



(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
24.05.2017 Bulletin 2017/21

(51) Int Cl.:
B22F 3/17 (2006.01) **B22F 3/20** (2006.01)
B22F 9/08 (2006.01) **C22C 1/04** (2006.01)
C22C 21/02 (2006.01) **C22F 1/043** (2006.01)
B22F 3/24 (2006.01)

(21) Application number: **16194363.4**

(22) Date of filing: **18.10.2016**

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
MA MD

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(30) Priority: **21.10.2015 JP 2015207274**

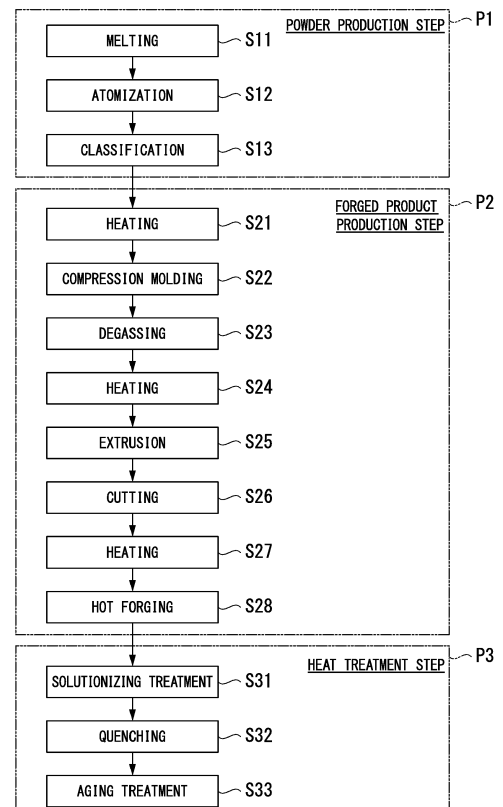
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(54) **ALUMINUM ALLOY POWDER FOR HOT FORGING OF SLIDING COMPONENT, METHOD OF PRODUCING THE SAME, ALUMINUM ALLOY FORGED PRODUCT FOR SLIDING COMPONENT, AND METHOD OF PRODUCING THE SAME**

(57) An aluminum alloy powder for hot forging of a sliding component of the present invention includes: Si: 10.0% to 19.0%; Mn: 3.0% to 10.0%; and Al and inevitable impurities as a balance, in which an average size of Si crystal grains is 15 μm or less.

FIG. 1



Description

BACKGROUND OF THE INVENTION

Field of the Invention

[0001] The present invention relates to an aluminum alloy powder appropriate for an aluminum alloy forged product used as a component that slides at a high speed under a high temperature, such as an engine piston used in an internal combustion engine of a vehicle or the like, and particularly a forged product obtained by performing hot forging on a powder extruded material, and a method of producing the aluminum alloy powder. Furthermore, the present invention relates to an aluminum alloy forged product for a sliding component, which uses the aluminum alloy powder, and a method of producing the aluminum alloy forged product.

[0002] Priority is claimed on Japanese Patent Application No. 2015-207274, filed on October 21, 2015, the content of which is incorporated herein by reference.

Description of Related Art

[0003] An engine piston of an internal combustion engine is a member which slides relative to a cylinder at a high speed under a high temperature, requires excellent wear resistance, requires strength, particularly excellent high-temperature strength, and also requires excellent seizure resistance.

[0004] On the other hand, as for vehicle components, due to the demand for an improvement in fuel efficiency in the automotive industry in recent years, a reduction in weight and high functionality are strongly required. Therefore, as the material of an engine piston for vehicles, there is an increasing trend toward the use of light aluminum alloys instead of general steel materials and cast iron materials in the related art.

[0005] From among various types of aluminum alloy, an Al-Si-based alloy containing about 10 mass% or more of Si, that is, an aluminum alloy having a eutectic composition to a hyper-eutectic composition with a high Si content, has a low coefficient of thermal expansion and excellent wear resistance and thus has been hitherto used as the material of a vehicle engine.

[0006] However, since such a type of Al-Si-based alloy containing a large amount of Si is generally produced according to a melting-casting method in the related art, it is difficult to completely prevent cast defects. In addition, primary crystal Si coarsely crystallizes and segregates, which results in a reduction in strength and toughness. Therefore, the Al-Si-based alloy is not satisfactory as the material of a vehicle engine. In addition, this type of Al-Si-based alloy with a high Si content causes a limitation on the types of alloy elements or the addition amounts thereof. Therefore, the development of an alloy with significantly improved characteristics has been limited.

[0007] Here, using a material, which is obtained by applying a so-called powder metallurgy method using an Al-Si-based alloy powder with a high Si content obtained by an atomization method, as the material of a vehicle engine may be considered. According to an atomization method, an aluminum alloy powder having a fine and uniform structure due to rapid cooling solidification can be obtained, and the addition of a large amount of alloy elements is possible. That is, in the atomization method, molten aluminum alloy can be rapidly cooled to solidify at a high cooling rate of about 10^3 to 10^5 °C/s, and thus the diffusion of alloy constituent elements is suppressed during the solidification, thereby suppressing coarsening of crystal grains and precipitates. Furthermore, due to the suppression of the formation of equilibrium phases and metastable phases, the amount of solutionized alloy elements, particularly transition elements represented by Fe, Ni, and Mn can be increased.

[0008] Hitherto, as a method of obtaining a material having high high-temperature strength required for an engine piston or the like that receives a high load, for example, Japanese Unexamined Patent Application, First Publication No. S63-266005 has proposed a method of producing, using an atomization method, a powder of an Al-Si-based aluminum alloy with a high Si content, which has a eutectic composition to a hyper-eutectic composition and contains a relatively large amount of transition elements such as Fe, Ni, and Mn added thereto, which are metals with high melting points, and using, as a material having wear resistance under high load for a vehicle engine or the like, a forged product, which is produced by performing compression molding, extrusion, and forging on the powder rapidly cooled and solidified according to the atomization method through a powder metallurgy method.

[0009] In the technique of Japanese Unexamined Patent Application, First Publication No. S63-266005 mentioned above, one or more of Fe, Ni, and Mn, which are transition elements, are added as alloy elements for strength improvement. However, according to experiments and examinations conducted by the inventors, it was determined that in a case where Fe and/or Ni are used from among such transition elements, sufficient wear resistance and high-temperature strength for a sliding component cannot be necessarily obtained after final forging. As a matter of course, when the amount of added Fe and/or Ni is increased, wear resistance and high-temperature strength can be increased. However, in this case, the material becomes brittle and there is a problem of cracking during forging or the like. Therefore, unnec-

essarily increasing the amount of added Fe and/or Ni has to be avoided.

