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European Patent Office
Office européen des brevets



Publication number:

0 592 665 A1

(12)

EUROPEAN PATENT APPLICATION
published in accordance with Art.
158(3) EPC

(21) Application number: **91918937.3**

(51) Int. Cl.⁵: **B22F 1/00, B22F 9/08**

(22) Date of filing: **31.10.91**

(86) International application number:
PCT/JP91/01488

(87) International publication number:
WO 92/07676 (14.05.92 92/11)

(30) Priority: **31.10.90 JP 295018/90**
31.10.90 JP 295019/90
31.10.90 JP 295099/90

(43) Date of publication of application:
20.04.94 Bulletin 94/16

(84) Designated Contracting States:
DE FR GB IT SE

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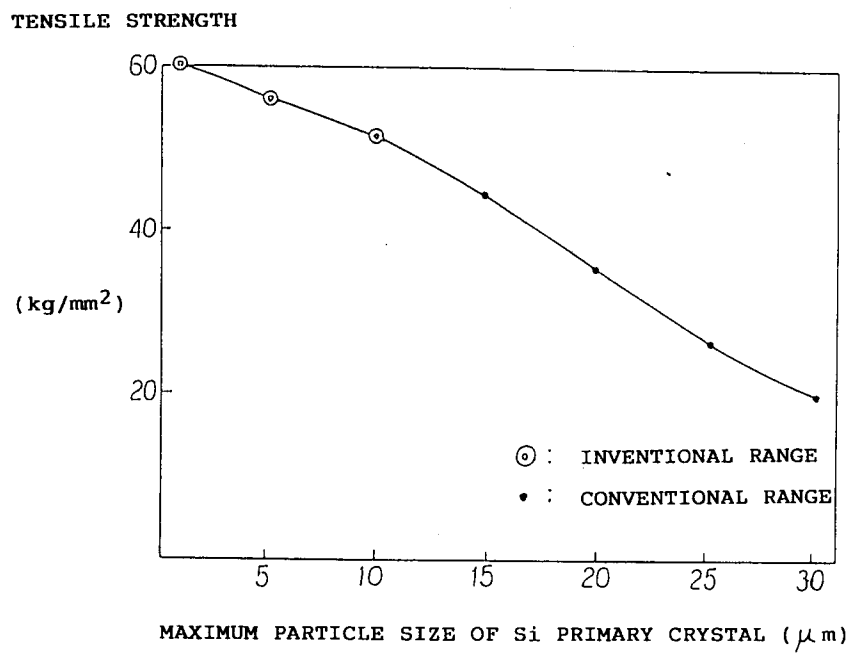
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(54) **HYPEREUTECTIC ALUMINUM/SILICON ALLOY POWDER AND PRODUCTION THEREOF.**

(57) A hypereutectic aluminum/silicon alloy powder wherein a primary crystal of silicon has a grain diameter of as minute as 10 μm or less is produced by the atomization process which comprises preparing a melt of a hypereutectic aluminium/silicon alloy containing phosphorus and spraying the melt by means of air or an inactive gas to effect rapid cooling for solidification. The obtained alloy powder contains 12 to 50 wt% of silicon and 0.0005 to 0.1 wt% of phosphorus. This powder can provide a solidified powder with improved mechanical properties in a high yield without any limitation to the grain size.

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FIG. 6



Technical Field

The present invention relates to hyper-eutectic aluminum-silicon alloy powder and a method of preparing the same, and more particularly, it relates to hyper-eutectic aluminum-silicon alloy powder which stably contains fine silicon primary crystals and a method of preparing the same.

Background

When silicon (Si) is added to aluminum (Al), remarkable effects are attained for reduction of a thermal expansion coefficient, increase in Young's modulus, improvement in wear resistance, and the like. Al-Si alloys utilizing such effects have already been widely used.

Among such Al-Si alloys, a cast material is classified as AC or ADC under the Japanese Industrial Standards, and employed in plenty as an aluminum alloy casting such as an engine block. An Al-Si alloy prepared as a wrought material is classified in the 4,000 series, and worked from a cast billet into various parts by extrusion, forging or the like.

