corresponding to the crown face portion 2 of the engine piston 1, no Al-Fe-Cr-Mn series gigantic compound will exist, and the crystallization status of primary Si can be made to be minute and even such that the maximum diameter is less than 50 μm . The lower limit of the diameter of the cast rod is not specifically limited, and can be, for example, 20 mm.

[0070] The reason that the cast rod is homogenized at 300 to 500 °C is as follows.

[0071] As the area of the boundary phase between an Al-Si series crystal or an Al-Fe-Cr-Mn series crystal and the aluminum base increases, an Al-Fe-Cr-Mn series crystal functions as a resistance at the time of plastic deformation at high temperatures, which harms plastic deformation at high temperatures. As a result, high temperature strength and high temperature fatigue strength will

be enhanced.

[0072] However, a homogenization treatment generally performed to improve forging performance immediately below the solidus temperature is high in processing temperature, causing segmentation of the Al-Si series crystal or Al-Fe-Cr-Mn series crystal into a spherical shape, which reduces the area of the boundary phase. In the present invention, the upper limit of the treatment temperature is set to a temperature which does not cause segmentation of the Al-Si series crystal or Al-Fe-Cr-Mn series crystal into a spherical shape. However, if the homogenization treatment temperature is lowered excessively, deformability becomes insufficient at the time of forging, causing defects such as cracks. Therefore, the homogenization treatment temperature is set to 300 to 500 °C, more preferably set to a temperature as low as possible within a range in which the forging material does not cause cracks at the time of forming into the shape of the engine piston. The homogenization treatment time is preferable set to 4 hours or more in holding time. By performing a homogenization treatment of the cast rod under such treatment conditions, it becomes possible to assuredly keep the state in which no Al-Si series crystal or no Al-Fe-Cr-Mn series crystal will be segmented into a spherical shape. The upper limit of the holding time of the homogenization treatment time is not specifically limited, and can be, for example, within 24 hours.

[0073] Next, a continuous casting device used at the time of

continuously casting the melt will be explained.

[0074] As a continuous casting device, the type is not limited as long as it can obtain a cast rod of 85 mm or less in diameter in a state in which the melt temperature is maintained at 720 °C or more. For example, a vertical type semi-continuous casting device, a hot-top continuous casting device, a horizontal continuous casting device, or a gas pressure continuous casting device can be used.

[0075] Fig. 5 is a cross-sectional view showing an example of a horizontal continuous casting device for performing a horizontal continuous casting. This continuous casting device 20A is provided with a melt receptor 21 for storing an aluminum alloy melt 30 and a solidifying continuous casting water cooled mold (water cooled casting mold) 22 having a melt passage 22a. The mold 22 is arranged horizontally so as to be in fluid communication with the melt receptor 21 via the melt inlet 23. The reference numeral "24" denotes a cooling water passage formed in the mold 22. The mold 22 and the cast rod 31 drawn from the mold 22 are cooled with cooling water 25 injected from the cooling water passage 24.

[0076] Fig. 6 is a cross-sectional view showing an example of a hot-top continuous casting device. This continuous casting device 20B is provided with a melt receptor 21 and a solidifying continuous casting water cooled mold 22 arranged below the melt receptor 21 and having a melt passage 22a. The mold 22 is arranged so as to be in fluid communication with the melt receptor 21 via

the melt inlet 23 with the outlet of the melt passage 22a facing downward. In this continuous casting device 20B, the aluminum alloy melt 30 in the melt receptor 21 is introduced into the cooled mold 22 from the above via the melt inlet 23. The melt 30 introduced into the mold 22 is drawn downward from the mold 22 while forming a hard shell (solidified shell) at the portion in contact with the mold 22. The cast rod 31 drawn from the mold 22 is cooled with cooling water 25 injected from the cooling water passage 24.

[0077] In the present invention, in each of the aforementioned continuous casting devices 20A and 20B mentioned above, it is preferable that a melt temperature is 720 °C or more, wherein the melt temperature is defined as a temperature of the melt 30 at the position C immediately before a position where the melt 30 is introduced into the mold 22. In the column of [Example] which will be described later, the temperature of the melt 30 at this position C denotes the melt temperature.

[0078] Next, a homogenization treatment furnace used in homogenizing the forged rod will be explained below.

[0079] A homogenization treatment furnace can be any conventionally used furnace, such as, e.g., either a direct heating furnace or a radiant tubular furnace in the case of a circulation hot air furnace, or either a continuous furnace or a batch furnace in the case of a conveying type furnace, as long as it can accommodate the cast rod and perform a homogenization treatment at a treatment temperature of 300 to 500 °C.

[0080] Next, a forging device used for forging a forging material will be explained below.

[0081] A forging device can be any device equipped with a forging mold for forging a forging material into a near-net-shape material of an engine piston. It is especially preferable that the forging device is further provided with a preheat treatment device and a lubricant applying device. The forging mold is preferably a closed forging mold. Specifically, as a forging device, a knuckle press, a crank press, a friction press, a hydraulic press, and a serve press can be used.

[0082] A production method of a near-net-shape material according to the embodiment will be carried out as follows.