[0010] In addition, in the case of Japanese Unexamined Patent Application, First Publication No. S63-266005 described above, characteristics of an extruded material are primarily evaluated, and there is hardly any evaluation of forged products subjected to forging after extrusion. In a case where an engine piston is produced from an extruded material, there may be a case where shaving is performed. However, a forged product in which metal flow exhibits a flow conforming to a product shape has excellent characteristics and is more advantageous in terms of costs. Therefore, evaluation in the stage of a forged product is an important factor. However, in Japanese Unexamined Patent Application, First Publication No. S63-266005 described above, hardly any evaluation was performed in the stage of a forged product, and it is unclear whether or not a forged product is optimal for an engine piston.

[0011] In addition, it was confirmed that in a case where a large amount of Fe and/or Ni is added, the following problems are incurred.

[0012] That is, since Ni is an expensive element, the addition of Ni causes an increase in material costs. On the other hand, Fe is an element which is likely to be incorporated into molten alloy from iron tools when an alloy is melted for atomization. Therefore, when Fe is used as an alloy element added for an improvement in characteristics, there is concern that strict control of the amount of Fe in the alloy becomes difficult. Furthermore, since Fe and Ni have high melting points, the melting temperature of molten alloy for atomization has to be high. Therefore, problems such as an increase in costs and an increase in the amount of refractory materials are easily incurred. Moreover, Fe and Ni have higher specific gravities than those of Al and Si. Therefore, the addition of a large amount of Fe and Ni is disadvantageous to the use for a vehicle engine piston that requires lightweight properties.

SUMMARY OF THE INVENTION

[0013] The present invention has been made taking the above-described circumstances into consideration as the background, and an object thereof is to provide an aluminum alloy powder for obtaining an aluminum alloy powder forged product having excellent wear resistance and high-temperature strength as a forged product for a sliding component used under high load, and an aluminum alloy forged product for a sliding member, which uses the aluminum alloy powder and has excellent wear resistance and high-temperature strength.

[0014] In order to solve the above-described problems, the inventors examined various cases, repeatedly conducted reviews, and found that, as for the characteristics of a forged product obtained by performing compression molding, extrusion, and hot forging on an Al-Si-based alloy powder obtained by an atomization method, in a case where Mn from among Fe, Ni, and Mn, which are transition elements, is added, compared to a case where Fe and Ni are added, considerably excellent wear resistance and high-temperature strength can be obtained even in the same addition amount. That is, it was found that in a sliding component used under high load, such as a vehicle engine piston, a case where Mn is added as a transition element is considerably superior to a case where Fe and Ni are added.

[0015] Furthermore, it was recognized that when Mn is used, a problem of an increase in material costs, which is incurred when Ni is added, is avoided, and a problem with Fe, which is incorporated into molten alloy from iron tools or the like in a case where Fe is added, is not incurred. In addition, since Mn has a lower melting point than Fe and Ni, the melting point of the molten alloy for atomization does not need to be increased. Moreover, since Mn has a lower specific gravity than Fe and Ni, Mn is advantageous to the use for a vehicle engine piston which requires lightweight properties.

[0016] As described above, it was found that for an Al-Si-based aluminum alloy powder with a high Si content, which has a eutectic composition to a hyper-eutectic composition, for a sliding component of a vehicle engine piston or the like, the use of only Mn other than Fe and/or Ni as an additive element (transition element) for an improvement in characteristics is advantageous, and the present invention was completed.

[0017] Therefore, an aluminum alloy powder for hot forging of a sliding component according to a basic aspect (first aspect) of the present invention, includes, by mass%: Si: 10.0% to 19.0%; Mn: 3.0% to 10.0%; and Al and inevitable impurities as a balance, in which an average size of Si crystal grains is 15 μm or less.

[0018] In addition, the aluminum alloy powder for hot forging of a sliding component according to a second aspect of the present invention, further includes, by mass%: in the first aspect, Cu: 0.5% to 10.0%; and Mg: 0.2% to 3.0%.

[0019] Furthermore, the aluminum alloy powder for hot forging of a sliding component according to a third aspect of the present invention, further includes, by mass%: in the first or second aspect, one or two or more of Ti, Zr, V, W, Cr, Co, Mo, Ta, Hf, Nb, each of which being in a proportion of 0.01% to 5.0%.

[0020] In addition, according to a fourth aspect of the present invention, a method of producing the aluminum alloy powder for hot forging of a sliding component according to any one of the first to third aspects, includes: producing molten alloy having a composition according to any one of the first to third aspects, and rapidly cooling the molten alloy to solidify and be atomized into a powder by using an atomization method.

[0021] Furthermore, according to a fifth aspect of the present invention, an aluminum alloy forged product for a sliding component, which is produced by performing hot forging on an extruded material of an aluminum alloy powder, includes, by mass%: Si: 10.0% to 19.0%; Mn: 3.0% to 10.0%; and Al and inevitable impurities as a balance, in which an average

size of Si crystal grains is 15 μm or less.

[0022] Furthermore, the aluminum alloy forged product for a sliding component according to a sixth aspect of the present invention, further includes, by mass%: in the fifth aspect, one or two of Cu: 0.5% to 10.0%; and Mg: 0.2% to 3.0%.

[0023] In addition, the aluminum alloy forged product for a sliding component according to a seventh aspect of the present invention, further includes, by mass%: in the any one of the fifth and sixth aspects, one or two or more of Ti, Zr, V, W, Cr, Co, Mo, Ta, Hf, Nb, each of which being in a proportion of 0.01% to 5.0%.

[0024] In addition, a method of producing the aluminum alloy forged product for a sliding component according to an eighth aspect of the present invention, includes: a compression molding process of performing compression molding on the aluminum alloy powder for hot forging of a sliding component according to any one of the first to third aspects, thereby obtaining a compact; an extrusion process of performing hot extrusion on the obtained compact, thereby obtaining an extruded material; and a forging process of performing hot forging on the extruded material, thereby obtaining a forged product having an average Si crystal grain size of 15 μm or less.

[0025] Furthermore, the method of producing the aluminum alloy forged product for a sliding component according to a ninth aspect of the present invention, further includes: in a case where the aluminum alloy powder includes Cu: 0.5% to 10.0% and Mg: 0.2% to 3.0% by mass%, performing a solutionizing treatment, quenching, and an aging treatment on the forged product after the forging process.

[0026] According to the present invention, as an aluminum alloy powder forged product for a sliding component used under high load, such as a vehicle engine piston, a forged product having excellent wear resistance and high-temperature strength can be obtained.

BRIEF DESCRIPTION OF THE DRAWINGS

[0027]

FIG. 1 is a flowchart schematically showing the entirety of an example of a production process of a forged product of the present invention.