It is well known that a hyper-eutectic Al-Si alloy is prepared by a casting method. A hyper-eutectic Al-Si alloy casting obtained by the casting method, which has excellent properties such as a low thermal expansion coefficient, a high Young's modulus and high wear resistance, is expected for employment in various fields. When such a hyper-eutectic Al-Si alloy casting contains coarse primary crystals of silicon, however, its mechanical properties and machinability in machine work are deteriorated.

It is also well known that a refiner, particularly phosphorus (P), may be added in order to refine primary crystals of silicon contained in a hyper-eutectic Al-Si alloy casting. Even if such a refiner is added when a hyper-eutectic Al-Si alloy is cast, however, refinement of silicon primary crystals is restricted. Particularly when the Al-Si alloy contains silicon in excess of 20 percent by weight, coarse primary crystals of silicon still remain even if the refiner is added, and hence the alloy is still deteriorated in mechanical properties and machinability in machine work.

In recent years, on the other hand, it is possible to prepare powder from a molten metal at a high cooling rate, which has been unavailable in a casting method, by a method of preparing rapidly solidified powder such as atomizing. Therefore, primary crystals of silicon can be so refined that it is possible to prepare hyper-eutectic Al-Si alloy powder containing silicon in excess of an eutectic composition and further containing a transition metal element X such as iron (Fe), nickel (Ni), chromium (Cr), manganese (Mn) or the like as a third alloy component. Powder metallurgical alloys such as Al-17Si-X, Al-20Si-X and Al-25Si-X, having properties further superior to those of cast alloys, have been put into practice as alloys prepared by a powder metallurgical method using such powder materials.

In order to further improve the mechanical properties of the aforementioned powder metallurgical alloys, it is necessary to further refine crystals of silicon while simultaneously homogenizing crystal grain sizes of silicon. Further, it is extremely important to reduce coarse crystals of silicon, which serve as starting points of rupture even if the amount thereof is small to cause dispersion in material strength. In addition, such primary crystals of silicon contained in the powder can hardly be refined by hot solidification such as forging or extrusion, but rather become coarse by Ostwald growth. Thus, the sizes of the silicon primary crystals contained in the alloy powder are definitely important.

It is known that a cooling rate in preparation of powder may be increased in order to refine primary crystals of silicon. However, such a cooling rate is generally decided by a method of and an apparatus for atomizing, and no other industrial method of increasing such a cooling rate has been implemented due to problems in economic property and productivity.

In the general atomizing method, further, the particle sizes of silicon primary crystals contained in the overall powder are extremely dispersed so far as the as-obtained powder has particle size distribution of a constant width, since the cooling rate depends on the particle size of the powder. For example, powder of about 400 μm in particle size has generally unavoidably contained coarse silicon primary crystals of about 20 μm in particle size.

To this end, coarse powder having a low cooling rate has generally been removed by sieving in order to eliminate particles having coarse silicon primary crystals, thereby preparing consolidates from only fine powder. According to this method, however, the economic property is deteriorated by reduction of the material yield, while handleability such as flowability or compactibility of the powder is extremely reduced and apprehension of dust explosion is increased.

In consideration of the aforementioned circumstances of the prior art, an object of the present invention is to provide a composition of hyper-eutectic Al-Si alloy powder containing fine and homogeneous primary crystals of silicon and being capable of suppressing primary crystallization of coarse primary crystals of

silicon in particular by atomizing, and a method of preparing the same.

Disclosure of the Invention

The inventors have made various experiments and study in consideration of the aforementioned problems of the prior art, to recognize that hyper-eutectic aluminum-silicon alloy powder containing extremely fine primary crystal silicon can be obtained by atomizing a molten metal of an aluminum-silicon alloy to which a primary crystal silicon refiner containing phosphorus is added, or an alloy molten metal obtained by melting an aluminum-silicon alloy ingot previously containing a primary crystal silicon refiner containing phosphorus, with air or an inert gas.

Hyper-eutectic aluminum-silicon alloy powder in accordance with a first aspect of the present invention contains at least 12 percent by weight and not more than 50 percent by weight of silicon, and at least 0.0005 percent by weight and not more than 0.1 percent by weight of phosphorus.