[0083] Using a continuous casting device, a melt having a predetermined composition is continuously cast into a cast rod of 85 mm or less at a melt temperature of 720 °C or more [Continuous Casting Step]. The cross-sectional shape of this cast rod is preferably a round shape, i.e., the cast rod is preferably a round rod shape.

[0084] Next, by subjecting the cast rod to a homogenization treatment at a temperature of 300 to 500 °C, a forging material is obtained. In the material, after the homogenization treatment, the outer peripheral surface of the material is subjected to a peeling treatment (outer peripheral surface cutting treatment) as needed. Thereafter, the material is cut in the longitudinal direction of the material into a predetermined length (thickness)

to obtain a circular plate or a circular column. The cut surfaces of the cast rod are defined as an upper surface and a lower surface of the material, and the outer peripheral surface of the cast rod or the inner vicinity thereof is defined as an outer peripheral surface of the material. This material is subjected to an upset treatment, a lubrication treatment and a preheat treatment as needed.

[0085] Next, the material is forged into a near-net-shape material of an engine piston shape [Forging Step].

[0086] Figs. 7 and 8 are figures showing forging steps for forging a material using a forging device.

[0087] The molds 41 of the forging devices 40 shown in Figs. 7 and 8 are each constituted by an upper mold 42 and a lower mold 43. When the upper and lower molds 42 and 43 are fitted with each other, a circular plate or a circular column material 32 is forged within a closed forming space 44. Thus, a near-net-shape material 11 for an engine piston can be obtained.

[0088] In Fig. 7, the reference numeral 32A denotes a long forging rod shaped material 32A obtained by homogenizing the cast rod 31. A circular plate or circular column material 32 obtained by cutting the rod shaped material 32A into a predetermined length (thickness) is arranged in the lower mold 43 of the forging device 40 and thereafter pressed in the axial direction of the material 32 with the upper mold 42 fitted in the lower mold 43. Thus, the material 32 is forged into a predetermined shape in the closed

forming space 44. As a result, a near-net-shape material 11 for an engine piston can be obtained. The mold 41 of the forging device 40 shown in Fig. 7 is configured to extrude forward the skirt portion corresponding portion (not illustrated) and the pin boss portion corresponding portion 15 and 15.

[0089] In Fig. 8, in the same manner as in the forging method shown in Fig. 7, the material 32 is forged to obtain a near-net-shape material 11 for an engine piston. The mold 41 of the forging device 40 shown in Fig. 8 is configured to extrude rearward the skirt portion corresponding portion (not illustrated) and the pin boss portion corresponding portion 15 and 15.

[0090] As shown in Figs. 7 and 8, the material 32 is arranged in the lower mold 43 so that the upper or lower surface of the material 32 is formed into a crown face portion corresponding portion 12 of the near-net-shape material 11 and that the outer peripheral surface of the material 32 is formed into the piston ring groove portion corresponding portion 17 and the skirt portion corresponding portion (not illustrated).

[0091] It is preferable that the treatment temperature of the preheating treatment to be performed immediately before the forging and the material temperature at the time of the forging are 470 °C or below and kept as short as possible. Especially, the temperature is preferably lower than a homogenization treatment temperature. Furthermore, as a heating time, the heating time can be a shortest time capable of increasing the material temperature to the treatment

temperature (i.e., 470 °C or below). Such a low temperature and short time treatment can maintain the status of the homogenized Al-Si series crystal or Al-Fe-Cr-Mn series crystal even after the forging.

[0092] The obtained near-net-shape material 11 is subjected to a solution treatment and an aging treatment as needed.

[0093] The solution treatment temperature is preferably the same or below the solidus temperature. The reason is that the status of the homogenized Al-Si series crystal or Al-Fe-Cr-Mn series crystal can be maintained.

[0094] As to the aging temperature and aging time, it is preferable to adjust the temperature and time so as to perform the aging treatment slightly excessively. By doing so, the size growth due to the aging at the time of using the product can be inhibited.

[0095] This near-net-shape material 11 is subjected to final finish processing by machine processing or the like and then matured into an engine piston by being attached by another parts such as piston rings.

[0096] The near-net-shape material 11 produced in accordance with the production method of the near-net-shape material of this embodiment as explained above has no cracks in the crown face portion corresponding portion 12 at the time of the forging processing, there appropriately exists primary Si at least at the skirt portion corresponding portion 14 and the piston ring groove portion corresponding portion 17, there exists no primary Si having a

maximum diameter of 50 μm or more, there exists no segregation of primary Si, and there exists no Al-Fe-Cr-Mn series gigantic crystal having a maximum diameter of 50 μm or more. Therefore, an engine piston 1 produced using this near-net-shape material 11 is excellent in wear resistance and also excellent in normal temperature tensile characteristics and high temperature characteristics (i.e., high temperature tensile characteristics, high temperature fatigue characteristics).

[0097] Although an embodiment of the present invention was explained above, the present invention is not limited to the embodiment and be changed in a various manner within a range not deviating from the gist of the present invention.