FIG. 2 is a perspective view illustrating situations before and after forging in an example of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0028] Hereinafter, embodiments of an aluminum alloy powder for hot forging of a sliding component, a method of producing the same, an aluminum alloy forged product for a sliding component, and a method of producing the same of the present invention will be described in detail.

[0029] The embodiments described below are only examples, and as a matter of course, the present invention is not limited to the embodiments.

[0030] First, the composition of an aluminum alloy powder will be described.

[0031] The aluminum alloy powder for hot forging of a sliding component of the present invention basically contains Si: 10.0% to 19.0% and Mn: 3.0% to 10.0% as essential alloy components, and Al and inevitable impurities as the Balance. In addition, if necessary, in addition to the essential components, one or two of Cu: 0.5% to 10.0% and Mg: 0.2% to 3.0% may be further included. Moreover, if necessary, in addition to the essential components, or in addition to the essential components and Cu and Mn, one or two or more of Ti, Zr, V, W, Cr, Co, Mo, Ta, Hf, Nb may be included, each of which being in a proportion of 0.01% to 5.0%. Next, the reason for limiting the alloy elements will be described. Here, "%" for each component means mass%.

<Si: 10.0% to 19.0%>

[0032] Si is a basically important element for the aluminum alloy powder of the present invention, causes the crystallization of a large amount of crystallized Si (primary crystal Si and eutectic Si) as Si in Al-Si-based eutectic to hyper-eutectic regions is contained. Particularly, Si contributes to an improvement in wear resistance due to finely crystallized Si and contributes to an improvement in strength. When the amount of Si is less than 10%, the amount of crystallized Si is small, which causes a reduction in wear resistance and strength. When the amount of Si is more than 19%, coarse primary crystal Si is crystallized, which causes a reduction in strength and embrittlement of the material. Therefore, forgeability is degraded. Here, in order to obtain high wear resistance and strength, particularly high-temperature strength and to cause forgeability to be compatible therewith, the amount of Si is set to be in a range of 10.0% to 19.0%. The amount of Si is particularly preferably in a range of 12% to 16%.

<Mn: 3.0% to 10.0%>

[0033] Mn is a transition metal and thus forms intermetallic compounds, thereby contributing to the improvement of wear resistance and high-temperature strength through dispersion strengthening. As described above, in order to improve the strength of an Al-Si-based alloy with a high Si content, Fe or Ni may be added. However, according to experiments and examinations conducted by the inventors, it is determined that a case of adding Mn rather than Fe and Ni is considerably effective in improving wear resistance. Not only that, but it is confirmed that the effect of the use of Mn on the improvement in high-temperature strength becomes more significant than the effect of the addition of Fe and Ni on the improvement. Furthermore, since Mn is cheap, an increase in material costs is not incurred unlike a case where expensive Ni is added. In addition, Mn is less likely to be incorporated during melting of an alloy or the like, and thus strict control of the amount of Mn in the alloy is easily performed. In addition, since Mn has a lower melting point than those of Fe and Ni, there is no need to set the melting temperature of the molten alloy for atomization to be high. Moreover, since Mn has a lower specific gravity than those of Fe and Ni, adding Mn rather than Fe and Ni is advantageous, and is particularly advantageous to the use of a vehicle engine piston that requires lightweight properties. From the viewpoint, in the present invention, Fe and Ni are not actively added, and by adding Mn, the improvement in wear resistance and high-temperature strength is achieved.

[0034] Here, regarding the amount of Mn, when the amount of Mn is less than 3.0%, dispersion strengthening due to intermetallic compound cannot be sufficiently achieved. On the other hand, when the amount of Mn is more than 10.0%, on the contrary, hardness and wear resistance decrease, and there is a tendency for the material in a formed body to become brittle. Here, the amount of Mn is set to be in a range of 3.0% to 10.0%. The amount of Mn is particularly preferably in a range of 6.0% to 8.0% in the above range.

<Cu: 0.5% to 10.0%>

[0035] Cu is an element effective in imparting age hardenability to an alloy in cooperation with Mg. Therefore, when Cu is added along with Mg, Cu effectively acts to perform a solutionizing treatment to quenching and an age hardening treatment on a forced material as a heat treatment type alloy, and to improve room-temperature and high-temperature strength.

[0036] When the amount of Cu is less than 0.5%, age hardenability is insufficiently obtained, and thus the effect of improving strength is low. On the other hand, when the amount of Cu is more than 10%, extrusion workability is deteriorated. Therefore, the amount of Cu is set to be in a range of 0.5% to 10%. In addition, the amount of Cu is particularly preferably in a range of 2.0% to 5.0% in the above range.

<Mg: 0.2% to 3.0%>

[0037] Mg is an element effective in imparting age hardenability to an alloy in cooperation with Cu as described above. Therefore, when Mg is added along with Cu, Mg effectively acts to perform a solutionizing treatment to quenching and an age hardening treatment on a forced material as a heat treatment type alloy, and to improve room-temperature and high-temperature strength.

[0038] When the amount of Mg is less than 0.2%, age hardenability is insufficiently obtained, and thus the effect of improving strength is low. On the other hand, when the amount of Mg is more than 3.0%, extrusion workability is deteriorated. Therefore, the amount of Mg is set to be in a range of 0.2% to 3.0%. In addition, the amount of Mg is particularly preferably in a range of 1.0% to 2.0% in the above range.

<One or Two or More of Ti, Zr, V, W, Cr, Co, Mo, Ta, Hf, and Nb: 0.01% to 5.0%>

[0039] These elements all have low diffusion rates in aluminum and thus have effects of improving heat resistance of an alloy and significantly improving high-temperature strength. Here, when the amount of any of the elements is less than 0.1%, the above-described effect is insufficiently obtained. When the amount thereof is more than 0.5%, there is a tendency for the material to become brittle. It is preferable that in a case where two or more of these elements are contained, the total amount thereof is 8.0% or less.

[0040] In addition, one of Cu and Mg, and one or two or more of Ti, Zr, V, W, Cr, Co, Mo, Ta, Hf, and Nb may be included, or both thereof may be simultaneously included.

[0041] Other than the above-described elements, Al and inevitable impurities may be basically included. In addition, in the present invention, Fe and Ni are basically treated as impurities, and typically, it is preferable that Fe is limited to 1.0% or less and Ni is limited to 1.0% or less. However, depending on the cases, including one or both of Fe and Ni is allowed in a range in which the amount of Fe is less than 3.0% and the amount of Ni is less than 2.0%.