The particle size of primary crystal silicon contained in the inventive hyper-eutectic aluminum-silicon alloy powder is by far smaller than the size of primary crystal silicon contained in a conventional hyper-eutectic aluminum-silicon alloy obtained by a casting method, and is not more than 10 μm in general.

The content of silicon in the inventive aluminum-silicon alloy powder is at least 12 percent by weight and not more than 50 percent by weight, preferably at least 20 percent by weight and not more than 30 percent by weight. If the content of silicon is less than 12 percent by weight, no primary crystal silicon is formed. If the content of silicon exceeds 50 percent by weight, on the other hand, the amount of primary crystal silicon is too much however primary crystals of silicon are refined, and hence consolidates prepared from the as-obtained powder are inferior in machinability while its mechanical strength is deteriorated.

The content of phosphorus in the inventive aluminum-silicon alloy powder is at least 0.0005 percent by weight and not more than 0.1 percent by weight, preferably at least 0.0005 percent by weight and not more than 0.05 percent by weight. If the content of phosphorus is less than 0.0005 percent by weight, no effect of refinement is attained and no improvement of mechanical strength is recognized. On the other hand, the effect of refinement is no more improved even if the content of phosphorus exceeds 0.1 percent by weight. Aluminum-silicon alloy powder containing at least 0.02 percent by weight and not more than 0.1 percent by weight of phosphorus is particularly excellent in machinability in machine work.

More preferable and concrete aluminum-silicon alloy powder according to the present invention contains at least 12 percent by weight and not more than 50 percent by weight of silicon, at least 2.0 percent by weight and not more than 3.0 percent by weight of copper, at least 0.5 percent by weight and not more than 1.5 percent by weight of magnesium, at least 0.2 percent by weight and not more than 0.8 percent by weight of manganese and at least 0.0005 percent by weight and not more than 0.05 percent by weight of phosphorus, with a rest of aluminum and unavoidable impurities. Aluminum-silicon alloy powder containing the respective elements of copper, magnesium and manganese has high mechanical strength.

According to a method of preparing hyper-eutectic aluminum-silicon alloy powder in accordance with a second aspect of the present invention, a molten metal of a hyper-eutectic aluminum-silicon alloy containing phosphorus is prepared previously. The molten metal is atomized with air or an inert gas, and quench-solidified.

The molten metal of a hyper-eutectic aluminum-silicon alloy containing phosphorus may be prepared from a molten metal of an aluminum-silicon alloy to which a primary crystal silicon refiner containing phosphorus is added, or an alloy molten metal obtained by melting an aluminum-silicon alloy ingot previously containing a primary crystal silicon refiner containing phosphorus.

In the inventive preparation method, the primary crystal silicon refiner containing phosphorus is prepared from a primary crystal silicon refiner employed in a conventional casting method, such as Cu-8wt.%P, Cu-15wt.%P, PCl_5 or mixed salt mainly composed of red phosphorus, or an Al-Cu-P refiner.

The primary crystal silicon refiner is generally used in an amount of at least 0.0005 percent by weight and not more than 0.1 percent by weight, preferably at least 0.002 percent by weight and not more than 0.05 percent by weight. If the amount of the primary crystal silicon refiner is less than 0.0005 percent by weight, no sufficient effect is attained by addition of the primary crystal silicon refiner. On the other hand, no further improvement of the effect is recognized even if the primary crystal silicon refiner is added in an amount exceeding 0.1 percent by weight.

In the inventive preparation method, the aluminum-silicon alloy molten metal is atomized according to a well-known method.

In the preparation method according to the present invention, the alloy molten metal is preferably atomized in a state being at a temperature of at least a level exceeding the liquidus temperature of the aluminum-silicon alloy by 100 °C and not more than 1300 °C. Also when the primary crystal silicon refiner is

added to the aluminum-silicon alloy, the alloy is preferably held at the aforementioned temperature.

The term "liquidus temperature" indicates a temperature at which the alloy of the composition is completely molten. For example, the liquidus temperature of an aluminum-silicon alloy containing 25 percent by weight of silicon is about 780 °C.