[EXAMPLES]

[0098] Next, concrete Examples and Comparative Examples of the present invention will be shown. It should be noted that the present invention is not limited to the following examples.

[0099] <Examples 1-8, Comparative Examples 1-16>

[0100]

[Table 1]

	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zr	P	Ca
Invention range	11.0- 13.0	0.6- 1.0	3.5- 4.5	≤ 0.25	0.4- 0.6	≤ 0.15	0.6- A	0.07- 0.15	0.005- 0.010	≤0.002
Example 1	11.86	0.81	4.46	0.00	0.60	0.00	2.00	0.11	0.009	0.001
Example 2	12.85	0.95	4.43	0.24	0.55	0.10	2.00	0.14	0.009	0.000
Example 3	11.20	0.64	3.64	0.00	0.41	0.00	0.65	0.08	0.006	0.000
Example 4	11.86	0.81	4.46	0.00	0.60	0.00	2.00	0.11	0.009	0.001
Example 5	11.86	0.81	4.46	0.00	0.60	0.00	2.00	0.11	0.009	0.001
Example 6	11.86	0.81	4.46	0.00	0.60	0.00	2.00	0.11	0.009	0.001
Example 7	11.86	0.81	4.46	0.00	0.60	0.00	2.00	0.11	0.009	0.001
Example 8	12.85	0.95	3.50	0.24	0.55	0.10	2.66	0.14	0.009	0.000
Comp. Ex. 1	10.20	0.81	4.46	0.00	0.60	0.00	2.00	0.11	0.009	0.001
Comp. Ex. 2	15.10	0.81	4.46	0.00	0.60	0.00	2.00	0.11	0.009	0.001
Comp. Ex. 3	11.86	1.82	4.46	0.00	0.60	0.00	2.00	0.11	0.009	0.001
Comp. Ex. 4	11.86	0.81	4.46	0.26	0.60	0.20	2.00	0.11	0.009	0.001
Comp. Ex. 5	11.86	0.81	2.80	0.00	0.25	0.00	2.00	0.11	0.009	0.001
Comp. Ex. 6	11.86	0.81	4.46	0.00	0.60	0.00	2.00	0.04	0.009	0.001
Comp. Ex. 7	11.86	0.43	4.46	0.00	0.60	0.00	2.00	0.11	0.009	0.001
Comp. Ex. 8	11.00	0.81	4.46	0.00	0.60	0.00	2.00	0.11	0.000	0.001
Comp. Ex. 9	12.80	0.81	4.46	0.00	0.60	0.00	2.00	0.11	0.000	0.001
Comp. Ex. 10	11.86	0.81	4.46	0.00	0.60	0.00	2.00	0.11	0.009	0.010
Comp. Ex. 11	11.86	0.81	4.46	0.00	0.60	0.00	2.00	0.11	0.009	0.001
Comp. Ex. 12	11.86	0.81	4.46	0.00	0.60	0.00	2.00	0.11	0.009	0.001
Comp. Ex. 13	11.86	0.81	4.46	0.00	0.60	0.00	2.00	0.11	0.009	0.001
Comp. Ex. 14	11.86	0.81	4.46	0.00	0.60	0.00	2.00	0.11	0.009	0.001
Comp. Ex. 15	11.86	0.81	4.46	0.00	0.60	0.00	0.00	0.11	0.009	0.001
Comp. Ex. 16	11.86	0.81	4.46	0.00	0.60	0.00	3.00	0.11	0.009	0.001

[0101]

[Table 2]

	Melt temp.	Diameter of cast rod (mm)	Homogenization Temp (°C)	Cracks	Presence or absence of Primary Si	Presence or absence of primary Si of 50 μm or more	Presence or absence of giantic crystal	Presence or absence of segregation of primary Si	Normal temperature tensile characteristics	High temperature tensile characteristics	High temperature fatigue characteristics
Invention	≥720°C	≤φ85	300-50								
Example 1	750	55	470	Nil	Existed	Absence	Absence	Absence	Good	Good	Good
Example 2	750	55	470	Nil	Existed	Absence	Absence	Absence	Good	Good	Good
Example 3	750	55	470	Nil	Existed	Absence	Absence	Absence	Good	Good	Good
Example 4	720	55	470	Nil	Existed	Absence	Absence	Absence	Good	Good	Good
Example 5	750	85	470	Nil	Existed	Absence	Absence	Absence	Good	Good	Good
Example 6	750	55	300	Nil	Existed	Absence	Absence	Absence	Good	Good	Good
Example 7	750	55	500	Nil	Existed	Absence	Absence	Absence	Good	Good	Good
Example 8	750	55	470	Nil	Existed	Absence	Absence	Absence	Good	Good	Good
Comp. Ex. 1	750	55	470	Nil	Absence	Absence	Absence	Absence	Good	Good	Good
Comp. Ex. 2	750	55	470	Generated	Existed	Absence	Absence	Existed	-	-	-
Comp. Ex. 3	750	55	470	Generated	Existed	Absence	Existed	Absence	-	-	-
Comp. Ex. 4	750	55	470	Generated	Existed	Absence	Existed	Absence	Good	Good	Not good
Comp. Ex. 5	750	55	470	Nil	Existed	Absence	Absence	Absence	Not good	Good	Good
Comp. Ex. 6	750	55	470	Nil	Existed	Absence	Absence	Absence	Good	Not good	Not good
Comp. Ex. 7	750	55	470	Nil	Existed	Absence	Absence	Absence	Good	Not good	Not good
Comp. Ex. 8	750	55	470	Nil	Absence	Absence	Absence	Absence	Good	Good	Good
Comp. Ex. 9	750	55	470	Nil	Existed	Existed	Absence	Absence	Good	Good	Good
Comp. Ex. 10	750	55	470	Nil	Existed	Existed	Absence	Absence	Good	Good	Good
Comp. Ex. 11	680	55	470	Nil	Existed	Absence	Absence	Existed	Good	Good	Good
Comp. Ex. 12	750	120	470	Nil	Existed	Existed	Absence	Absence	Good	Good	Good
Comp. Ex. 13	750	55	250	Generated	Existed	Absence	Absence	Absence	-	-	-
Comp. Ex. 14	750	55	550	Generated	Existed	Absence	Absence	Absence	-	-	-
Comp. Ex. 15	750	55	470	Nil	Existed	Absence	Absence	Absence	Good	Not good	Good
Comp. Ex. 16	750	55	470	Generated	Existed	Absence	Absence	Absence	-	-	-