[0042] Furthermore, regarding the aluminum alloy powder for hot forging of a sliding component, of the present in-

vention, the average size of Si crystal grains in powder particles needs to be 15 μm or less. Here, Si crystal grains in the powder particles are crystal grains of a Si simple substance and includes both primary crystal Si and eutectic Si. In the Si crystal grains, primary crystal Si is likely to coarsen. However, by limiting the average size thereof to 15 μm or less, as described later, the average size of Si crystal grains in the material (forged product) after compression molding, extrusion, and hot forging can be easily limited to as fine as 15 μm or less. As a result, the improvement in wear resistance, and the improvement in strength and high-temperature strength can be achieved. When the average size of Si crystal grains in the powder particles is more than 15 μm , Si crystal grains in the forged product after compression molding, extrusion, and hot forging become coarse, and it becomes difficult to sufficiently improve wear resistance, strength, and high-temperature strength.

[0043] In addition, the particle size of the aluminum alloy powder particles is not particularly limited, and typically, is preferably about 30 to 70 μm on average. When the average particle size thereof is less than 30 μm , the yield significantly decreases. When the average particle size thereof is more than 70 μm , there is concern that coarse oxides and foreign matter may be incorporated.

[0044] Here, fine alloy powder which is formed of an Al-Si-based alloy with a high Si content as described above, contains a relatively large amount of Fe as an alloy element, has an average Si crystal grain size of 15 μm or less, and an average powder particle size of about 30 to 70 μm can be reliably obtained by using an atomization method. That is, the atomization method is a method of spraying molten aluminum alloy through a nozzle along with gas, rapidly cooling fine molten alloy particles at a cooling rate of about 10^2 to 10^5 $^\circ\text{C/s}$, thereby obtaining solidified powder. As described above, by rapidly cooling the fine molten alloy particles, the diffusion of alloy elements is suppressed during solidification, coarsening of crystal grains or precipitates is suppressed, and furthermore, the formation of equilibrium phases and metastable phases is suppressed. Accordingly, the amount of solutionized Mn, which is a transition element, can be increased.

[0045] Next, as an aspect of the present invention, an aluminum alloy forged product for a sliding component will be described.

[0046] The aluminum alloy forged product for a sliding component according to the aspect of the present invention is preferably produced by performing compression molding on the aluminum alloy powder for hot forging of a sliding component described above, performing extrusion on the resultant, and thereafter performing hot forging on the resultant. Therefore, the composition of the forged product may be the same as that of the alloy powder described above. That is, Si: 10.0% to 19.0% and Mn: 3.0% to 10.0% are included as essential alloy components, and Al and inevitable impurities are included as the balance. In addition, if necessary, in addition to the essential components, one or two of Cu: 0.5% to 10.0% and Mg: 0.2% to 3.0% may be further included. Moreover, if necessary, in addition to the essential components, or in addition to the essential components and Cu and Mg, one or two or more of Ti, Zr, V, W, Cr, Co, Mo, Ta, Hf, Nb may be included, each of which being in a proportion of 0.01% to 5.0%. Next, the reason for limiting the alloy elements is the same as that described above.

[0047] In addition, as described above regarding the alloy powder, the average size of Si crystal grains in the aluminum alloy forged product for a sliding component needs to be 15 μm or less. Here, Si crystal grains are crystal grains of a Si simple substance and include both primary crystal Si and eutectic Si. In the Si crystal grains, primary crystal Si is likely to coarsen. However, by limiting the average size thereof to 15 μm or less, the improvement in wear resistance, and the improvement in strength and high-temperature strength of the material for a sliding component such as a vehicle engine piston can be achieved. When the average size of Si crystal grains is more than 15 μm and becomes coarse, it becomes difficult to sufficiently improve wear resistance, strength, and high-temperature strength.

[0048] Here, in the process of compression molding, extrusion, and hot forging of the alloy powder, the average size of Si crystal grains rarely changes. Therefore, when a powder in which the average size of Si crystal grains in the particles is 15 μm is used as the alloy powder as described above, the average size of Si crystal grains in the forged product after compression molding, extrusion, and hot forging can be 15 μm or less.

[0049] Next, an example of a process for producing the aluminum alloy forged product for a sliding component according to the aspect of the present invention will be described with reference to FIG. 1.

[0050] The overall concept of the process for producing the aluminum alloy forged product for a sliding component includes, as illustrated in FIG. 1, a powder production step P1 of producing an alloy powder through an atomization method by melting an aluminum alloy, a forged product production step P2 of obtaining a forged product by performing compression molding on the alloy powder obtained in the powder production step P1 into a predetermined shape (for example, a cylindrical shape), and performing extrusion and hot forging on the resultant, and a heat treatment step P3 of performing a solutionizing treatment to quenching on a final forged product and performing an aging treatment (in practice, preferably an over-aging stabilization treatment) thereon in a case of a heat treatment type alloy containing Cu and Mg. Each of the steps will be described in more detail.

<Powder Production Step P1>

[0051] First, molten aluminum alloy of which the composition is adjusted as described above is produced according to a typical melting method (S11). The obtained molten aluminum alloy is atomized into powder by using an atomization method (S12). The atomization method is a method of spraying small liquid droplets of the molten alloy into mist through a spraying nozzle using a gas flow such as nitrogen gas to rapidly cool and solidify the small liquid droplets, thereby obtaining fine alloy powder. There are various types of the method. However, the point is that the type is not particularly limited as long as the method achieves a cooling rate of about 10^3 to 10^5 °C/s and an alloy with an average particle size of as fine as about 30 to 70 μm .

[0052] The alloy powder obtained by using the atomization method is classified by a sieve if necessary (S13), and only alloy powder with a size of less than 150 μm is sent to the subsequent process. The alloy powder sent to the subsequent process in this step has the composition as described above, and the average size of Si crystal grains in the alloy powder particles needs to be 15 μm or less.

<Forged Material Production Step P2>

[Compression Molding]

[0053] The alloy powder obtained as described above is heated to, for example, about 250°C to 300°C (S21), is inserted into a mold preheated to, for example, about 230°C to 270°C, is compression-molded into a predetermined shape (S22), thereby obtaining a compact. The pressure of the compression molding is not particularly limited but is typically a pressure of about 0.5 to 3.0 ton/cm², and the compact preferably has a relative density of about 60% to 90%. In addition, the shape of the compact is not particularly limited, but typically, a cylindrical shape or a disk shape is preferable in consideration of the extrusion process.

[Extrusion]

[0054] The compact is subjected to machining such as face milling if necessary, is then subjected to a degassing treatment (S23), and is heated (S24) to be subjected to an extrusion process (S25). The heating temperature (preheating temperature) before the extrusion is, for example, preferably about 300°C to 450°C. During the extrusion, the compact is loaded into an extrusion container, and receives a pressurization force from an extrusion ram, and is extruded, for example, into a round bar shape from an extrusion die. It is preferable that the extrusion container is also heated to about 300°C to 400°C in advance. By performing hot extrusion as described above, plastic deformation proceeds in the compact, and alloy powder particles are bonded together, thereby obtaining an integrated extruded body.