When the alloy molten metal is held at a temperature lower than the temperature of (liquidus temperature of the aluminum-silicon alloy + 100) °C, phosphorus is so insufficiently molten that the amount of phosphorus contained in the alloy is reduced as compared with the amount of the added phosphorus, and hence it is difficult to obtain alloy powder containing phosphorus in a correct amount. If the alloy molten metal is held at a temperature exceeding 1300 °C, on the other hand, a crucible and a furnace material are so extremely damaged that contained alloy elements may be partially evaporated and it may be impossible to obtain an alloy having a desired composition.

More preferably, the alloy molten metal is held at the temperature of at least a level exceeding the liquidus temperature of the aluminum-silicon alloy by 100 °C and not more than 1300 °C at least for 30 minutes, and thereafter atomized. Also when the holding time is shorter than 30 minutes, phosphorus is so insufficiently molten that the amount of phosphorus contained in the alloy is reduced as compared with the amount of the added phosphorus, and it is difficult to obtain alloy powder containing phosphorus in a correct amount. However, this does not apply to employment of an Al-Cu-P inoculant (holding time may be reduced to be shorter than 30 minutes).

An aluminum-silicon alloy to which the inventive method is applied is not particularly restricted but can also include a general aluminum-silicon alloy containing elements other than aluminum and silicon, such as copper, magnesium, manganese, iron, nickel, zinc and the like. The inventive preparation method is particularly useful for an aluminum-silicon alloy having a high content (at least 20 percent by weight and not more than 40 percent by weight) of silicon.

Thus, according to the present invention, it is possible to obtain hyper-eutectic aluminum-silicon alloy powder in which extremely fine primary crystal silicon is homogeneously dispersed. Upon preparation under the aforementioned preferred conditions, it is possible to obtain hyper-eutectic aluminum-silicon alloy powder having a desired composition.

Consolidates prepared from the inventive hyper-eutectic aluminum-silicon alloy powder have extremely superior machinability and mechanical properties.

According to a method of preparing hyper-eutectic aluminum-silicon alloy powder in accordance with a third aspect of the present invention, a molten metal of a hyper-eutectic aluminum-silicon alloy containing phosphorus is prepared previously. This molten metal is atomized with air and quench-solidified, thereby preparing hyper-eutectic aluminum-silicon alloy powder. Only alloy powder of not more than 400 μm in particle size is selected.

In the inventive preparation method, an inoculation method which has been employed in a casting method is applied, to first inoculate a hyper-eutectic aluminum-silicon alloy molten metal for atomizing with phosphorus.

It is possible to previously prepare nuclei in solidification thereby suppressing heterogeneous nucleation caused by supercooling, by inoculating a homogeneously melted alloy molten metal with phosphorus and dispersing the same. The inoculated phosphorus must be homogeneously dispersed in the molten metal as solid particulates at the atomizing temperature. At the same time, it is necessary to eliminate unmolten components other than phosphorus from the molten metal, since such components easily form coarse crystallized substances. The inoculated molten metal can be temporarily cooled/solidified and thereafter again molten to be returned to the original state of the inoculated molten metal.

Then, the inoculated molten metal is atomized by air atomizing, and quench-solidified. The air atomizing is employed as the method of preparing powder by quench solidification, since this method is more economic as compared with other methods and the powder can be easily handled since its surface is stabilized by suitable oxidation.

In relation to conditions for quench solidification, it is known that the structure is more refined as the cooling rate is increased. In the preparation method according to the present invention, however, a large number of crystallized nuclei of silicon primary crystals are previously provided in the molten metal, so that the maximum crystal grain size of primary crystal silicon can be regularly controlled in a fine and narrow range with respect to the particle size of the as-obtained powder without strongly depending on the cooling rate, which is difficult to be controlled. Namely, it is possible to obtain fine and relatively homogeneous primary crystals of silicon even at a slower cooling rate (particle size of the as-obtained powder is relatively large) as compared with the conventional atomizing method.

When the particle size of the as-obtained alloy powder is selected to be not more than 400 μm, the maximum crystal grain size of the primary crystal silicon can be controlled to be not more than 10 μm.