[0102]

In Table 1, the unit of each composition element is

"mass%". In the column of Ni in Table 1, "A" denotes $\{(-4/6) \times [\text{Cu mass\%}] + 5\} \text{mass\%}$.

[0103] The Al alloy melt having a composition shown in Table 1 was continuously cast using a hot-top continuous casting device (see Fig. 6) to obtain a cast rod having a round rod shape. In the continuous casting, the melt temperatures before pouring the continuous casting mold were set as described in the "Melt temp." in Table 2. The diameter of the obtained cast rod is shown in the column of "Diameter of cast rod" in Table 2.

[0104] In casting, a melt was poured into a mold according to JIS Z 2611 to obtain an analysis sample 50 of an approximately disk shape as shown in Fig. 9. Using this analysis sample 50, the composition elements of the melt was subjected to quantitative analysis by emission spectrochemical analysis according to JIS H 1305. In Fig. 9, "51" denotes a portion to be analyzed. This portion 51 was cut with a milling machine about 0.5 mm (0.3-0.6mm) and then analyzed. The dimensions of each portion of the analysis sample 50 were A=50 mm, B=30 mm, C=18mm, D=5mm, E=5mm, and F=35mm.

[0105] Next, the cast rod was cut into a length of 6,000 mm. Then, the cut cast rod was homogenized. In this homogenization treatment, the treatment temperatures were set as described in the column of "Homogenization Temp" in Table 2. The treatment time was 7 hours in each case.

[0106] Thereafter, the cast rod was cut to remove the outer periphery to have a diameter of 50 mm. Further, the cast rod was

cut into a length of 60 mm to obtain a circular columnar shaped forging material.

[0107] Next, this material was pre-heated at 420 °C, and then the material was pressurized from its end face in the axial direction to upset forge the material into a thickness of 10 mm. This upset forging corresponds to the forging at the forging step of the present invention and was performed at a forge processing rate corresponding to the forge processing rate at the time of actually forging a material into a near-net-shape material for an engine piston.

[0108] Thereafter, the upset forged product was subjected to a T6 heat treatment. Concretely, the upset forged product was subjected to a solution treatment at 495 °C and then to artificial aging under the conditions of the aging temperature of 200 °C and the aging time of 6 hours.

[0109] With respect to the upset forged product to which a T6 heat treatment was subjected, it was visually examined to confirm whether there exist surface cracks and hole defects in the upset forged product by a solvent removal penetrant test (color check). Thereafter, the upset forged product was cut, the cut surface was mirror polished, and the microstructure of the mirror polished surface was observed from the center portion of the upset forged product to the outer peripheral portion using a metallograph to check whether there exist primary Si, primary Si having a maximum diameter of 50 μm or more, Al-Fe-Cr-Mn series gigantic crystal and segregation of primary Si. These results are shown in the column

of "Presence or absence of Primary Si", the column of "Presence or absence of primary Si 50 μm or more", the column of "Presence or absence of gigantic crystal" and the column of "Presence or absence of segregation of primary Si" in Table 2. "In each of Examples 1-8, there existed primary Si in the entire upset forged product. Further, the upset forged product to which a T6 heat treatment was subjected was evaluated in normal temperature tensile characteristics, high temperature tensile characteristics and high temperature fatigue characteristics.

[0110] Among structural images of Examples 1-8 photographed at the microstructure observation, a structure image of Example 1 is shown in Fig. 10 as an example. Among structural images of Comparative Examples 1-16 photographed at the microstructure observation, a structure image of Comparative Example 3 is shown in Fig. 11 as an example. As an image analyzing device analyzed the image of the structure image, a device called LUZEX made by a Nireco Corporation was used.