[0055] Here, it is preferable that the extrusion pressure is about 10 to 25 MPa, the extrusion ratio (the outer diameter ratio before and after extrusion) is about 5.0 to 50, and the density of the extruded body is about 2.80 to 2.90.

[Hot Forging]

[0056] For example, the round bar-shaped extruded body is cut into a predetermined depth if necessary (S26) and is thereafter heated to a temperature appropriate for hot forging (S27), thereby being subjected to hot forging (S28). As the hot forging, closed-die forging or half-closed-die forging is preferable so as to cause the finish forged material (forged product) to have a shape close to a product shape (for example, an engine piston shape). However, depending on the product shape, free forging may also be employed. The temperature of the hot forging is preferably about 300°C to 450°C in a case of the alloy as an object of the present invention.

[0057] In addition, depending on the cases, in order to complete a shape which is further close to the product shape, cold forging may be performed after the hot forging.

[0058] The finish forged material may be appropriately subjected to cutting, surface polishing, or the like to be immediately used as a sliding component (for example, engine piston) of a product. However, in a case of the heat treatment type alloy containing Cu and Mg, which are alloy elements for imparting age hardenability, the finish forged material is subjected to a subsequent heat treatment step P3.

<Heat Treatment Step P3>

[Solutionizing Treatment (S31)]

[0059] The solutionizing treatment is a treatment for forming supersaturated solid solutions of Cu, Mg, and the like, which contribute to age hardening. The heating temperature of the solutionizing treatment is preferably 480°C to 500°C.

When the heating temperature is lower than 480°C, supersaturated solid solutions cannot be sufficiently obtained, and age hardenability decreases. When the heating temperature is higher than 500°C, crystal grains or eutectic Si becomes coarse, and there are problems in that a reduction in strength is incurred or the growth of pores is promoted. In addition, the heating time of the solutionizing treatment is preferably 2 hours to 4 hours. When the heating time is shorter than 2 hours, supersaturated solid solutions cannot be sufficiently obtained, and when the heating time is longer than 4 hours, coarsening of crystal grains or eutectic Si occurs.

[Quenching (S32)]

[0060] After the heating for solutionizing, rapid cooling (quenching) such as water quenching is performed to obtain a material in which supersaturated solid solutions of Cu, Mg, and the like are formed over the solid solubility limit at room temperature (supersaturated solid solutions). The quenching temperature is preferably 0°C to 50°C. When the quenching temperature is lower than 0°C, there is concern that cracks may occur due to rapid thermal contraction, resulting in cracking. When the quenching temperature is higher than 50°C, supersaturated solid solutions are insufficiently obtained, and strength is insufficiently obtained.

[Aging Treatment (S33)]

[0061] After the solutionizing treatment to the quenching, an aging treatment is performed. Due to the aging treatment, intermetallic compounds of Cu, Mg, and the like are finely precipitated, and strength and wear resistance can be significantly improved.

[0062] However, in the case of the present invention, the present invention is applied to the production of a sliding component represented by an engine piston, and the sliding component preferably requires good dimensional stability. For example, in an engine piston, it is preferable that the clearance from the inner circumferential surface of a cylinder is stably maintained. Here, in the case of the present invention, the aging treatment preferably proceeds to a stabilization treatment in a so-called T7 treatment to achieve overaging which exceeds aging treatment conditions in a general T6 treatment (aging treatment conditions for obtaining maximum strength).

[0063] From the viewpoint, the conditions of the aging treatment include a temperature in a range of 180°C to 280°C and a time of 1 hour to 4 hours. When the aging treatment temperature is lower than 180°C, long-term aging is necessary, resulting in a reduction in production efficiency. When the aging treatment temperature is higher than 280°C, coarsening of crystal grains or eutectic Si occurs within a short period of time, and there is concern that strength may be decreased. In addition, when the aging time is shorter than 1 hour, overaging is not achieved such that stabilization becomes insufficient and sufficient dimensional stability is not obtained. When the aging time is longer than 4 hours, coarsening of crystal grains and eutectic Si occurs due to excessive overaging, and there is concern that strength may be decreased.

[0064] The forged product after the aging treatment described above is appropriately subjected to machining such as cutting, surface polishing, or the like, thereby completing a sliding component of a vehicle engine piston or the like.

[0065] Hereinafter, examples of the present invention will be described. The following examples are described to clarify the actions and effects of the present invention, and as a matter of course, conditions described in the examples do not limit the technical scope of the present invention.

[Examples]

[Example 1]

[0066] Molten aluminum alloy with a high Si content and a composition shown as Nos. 1 to 12 of Table 1 was atomized with gas into powder, and the powder was classified by a sieve, thereby obtaining -100 mesh powder. It is assumed from the measurement results of the size of the Si crystal grains in a sample (forged product), the size of Si crystal grains in the particles of the powder was 15 μm or less.

[0067] Next, the powder was preheated to a temperature of 280°C, was inserted into a mold heated and retained at the same temperature, and was subjected to compression molding at a pressure of 1.5 ton/cm², thereby obtaining a disk-shaped compact having a diameter of 210 mm and a length of 250 mm. Next, the compact was subjected to face milling to a diameter of 203 mm to form a billet of the compact. Next, the compact billet was heated to 350°C, was inserted into an extrusion container having an inner diameter of 210 mm, which was heated and retained at 350°C, and was extruded at an extrusion ratio of 7.8 using a die having an inner diameter of 75 mm according to an indirect extrusion method. The obtained extruded material was cut into a length of 30 mm, was heated to 450°C, and was subjected to hot free forging, thereby obtaining a sample (forged product) of φ107.5 x L15 mm. In addition, in order to produce an actual sliding component, die forging is widely performed. In the description, since only the evaluation of characteristics was desired, free forging was applied. FIG. 2 shows an extruded material 10 before forging and a forged product 20

after the forging.

[0068] A sample of 10 mm x 10mm was cut from the obtained sample (forged product) and was embedded in a resin. Thereafter, the resultant was subjected to rough polishing using emery paper and finish polishing using buff. The structure thereof was observed using an optical microscope, and the sizes of Si crystal grains were measured. As a result, it was confirmed that the size of Si crystal grains in any sample was 15 μm or less.

[0069] The obtained sample was heated to 490°C and retained for 3 hours as the solutionizing treatment and was thereafter subjected to quenching with water at 20°C. Thereafter, as the aging treatment (over-aging stabilization treatment), the resultant was heated at 220°C for 1 hour to obtain a T7 treatment product. The obtained T7 treatment product was processed into a room-temperature tensile test piece having a gauge length of 25.4 mm and a parallel portion diameter of 2.85 mm, and a flanged high-temperature tensile test piece having a gauge length of 20 mm and a parallel portion diameter of 4 mm, and a tensile test was conducted at room temperature, 150°C, and 300°C.