Preferably, the maximum crystal grain size of the primary crystal silicon can be controlled to be not more than 7 μm when the particle size of the as-obtained alloy powder is selected to be not more than 200 μm . More preferably, the maximum crystal grain size of the primary crystal silicon can be controlled to be not more than 5 μm when the particle size of the as-obtained alloy powder is selected to be not more than 100 μm . Further, the maximum crystal grain size of the primary crystal silicon can be controlled to be not more than 3 μm when the particle size of the as-obtained alloy powder is selected to be not more than 50 μm .

In order to stably attain the aforementioned working effect, the concentration of the inoculated phosphorus is preferably in a range of at least 0.005 percent by weight and not more than 0.02 percent by weight.

According to the third aspect of the present invention, as hereinabove described, it is possible to refine and homogenize primary crystal silicon contained in hyper-eutectic aluminum-silicon alloy powder prepared by atomizing, as well as to remarkably reduce dependency of the particle size of the primary crystal silicon on the grain size of the alloy powder as compared with the prior art. Consequently, it is possible to prepare consolidates of powder which are more improved in mechanical properties as compared with the prior art, with no restriction of powder grain size in a high yield by employing the as-obtained hyper-eutectic aluminum-silicon alloy powder.

Brief Description of the Drawings

Fig. 1 is an optical micrograph, showing the micro-structure of primary crystal silicon contained in aluminum alloy powder obtained in Example 1 (magnification: x 400).

Fig. 2 is an optical micrograph, showing the micro-structure of primary crystal silicon contained in aluminum alloy powder obtained in Comparative Example 1 (magnification: x 400).

Fig. 3 is an optical micrograph, showing the structure of primary crystal silicon contained in an aluminum cast alloy (magnification: x 400).

Fig. 4 is an optical microphotograph showing the metallographic structure of hyper-eutectic aluminum-25wt.%silicon alloy powder obtained in Example 3 and inoculated with phosphorus (magnification: x 400).

Fig. 5 is an optical microphotograph showing the metallographic structure of hyper-eutectic aluminum-25wt.%silicon alloy powder obtained in Example 3 and inoculated with no phosphorus (magnification: x 400).

Fig. 6 is a graph showing relation between the maximum particle size of silicon primary crystals contained in the hyper-eutectic aluminum-25wt. %silicon alloy powder in Example 3 and tensile strength of consolidates obtained from the powder at the room temperature.

Best Modes for Carrying Out the Invention

Example 1

Molten metals of aluminum alloys having compositions shown in Table 1 were held at a temperature of 950 °C, and Cu-8wt.%P was added to the molten metals to attain contents of phosphorus shown in Table 1. The molten metals were held at the temperature of 950 °C for 1 hour, and then powdered by air atomizing (refer to alloy powder samples No. 1 to No. 4 in Table 1).

The as-obtained alloy powder samples were classified in -42 to -80 meshes (particle sizes of 175 to 350 μm), and thereafter sizes of primary crystal silicon particles contained in the powder samples were measured through structure observation with an optical microscope. The results are shown in Table 1. Fig. 1 shows a structure photograph of the alloy powder No. 1 through an optical microscope.

Comparative Example 1

Alloy powder No. 5 was prepared under the same conditions as the alloy powder No. 1. In this case, however, no Cu-8wt.%P was added to the molten metal of the aluminum alloy.

The as-obtained alloy powder was classified in -42 to -80 meshes (particle sizes of 175 to 350 μm), and thereafter sizes of primary crystal silicon particles contained in the powder were measured through structure observation with an optical microscope. The results are shown in Table 1. Fig. 2 shows a structure photograph of the alloy powder No. 5 through an optical microscope.

Comparative Example 1A

A molten metal of an aluminum alloy having the same composition as the alloy powder No. 1 was held at a temperature of 950 °C, and Cu-8wt.%P was added to attain the content of phosphorus shown in Table 1. This molten metal was held at the temperature of 950 °C for 1 hour, and thereafter cast in a metal mold of 30 mm in diameter by 80 mm in height, to prepare an alloy casting (No. 6).