[0111] In the structure image, the Al-Fe-Cr-Mn series crystal is a light gray color crystal, the primary Si is a gray-brown block-shaped crystal, and eutectic Si is a gray-brown crystal smaller than primary Si and having an average grain diameter of about 5 μm . In cases where there exists Al-Fe-Ni-Cu series crystal in the upset forged product, in the structural image, the Al-Fe-Ni-Cu series crystal is observed as a crystal of a gray color lighter than the Al-Fe-Cr-Mn series crystal.

[0112] In the case shown in Fig. 10 (Example 1), there existed many eutectic Si in a dispersed manner, and the average grain diameter thereof was about 5 μm . There existed many primary Si in a dispersed manner and the maximum grain diameter thereof was about 25 μm and the average grain diameter was about 20 μm . However, there existed no primary Si having a maximum diameter of 50 μm or more. There existed many Al-Fe-Cr-Mn series crystal in a dispersed manner, and the average grain diameter was about 5 μm . However, there existed no Al-Fe-Cr-Mn series gigantic crystal having a maximum diameter of 50 μm or more. Further, there existed many Al-Fe-Ni-Cu series crystals in a dispersed manner, and the average grain diameter was about 5 μm .

[0113] In the case shown in Fig. 11 (Comparative Example 3), there existed many eutectic Si in a dispersed manner, and the average grain diameter was about 5 μm . There existed primary Si in an unevenly distributed manner, the maximum diameter was about 35 μm , and the average grain diameter was about 20 μm . There existed two kinds of Al-Fe-Cr-Mn series crystals. Between them, one of them was a crystal having an average grain diameter of about 5 μm , and there existed many such crystals in a dispersed manner. The other of them was a block shaped crystal having an average grain diameter of about 60 μm , and there existed Al-Fe-Cr-Mn series gigantic crystal having a maximum grain diameter of 50 μm or more.

[0114] The evaluation method of the normal temperature tensile characteristics was as follows.

[0115] A JIS 14A comparative test piece was obtained from the upset forged product to which a T6 heat treatment was performed, and the tensile strength of this test piece at 25 °C was measured. When the tensile strength was 350 MPa or more, it was evaluated as "Good", while the tensile strength was less than 350MPa, it was evaluated as "Not Good". The results are shown in the column of "Normal temperature tensile characteristics" in Table 2.

[0116] The evaluation method of the high temperature tensile characteristics was as follows.

[0117] After holding an upset forged product to which a T6 heat treatment was performed at 250 °C for 100 hours, a JIS 14A comparative flanged test piece was obtained from the upset forged product. At the time of the strength test, after holding the test piece at 250 °C for 15 minutes, the tensile strength of the test piece was measured at 250 °C. When the tensile strength was 120 MPa or more, it was evaluated as "Good", while when the tensile strength was less than 120 MPa, it was evaluated as "Not Good". The results are shown in the column of "High temperature tensile characteristics" in Table 2.

[0118] The evaluation method of the high temperature fatigue characteristics was as follows.

[0119] After holding an upset forged product to which a T6 heat treatment was performed at 250 °C for 100 hours, a fatigue test piece was obtained from the upset forged product. A fatigue test of the test piece was performed at 250 °C with a Ono type rotary

bending fatigue testing machine. A stress value at which no fracture occurs even at 10,000,000 cycles is defined as a fatigue strength. When the stress value was 60 MPa or more, it was evaluated as "Good", while when the stress value was less than 60 MPa, it was evaluated as "Not Good". The results are shown in the column of "High temperature fatigue characteristics" in Table 2.

[0120] In Examples 1-8, since they satisfy all of the requirements of the present invention, no crack was formed, there existed primary Si entirely in the upset forged product, there existed no primary Si having a maximum diameter of 50 μm or more, there existed no Al-Fe-Cr-Mn series gigantic crystal having a maximum diameter of 50 μm or more, and there existed no segregation of primary Si. Further, they were excellent in normal temperature tensile characteristics, high temperature tensile characteristics, and high temperature fatigue characteristics.

[0121] In Comparative Example 1, since the additive amount of Si was small, there existed no primary Si.

[0122] In Comparative Example 2, since the additive amount of Si was too much, primary Si was segregated. Since the grain diameter of the primary Si was large, cracks starting from the primary Si occurred at the time of the upset forging.

[0123] In Comparative Example 3, since the additive amount of Fe was too much, Al-Fe-Cr-Mn series gigantic crystals were generated, and cracks starting from the gigantic crystals occurred at the time of the upset forging.

[0124] In Comparative Example 4, since the additive amounts of Mn and Cr were too much, Al-Fe-Cr-Mn series gigantic crystals were generated, and cracks starting from the gigantic crystals occurred at the time of the upset forging.

[0125] In Comparative Example 5, since the additive amounts of Cu and Mg were too small, the normal tensile characteristics were deteriorated.

[0126] In Comparative Example 6, since the additive amount of Zr was too small, high temperature tensile characteristics and high temperature fatigue characteristics were deteriorated.