[0070] The tensile test was conducted after retention at each test temperature for 100 hours. Here, Samples Nos. 1 to 5, 8, 11, and 12 are comparative examples, and Nos. 6, 7, 9, and 10 are present invention examples. The results thereof are shown in Table 2.

[0071] As is apparent from Table 2, the forged products of Nos. 6 and 7 as the present invention examples had higher tensile strength and proof stress at high temperatures than those of Nos. 1 to 4 as the comparative examples.

[0072] Regarding No. 5 as the comparative example, although high-temperature strength was excellent, cracking also had occurred during forging, and the proportion of forging without cracking was 20%. Therefore, it was confirmed that forgeability was extremely poor.

[0073] In addition, regarding No. 8 as the comparative example, although forging could be performed with substantially no cracking, cracking had occurred due to water quenching after the solutionizing treatment. Warm water quenching at 60°C was attempted to prevent quenching cracking. However, the cracking occurrence ratio was not significantly improved, and the attempt also caused a reduction in strength. As a result, high strength could not be obtained.

[0074] When No. 7 as the present invention example is compared to Nos. 9 to 12 in which the amount of Mn varies while the amount of Si is constant, Nos. 9 and 10 as the present invention examples had sufficient wear resistance and high-temperature strength. However, in No. 11 as the comparative example, dispersion strengthening of Al-Mn-Si-based intermetallic compounds could not be sufficiently achieved, and the high-temperature strength thereof was not excellent. In addition, in No. 12 as the comparative example, toughness was decreased due to an excessive amount of Mn and thus forgeability was decreased. Accordingly, cracking had occurred during quenching after the solutionizing treatment.

[0075] Next, the forged product after being subjected to the heat treatments described above was cut to obtain an evaluation material (fixed piece) of 5 x 25 x 40 mm, and an Ogoshi wear test was conducted thereon. SS400 was used as a mating material (rotating disk), and the rotating disk was pressed and rubbed against the fixed piece. The wear amount and specific wear rate were calculated from a wear trace on the surface of the fixed piece. The calculation results of the specific wear rate are shown in Table 2. The wear amount was obtained using an approximation expression from the diameter and the thickness of the rotating disk and the width of the wear trace, and the specific wear rate was calculated from the obtained wear amount, the frictional distance, and the final load. The wear amount is the amount of the evaluation material being worn, and the specific wear rate is a value representing the amount of SS400 as the mating material being worn. As the specific wear rate decreases, better wear resistance is obtained.

[0076] A conversion expression of the specific wear rate is shown as follows.

$$W = B \times b^3 / 12 \times r$$

$$W_s = B \times b^3 / 8 \times r \times P \times L$$

$$= 3 \times W / 2 \times P \times L$$

where

W: the wear amount (mm^3)

Ws: the specific wear rate (mm^2/kgf)

r: the diameter of the rotating disk (mm)

B: the thickness of the rotating disk (mm)

b: the width of the wear trace (mm)

P: the final load (kgf)

L: the frictional distance (mm)

[0077] When Nos. 1, 2, and 5 as the comparative examples are compared to each other, it can be seen that No. 5 having a Si content of 20%, which was the maximum, had the lowest specific wear rate and good wear properties. When No. 5 is compared to No. 7 as the present invention example, it can be seen that while the specific wear rate was substantially the same, the material of the present invention had good wear properties.

[0078] In addition, even in Nos. 9 and 10 as the present invention examples, it can be seen that the specific wear rate was the same as that of No. 7, and all the materials of the present invention had excellent wear resistance.

[0079] Furthermore, when No. 1 as the comparative example in which the amount of Si was 12.0% and 7.0% of Fe was contained, No. 3 as the comparative example in which the amount of Si was 12.0% and 7.0% of Ni was contained, and No. 6 as the present invention example in which the amount of Si was 12.0% and 7.0% of Mn was contained are compared to each other, it can be seen that No. 6 as the present invention example containing 7.0% of Mn had excellent wear resistance. In addition, when No. 2 as the comparative example in which the amount of Si was 16.0% and 7.0% of Fe was contained, No. 4 as the comparative example in which the amount of Si was 16.0% and 7.0% of Ni was contained, and No. 7 as the present invention example in which the amount of Si was 16.0% and 7.0% of Mn was contained are compared to each other, it can be seen that No. 7 as the present invention example containing 7.0% of Mn had excellent wear resistance. From the results, the superiority of a case of using Mn instead of Fe and Ni is apparent.

[Table 1]

No.	Composition (unit: mass%)							Classification
	Si	Fe	Ni	Mn	Cu	Mg	Al	
1	12.0	7.0	-	-	3.0	1.5	Balance	Comparative alloy
2	16.0	7.0	-	-	3.0	1.5	Balance	Comparative alloy
3	12.0	-	7.0	-	3.0	1.5	Balance	Comparative alloy
4	16.0	-	7.0	-	3.0	1.5	Balance	Comparative alloy
5	20.0	-	7.0	-	3.0	1.5	Balance	Comparative alloy
6	12.0	-	-	7.0	3.0	1.5	Balance	Present invention alloy
7	16.0	-	-	7.0	3.0	1.5	Balance	Present invention alloy
8	20.0	-	-	7.0	3.0	1.5	Balance	Comparative alloy
9	16.0	-	-	4.0	3.0	1.5	Balance	Present invention alloy
10	16.0	-	-	9.0	3.0	1.5	Balance	Present invention alloy
11	16.0	-	-	2.0	3.0	1.5	Balance	Comparative alloy
12	16.0	-	-	12.0	3.0	1.5	Balance	Comparative alloy
13	16.0	-	-	7.0	-	-	Balance	Present invention alloy
14	16.0	-	-	4.0	-	-	Balance	Present invention alloy
15	16.0	-	-	9.0	-	-	Balance	Present invention alloy
16	16.0	-	-	2.0	-	-	Balance	Comparative alloy
17	16.0	-	-	12.0	-	-	Balance	Comparative alloy

[Table 2]