Sizes of primary crystal silicon particles contained in the as-obtained alloy casting were measured through micro-structure observation with an optical microscope. The results are shown in Table 1. Fig. 3 shows a structure photograph of the alloy casting through an optical microscope.

Comparing the structure photographs through the optical microscope shown in Figs. 1 to 3, it is clearly understood that the primary crystal silicon particles contained in the alloy powder samples obtained according to the inventive method are finely and homogeneously dispersed as compared with those contained in the alloy powder sample of the same composition obtained in Comparative Example 1, containing no phosphorus.

Table 1

	Alloy No.	Composition (wt.%)					Particle Size of Si Primary Crystal (μm)
		Si	Cu	Mg	Mn	P	
Example 1	1	25	2.5	1.0	0.5	0.0240	1 - 5
	2	25	3.5	0.5	0.5	0.0055	1 - 6
	3	25	3.5	1.0	0.0	0.0545	1 - 5
	4	25	2.5	1.5	0.5	0.0125	1 - 5
Comparative Example 1	5	25	2.5	1.0	0.5	<0.0005	3 - 20
Comparative Example 1A	6	25	2.5	1.0	0.5	0.0240	5 - 80

Then, compacts prepared from the alloy powder and alloy casting samples obtained in the aforementioned Example and Comparative Examples were subjected to a machinability test.

The alloy powder samples No. 1 and No. 5 obtained in Example 1 and Comparative Example 1 were classified in -42 meshes (particle sizes of not more than 350 μm), and cold-preformed in sizes of 30 mm in diameter by 80 mm in height at a pressure of 3 ton/cm². Thereafter these consolidated compacts were hot worked into round bars of 10 mm in diameter at an extrusion temperature of 450 °C at an extrusion ratio of 10. The alloy casting sample No. 6 obtained in Comparative Example 1A was also extruded into a round bar of 10 mm in diameter in a similar manner.

The round bar extruded materials obtained in the aforementioned manner were cut with a cemented carbide tool at a cutting speed of 100 m/min. in a dry type, to measure amounts of wear of the tools after cutting for 10 minutes. The results are shown in Table 2.

Table 2

	Amount of Tool Wear (mm)
Example 1 (Alloy No. 1)	0.03
Comparative Example 1 (Alloy No. 5)	0.12
Comparative Example 1A (Alloy No. 6)	1.01

It is clearly understood from the results shown in Table 2 that machinability of the hot worked product prepared from the inventive alloy powder is remarkably excellent.

Example 2

As shown in Table 3, molten metals obtained by melting aluminum alloy ingots containing phosphorus were held at a temperature of 950 °C for 1 hour. Thereafter these molten metals were powdered by air atomizing (refer to alloy powder samples No. 11 to No. 15 in Table 3).

The as-obtained alloy powder samples were classified in -100 meshes (particle sizes of not more than 147 μm), and thereafter sizes of primary crystal silicon particles contained in the powder samples were measured through structure observation with an optical microscope. The results are shown in Table 3.

5 Comparative Example 2

Alloy powder samples No. 16 to No. 18 were prepared under the same conditions as the alloy powder samples No. 11 to No. 15. In this case, however, aluminum alloy ingots containing no phosphorus were employed.

10 The as-obtained alloy powder samples were classified in -100 meshes (particle sizes of not more than 147 μm), and sizes of primary crystal silicon particles contained in the powder samples were measured through micro-structure observation with an optical microscope. The results are shown in Table 3.

Table 3

15

	Alloy No.	Composition (wt.%)					Particle Size of Si Primary Crystal (μm)
		Si	Cu	Mg	Mn	P	
Example 2	11	25	2.5	1.0	0.5	0.0041	1 - 10
	12	25	2.5	1.0	0.5	0.0116	1 - 10
	13	25	2.5	1.0	0.0	0.0395	1 - 5
	14	25	3.5	2.0	0.5	0.0075	1 - 10
	15	25	2.5	1.0	0.0	0.0152	1 - 10
Comparative Example 2	16	25	2.5	1.0	0.5	<0.0005	1 - 20
	17	25	3.5	2.0	0.5	<0.0005	1 - 20
	18	25	2.5	1.0	0.0	<0.0005	1 - 20

30 Then, the alloy powder samples obtained in the aforementioned Example and Comparative Example were subjected to a transverse rupture strength test.