[0127] In Comparative Example 7, since the additive amount of Fe was too small, high temperature tensile characteristics and high temperature fatigue characteristics were deteriorated.

[0128] In Comparative Example 8, since the additive amount of Si was too small and no P was added, there existed no primary Si.

[0129] In Comparative Example 9, since the additive amount of Si was rather large and no P was added, the primary Si grew up.

[0130] In Comparative Example 10, since the additive amount of Ca was not reduced by flux, the primary Si grew up.

[0131] In Comparative Example 11, since the melt temperature was too low, segregation of primary Si occurred.

[0132] In Comparative Example 12, since the diameter of the cast rod was too big, the primary Si located at the center of the upset forged product grew up.

[0133] In Comparative Example 13, since the homogenization

treatment temperature was too low, eutectic Si, etc. were not sufficiently formed into a spherical shape, caused cracks at the time of the upset forging.

[0134] In Comparative Example 14, since the homogenization treatment temperature was too high, eutectic melting occurred by preheating before the upset forging, caused cracks starting the molten portion at the time of the upset forging.

[0135] In Comparative Example 15, since the additive amount of Ni was too small, there existed smaller amount of crystals stable even at high temperatures. Therefore, high temperature tensile characteristics were deteriorated.

[0136] In Comparative Example 16, since the additive amount of Ni was too much and exceeded $\{(-4/6) \times [\text{Cu mass\%}] + 5\} \text{mass\%}$, caused cracks at the time of upset forging.

[0137] <Examples 9-12, and Comparative Examples 17-24>

[0138]

[Table 3]

	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zr	P	Ca
Invention range	11.0-13.0	0.6-1.0	3.5-4.5	$\leq$ 0.25	0.4-0.6	$\leq$ 0.15	0.6-A	0.07-0.15	0.005-0.010	$\leq$ 0.002
Ex. 9	11.20	0.64	3.64	0.00	0.41	0.00	0.11	0.08	0.005	0.000
Ex. 10	12.55	0.81	4.46	0.00	0.60	0.00	0.11	0.11	0.007	0.001
Ex. 11	12.85	0.82	4.45	0.00	0.61	0.00	0.11	0.10	0.010	0.000
Ex. 12	11.20	0.64	3.64	0.00	0.41	0.00	0.11	0.08	0.007	0.000
Comp. Ex. 17	10.20	0.81	4.46	0.00	0.60	0.00	0.11	0.11	0.001	0.001
Comp. Ex. 18	11.86	0.81	4.46	0.00	0.60	0.00	0.11	0.11	0.003	0.001
Comp. Ex. 19	14.30	0.81	4.46	0.00	0.60	0.00	0.11	0.11	0.006	0.001
Comp. Ex. 20	14.30	0.81	4.46	0.00	0.60	0.00	0.11	0.11	0.010	0.001
Comp. Ex. 21	14.30	0.81	4.46	0.00	0.60	0.00	0.11	0.11	0.015	0.001
Comp. Ex. 22	11.86	0.81	4.46	0.00	0.60	0.00	0.11	0.11	0.015	0.001
Comp. Ex. 23	10.20	0.81	4.46	0.00	0.60	0.00	0.11	0.11	0.007	0.001
Comp. Ex. 24	10.20	0.81	4.46	0.00	0.60	0.00	0.11	0.11	0.004	0.001

[0139]

[Table 4]

	Presence or absence of primary Si		Presence or absence of segregation of primary Si	Shape of eutectic Si	Evaluation
	Center portion	Outer periphery			
Ex. 9	Existed	Existed	Absence	Spherical	o
Ex. 10	Existed	Existed	Absence	Spherical	o
Ex. 11	Existed	Existed	Absence	Spherical	o
Ex. 12	Existed	Existed	Absence	Spherical	o
Comp. Ex. 17	Absence	Absence	-	Spherical	x
Comp. Ex. 18	Existed	Absence	Absence	Spherical	x
Comp. Ex. 19	Existed	Existed	Existed	Spherical	x
Comp. Ex. 20	Existed	Existed	Existed	Spherical	x
Comp. Ex. 21	Existed	Existed	Existed	Spherical	x
Comp. Ex. 22	Existed	Existed	Absence	Needle shape	x
Comp. Ex. 23	Absence	Absence	-	Spherical	x
Comp. Ex. 24	Absence	Absence	-	Spherical	x

[0140] In Table 3, the units of the composition elements are "mass%" respectively. In the column of Ni in Table 3, "A" denotes $\{(-4/6) \times [\text{Cu mass\%}] + 5\}\text{mass\%}$.

[0141] Fig. 12 is a diagram showing the relation between the additive amount of P and the additive amount of Si in Examples 9-12

and Comparative Examples 17-24. In the formulas shown in this figure, [P] denotes an additive amount of P (unit: mass%) and [Si] denotes an additive amount of Si (unit: mass%).

[0142] The Al alloy melt having the composition shown in Table 3 was continuously cast using a hot-top continuous casting device (see Fig.6) to obtain a round rod-shaped cast rod. In this continuous casting, the melt temperature before pouring into the continuous casting mold was set to 750 °C and the diameter of the cast rod was set to 55 mm.