NO.	Cracking occurrence ratio during forging	Presence or absence of occurrence of quenching cracking after solutionizing	Strength (MPa)		Proof stress (MPa)		Wear test results (specific wear rate: mm ² /kgf)	Comprehensive evaluation	Classification
			150°C	300°C	150°C	300°C			
1	0%	Absent	415	126	332	79	2.15×10 ⁻⁷	C	Comparative alloy
2	0%	Absent	370	127	300	79	1.08×10 ⁻⁸	C	Comparative alloy
3	0%	Absent	352	108	276	67	3.46×10 ⁻⁷	C	Comparative alloy
4	0%	Absent	381	132	294	79	4.38×10 ⁻⁸	C	Comparative alloy
5	80%	Absent	377	161	309	93	7.39×10 ⁻⁹	C	Comparative alloy
6	0%	Absent	399	128	316	96	1.16×10 ⁻⁸	B	Present invention alloy
7	0%	Present	446	158	348	111	7.50×10 ⁻⁹	A	Present invention alloy
8	10%	Absent	-	-	-	-	-	C	Comparative alloy
9	0%	Absent	399	111	311	78	5.84×10 ⁻⁹	B	Present invention alloy
10	0%	Absent	477	189	372	133	5.29×10 ⁻⁹	A	Present invention alloy
11	0%	Absent	367	79	286	56	1.56×10 ⁻⁸	C	Comparative alloy
12	20%	Present	-	-	-	-	-	C	Comparative alloy
13	0%	-	410	127	320	89	7.18×10 ⁻⁹	B	Present invention alloy
14	0%	-	363	80	283	56	1.05×10 ⁻⁸	B	Present invention alloy

(continued)

NO.	Cracking occurrence ratio during forging	Presence or absence of occurrence of quenching cracking after solutionizing	Strength (MPa)		Proof stress (MPa)		Wear test results (specific wear rate: mm ² /kgf)	Comprehensive evaluation	Classification
			150°C	300°C	150°C	300°C			
15	0%	-	441	158	344	111	4.82×10 ⁻⁹	A	Present invention alloy
16	0%	-	331	48	259	34	1.66×10 ⁻⁸	C	Comparative alloy
17	15%	-	-	-	-	-	-	C	Comparative alloy

[Example 2]

[0080] Molten aluminum alloy with a high Si content and a composition shown as Nos. 13 to 17 of Table 1, that is, a non-heat-treatment type alloy composition, was atomized into powder by using an atomization method, and the powder was classified by a sieve, thereby obtaining -100 mesh powder. It is assumed that even in the powder, the size of Si crystal grains in the particles of the powder was 15 μm or less.

[0081] Next, a compact billet obtained by performing compression molding and face milling as in Example 1 was subjected to hot extrusion, and the obtained extruded body was cut and subjected to hot free forging as in Example 1.

[0082] The size of Si crystal grains in the obtained sample (forged product) was examined as in Example 1. It was confirmed that all the sizes were 15 μm or less.

[0083] In addition, in the case of Example 2, the heat treatments (the solutionizing treatment, quenching, and aging treatment) were not performed on the sample (forged product).

[0084] In addition, from the obtained sample (forged product), a room-temperature tensile test piece and a flanged high-temperature tensile test piece having the same dimensions as those in Example 1 were cut, and a tensile test was conducted at room temperature, 150°C, and 300°C. The tensile test was conducted after retention at each test temperature for 100 hours.

[0085] Furthermore, as in Example 1, an Ogoshi wear test was conducted.

[0086] The test results of Nos. 13 to 17 are shown in Table 2.

[0087] In Nos. 13 to 15 as the present invention examples, sufficient wear resistance and high-temperature strength could be obtained even though the heat treatments were not performed. However, in No. 16 as the comparative example, dispersion strengthening of Al-Mn-Si-based intermetallic compounds was insufficient, and high high-temperature strength could not be obtained. In addition, in No. 17 as the comparative example, toughness was decreased due to an excessive amount of Mn and thus forgeability was decreased. Accordingly, cracking had occurred during quenching after the solutionizing treatment.

[0088] From the above-described examples, it became apparent that the materials of the present invention combine high-temperature strength, wear resistance, and forgeability and are appropriate for a sliding member used under high load, such as a vehicle engine piston.

[0089] While preferred embodiments of the invention have been described and illustrated above, it should be understood that these are exemplary of the invention and are not to be considered as limiting. Additions, omissions, substitutions, and other modifications can be made without departing from the spirit or scope of the present invention. Accordingly, the invention is not to be considered as being limited by the foregoing description, and is only limited by the scope of the appended claims.

Description of Symbols

[0090]

10 EXTRUDED MATERIAL

20 FORGED PRODUCT

Claims

1. An aluminum alloy powder for hot forging of a sliding component, comprising, by mass%:

Si: 10.0% to 19.0%;

Mn: 3.0% to 10.0%; and

Al and inevitable impurities as a balance,

wherein an average size of Si crystal grains is 15 μm or less.

2. The aluminum alloy powder for hot forging of a sliding component according to claim 1, further comprising, by mass%:

Cu: 0.5% to 10.0%; and

Mg: 0.2% to 3.0%.

3. The aluminum alloy powder for hot forging of a sliding component according to claim 1 or 2, further comprising, by mass%:

one or two or more of Ti, Zr, V, W, Cr, Co, Mo, Ta, Hf, Nb, each of which being in a proportion of 0.01% to 5.0%.

4. A method of producing the aluminum alloy powder for hot forging of a sliding component according to any one of claims 1 to 3, comprising:

producing molten alloy having a composition according to any one of claims 1 to 3, and rapidly cooling the molten alloy to solidify and be atomized into a powder by using an atomization method.

5. An aluminum alloy forged product for a sliding component, which is produced by performing hot forging on an extruded material of an aluminum alloy powder, comprising, by mass%:

Si: 10.0% to 19.0%;
Mn: 3.0% to 10.0%; and
Al and inevitable impurities as a balance,

wherein an average size of Si crystal grains is 15 μm or less.

6. The aluminum alloy forged product for a sliding component according to claim 5, further comprising, by mass%:

one or two of
Cu: 0.5% to 10.0%; and
Mg: 0.2% to 3.0%.

7. The aluminum alloy forged product for a sliding component according to claim 5 or 6, further comprising, by mass%:

one or two or more of Ti, Zr, V, W, Cr, Co, Mo, Ta, Hf, Nb, each of which being in a proportion of 0.01% to 5.0%.

8. A method of producing the aluminum alloy forged product for a sliding component, the method comprising:

a compression molding process of performing compression molding on the aluminum alloy powder for hot forging of a sliding component according to any one of claims 1 to 3, thereby obtaining a compact;
an extrusion process of performing hot extrusion on the obtained compact, thereby obtaining an extruded material; and
a forging process of performing hot forging on the extruded material, thereby obtaining a forged product having an average Si crystal grain size of 15 μm or less.

9. The method of producing the aluminum alloy forged product for a sliding component according to claim 8, further comprising:

in a case where the aluminum alloy powder includes Cu: 0.5% to 10.0% and Mg: 0.2% to 3.0% by mass%, performing a solutionizing treatment, quenching, and an aging treatment on the forged product after the forging process.

FIG. 1

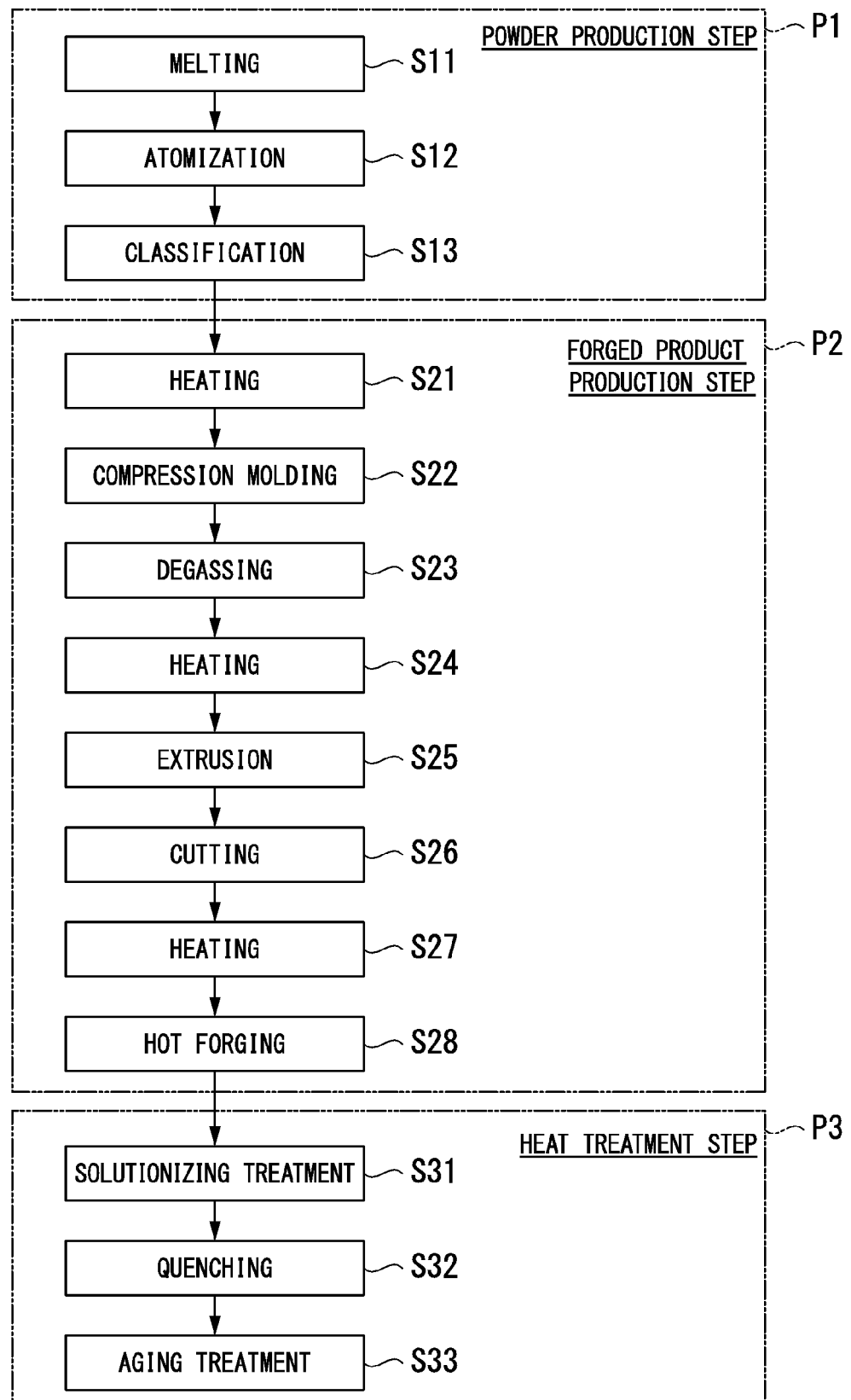
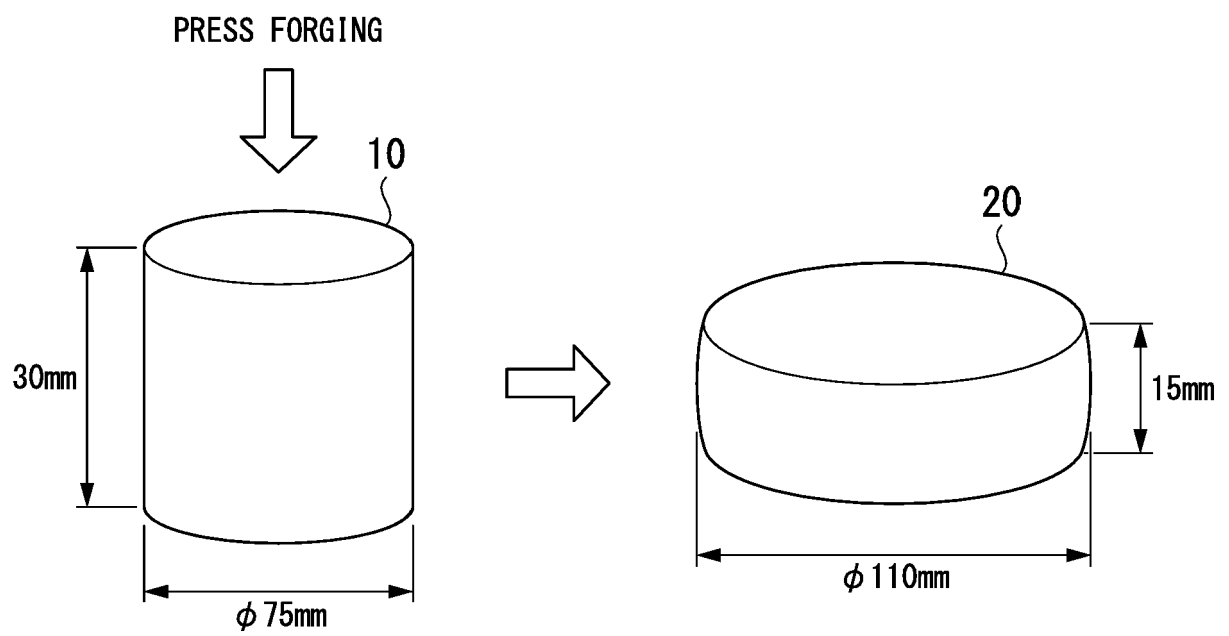


FIG. 2





EUROPEAN SEARCH REPORT

Application Number
EP 16 19 4363

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Y	US 2003/156968 A1 (HATTORI HISAO [JP] ET AL) 21 August 2003 (2003-08-21) * claims 1, 6, 12 * * paragraphs [0057], [0067] - [0070], [0075], [0084] * * tables 1, 3 *	1,3-5,7,8 2,6,9	TECHNICAL FIELDS SEARCHED (IPC)
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Place of search The Hague		Date of completion of the search 30 March 2017	Examiner Traon, Nicolas
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**ANNEX TO THE EUROPEAN SEARCH REPORT
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