[0143] In casting, the melt was poured into the mold in accordance with JIS Z 2611 to obtain an analysis sample 50 having an approximately disk shape as shown in Fig. 9. Using this analysis sample 50, the composition elements of the melt was quantitatively analyzed according to JIS H 1305.

[0144] Next, the cast rod was cut into a length of 6,000 mm. Then, the cut cast rod was homogenized under the conditions of the treatment temperature of 470 °C and the holding time of 7 hours.

[0145] Thereafter, the cast rod was cut to remove the outer periphery to have a diameter of 50 mm. Further, the cast rod was cut into a length of 60 mm to obtain a round columnar shaped forging material.

[0146] Next, this material was preheated to 420 °C and then pressurized from its end face in the axial direction to perform upset forging into a thickness of 10 mm. This upset forging corresponds to the forging at the forging step of the present

invention, and the upset forging was performed at the forge processing rate corresponding to the forge processing rate at the time of actually forging the material into a near-net-shape material for an engine piston.

[0147] Thereafter, the upset forged product was subjected to a T6 heat treatment. In detail, the upset forged product was subjected to a solution treatment at 495 °C and then to artificial aging under the conditions of the aging temperature of 200° C and the aging time of 6 hours.

[0148] The upset forged product to which a T6 heat treatment was subjected was cut and the cut surface was mirror polished, and the microstructure of the mirror polished surface was observed from the center portion of the upset forged product to the outer peripheral portion using a metallograph to check whether there existed primary Si, segregation of primary Si, and the shape of eutectic Si.

[0149] As to the presence or absence of primary Si, it was judged based on whether there existed gray-brown block-shaped crystals when microstructure observation was performed.

[0150] As to the presence or absence of segregation of primary Si, it was judged that there existed segregation of primary Si when three or more primary Si were gathered and there existed a primary Si aggregation in which at least one of distances between primary Si is shorter than the grain diameter of primary Si, and judged that there existed no segregation of primary Si when there existed

no such primary Si aggregation.

[0151] Eutectic Si is a gray-brown crystal smaller than primary Si. When the size of eutectic crystal was measured, if "maximum length"/"minimum length" is 3 or more, it was judged that eutectic Si was formed into a needle-shape. If the ratio was less than 3, it was judged that eutectic Si was formed into a spherical shape.

[0152] In the column of "Evaluation" in Fig. 12, "o" denotes that it is suitable for a near-net-shape material for an engine piston, and "x" denotes that it is not suitable.

[0153] As shown in Table 4 and Fig. 12, in Examples 9-12, the additive mount of Si was within the range of 11.0 to 13.0 mass%, the additive amount of P was within the range of 0.005 to 0.010 mass%, and the additive amount of P satisfied the aforementioned formula (1). Therefore, the crystallization of primary Si due to continuous casting becomes stable. As a result, primary Si entirely existed from the center portion of the upset forged product to the outer peripheral portion thereof, and there existed no segregation of primary Si. Furthermore, eutectic Si was formed into a spherical shape. Accordingly, an excellent microstructure was obtained.

[0154] In Comparative Examples 17, 23, and 24, since the additive amount of Si was too small, primary Si was partially existed in the upset forged product, i.e., primary Si was not entirely existed in the upset forged product.

[0155] In Comparative Example 18, although the additive amount of Si was within the range of the present invention, since the additive amount of P was too small, primary Si existed only at the center portion of the upset forged product and no primary Si was existed at the outer peripheral portion.

[0156] In Comparative Examples 19, 20, and 21, since the additive amount of Si was too much, segregation of primary Si occurred.

[0157] In Comparative Example 22, although the additive amount of Si was within the range of the present invention, since the additive amount of P was too much, eutectic Si was formed into a needle-shape. Thus, the toughness of the upset forged product was low.

[0158] This application claims priority to Japanese Patent Application No. 2009-250278 filed on October 30, 2009, and the entire disclosure of which is incorporated herein by reference in its entirety.

[0159] It should be understood that the terms and expressions used herein are used for explanation and have no intention to be used to construe in a limited manner, do not eliminate any equivalents of features shown and mentioned herein, and allow various modifications falling within the claimed scope of the present invention.

[0160] While the present invention may be embodied in many different forms, a number of illustrative embodiments are described

herein with the understanding that the present disclosure is to be considered as providing examples of the principles of the invention and such examples are not intended to limit the invention to preferred embodiments described herein and/or illustrated herein.

[0161] While illustrative embodiments of the invention have been described herein, the present invention is not limited to the various preferred embodiments described herein, but includes any and all embodiments having equivalent elements, modifications, omissions, combinations (e.g., of aspects across various embodiments), adaptations and/or alterations as would be appreciated by those in the art based on the present disclosure. The limitations in the claims are to be interpreted broadly based on the language employed in the claims and not limited to examples described in the present specification or during the prosecution of the application, which examples are to be construed as non-exclusive. For example, in the present disclosure, the term "preferably" is non-exclusive and means "preferably, but not limited to." Means-plus-function or step-plus-function limitations will only be employed where for a specific claim limitation all of the following conditions are present in that limitation: a) "means for" or "step for" is expressly recited; b) a corresponding function is expressly recited; and c) structure, material or acts that support that structure are not recited. In this disclosure and during the prosecution of this application,

the terminology "present invention" or "invention" may be used as a reference to one or more aspect within the present disclosure. The language present invention or invention should not be improperly interpreted as an identification of criticality, should not be improperly interpreted as applying across all aspects or embodiments (i.e., it should be understood that the present invention has a number of aspects and embodiments), and should not be improperly interpreted as limiting the scope of the application or claims. In this disclosure and during the prosecution of this application, the terminology "embodiment" can be used to describe any aspect, feature, process or step, any combination thereof, and/or any portion thereof, etc. In some examples, various embodiments may include overlapping features. In this disclosure and during the prosecution of this case, the following abbreviated terminology may be employed: "e.g." which means "for example;" and "NB" which means "note well."

INDUSTRIAL APPLICABILITY

[0162] The present invention can be used for a production method of producing a near-net-shape material for an engine piston to be mounted on a vehicle such as an automobile or a motorcycle and a near-net-shape material for an engine piston.

DESCRIPTION OF THE REFERENCE NUMERALS

[0163]

1	engine piston
2	crown face portion
4	skirt portion
7	piston ring groove portion
11	near-net-shape material for an engine piston
12	crown face portion corresponding portion
14	skirt portion corresponding portion
17	piston ring portion corresponding portion
20A	horizontal continuous casting device
20B	hot-top continuous casting device
22	continuous casting mold
30	melt
31	cast rod
32	forging material
40	forging device

CLAIMS

1. A method of producing a near-net-shape material for an engine piston, the method including the steps of:

a continuous casting step of continuously casting a melt having a composition consisting of Si: 11.0 to 13.0 mass%, Fe: 0.6 to 1.0 mass%, Cu: 3.5 to 4.5 mass%, Mn: 0.25 mass% or less, Mg: 0.4 to 0.6 mass%, Cr: 0.15 mass% or less, Ni: 0.6 to $\{(-4/6) \times [\text{Cu mass\%}] + 5\}$ mass%, Zr: 0.07 to 0.15 mass%, P: 0.005 to 0.010 mass%, Ca: 0.002 mass% or less, and the balance being Al and inevitable impurities by setting a melt temperature before pouring the melt into a continuous casting mold to 720 °C or above to thereby obtain a cast rod having a diameter of 85 mm or less; and

a forging step of forging a forging material obtained by homogenizing the cast rod at a temperature of 300 to 500 °C to obtain a near-net-shape material for an engine piston.

2. The method of producing a near-net-shape material for an engine piston as recited in claim 1, wherein an additive amount of P in the composition of the melt satisfies the following formula (1):

$$0.0025 \times \text{an additive amount of Si} - 0.025 \leq \text{an additive amount of P} \leq 0.0025 \times \text{the additive amount of Si} - 0.02 \quad \dots \text{Formula (1)}$$

where a unit of the additive amount of P and a unit of the additive amount of Si are "mass%", respectively.

3. A near-net-shape material for an engine piston produced by the method of producing a near-net-shape material for an engine piston as recited in claim 1 or 2,

wherein there exists primary Si at least in a portion of the near-net-shape material corresponding to a skirt portion and a portion of the near-net-shape material corresponding to a piston ring groove portion, and

wherein there exists no primary Si having a maximum diameter of 50 μm or more and no Al-Fe-Cr-Mn series gigantic crystal having a maximum diameter of 50 μm or more.

4. A near-net-shape material for an engine piston produced by forging,

wherein the near-net-shape material has a composition consisting of: Si: 11.0 to 13.0 mass%, Fe: 0.6 to 1.0 mass%, Cu: 3.5 to 4.5 mass%, Mn: 0.25 mass% or less, Mg: 0.4 to 0.6 mass%, Cr: 0.15 mass% or less, Ni: 0.6 to $\{(-4/6) \times [\text{Cu mass\%}] + 5\}$ mass%, Zr: 0.07 to 0.15 mass%, P: 0.005 to 0.010 mass%, Ca: 0.002 mass% or less, and the balance being Al and inevitable impurities.

5. The near-net-shape material for an engine piston as recited in claim 4,

wherein an additive amount of P in the composition of the near-net-shape material satisfies the following formula (1):

$0.0025 \times \text{an addition amount of Si} - 0.025 \leq \text{an additive amount of P} \leq 0.0025 \times \text{the additive amount of Si} - 0.02$...Formula (1)

where a unit of the additive amount of P and a unit of the additive amount of Si are "mass%", respectively.

6. The near-net-shape material for an engine piston as recited in claim 4 or 5,

wherein there exists primary Si at least in a portion of the near-net-shape material corresponding to a skirt portion and a portion of the near-net-shape material corresponding to a piston ring groove portion, and

wherein there exists no primary Si having a maximum diameter of 50 μm or more and no Al-Fe-Cr-Mn series gigantic crystal having a maximum diameter of 50 μm or more.