35 The alloy powder samples No. 11 to No. 18 obtained in Example 2 and Comparative Example 2 were classified in - 100 meshes (particle sizes of not more than 147 μm), and thereafter cold-preformed into sizes of 30 mm in diameter by 80 mm in height at a pressure of 3 ton/cm². Thereafter these consolidated compacts were hot worked into flat plates of 20 mm in width by 4 mm in thickness at an extrusion temperature of 450 °C at an extrusion ratio of 10. The flat plate extruded materials obtained in the above manner were T6 treated, and thereafter subjected to measurement of transverse rupture strength on the basis of JISZ2203 with a gauge length of 30 mm. The results are shown in Table 4.

Table 4

40

	Alloy Powder	Transverse Rupture Strength (kg/mm ²)
Example	No. 11	79.9
	12	80.3
	13	67.0
	14	73.1
	15	71.6
Comparative Example	16	72.2
	17	66.9
	18	65.0

55 It is clearly understood from the results shown in Table 4 that the transverse rupture strength levels of the inventive alloy powder samples containing phosphorus are higher than those of the alloy powder samples containing no phosphorus by about 10 percent. Further, the inventive alloy powder sample No. 13 with a content of phosphorus exceeding 0.02 percent by weight is sufficiently employable although its transverse rupture strength is slightly reduced as compared with the comparative alloy powder sample No.

16.

Example 3

The following hyper-eutectic aluminum-silicon alloys were prepared from ingots:

A-17: 2024 ingot + 17wt.%Si

A-20: 2024 ingot + 20wt.%Si

A-25: 2024 ingot + 25wt.%Si

B-25: 2024 ingot + 25wt.%Si + 5wt.%Fe

C-25: 2024 ingot + 25wt.%Si + 5wt.%Fe + 2wt.%Ni

D-25: Al + 25wt.%Si + 2.5wt.%Cu + 1wt.%Mg + 0.5wt.%Fe + 0.5wt.%Mn

E-25: Al ingot of 99.9 % purity + 25wt.%Si

Molten metals of the aforementioned respective alloys were inoculated with phosphorus at the rates shown in Table 5 or inoculated with no phosphorus, atomized under conditions of air pressures of 5 to 10 kg/mm² by open air atomizing, and quench-solidified.

The as-obtained alloy powder samples were continuously collected, classified with air, and further classified through a sieve. Table 5 shows relations between powder grain sizes D_p and the maximum particle sizes D_{Si} of Si primary crystals as the results of deciding particle sizes of silicon primary crystals contained in these alloy powder samples with a image analysis microscope.

Table 5

		Maximum Particle Size of Si Primary Crystal D_{Si} (μm)			
Powder Grain Size D_p (μm)		200< D_p ≤400	100< D_p ≤200	50< D_p ≤100	D_p ≤50
Alloy	P inoculation				
A-17	0.008 wt. %	5	4	3	2
A-17	no	15	8	7	5
A-20	0.008 wt. %	6	5	3	2
A-20	no	20	8	7	6
A-25	0.008 wt. %	8	5	3	2
A-25	no	20	12	6	5
B-25	0.012 wt. %	7	4	3	2
B-25	no	18	8	8	4
C-25	0.007 wt. %	7	4	2	2
D-25	0.010 wt. %	8	5	2	2
E-25	0.015 wt. %	9	7	5	3

Fig. 4 shows the metallographic structure of hyper-eutectic aluminum-silicon alloy powder obtained by inoculating the aforementioned A-25 alloy with phosphorus with an optical microphotograph of 400 magnifications. Fig. 5 similarly shows the metallographic structure of hyper-eutectic aluminum-silicon alloy powder obtained by inoculating the aforementioned alloy A-25 with no phosphorus. Referring to Figs. 4 and 5, dark gray portions show silicon primary crystals, pale gray portions show matrix, and black portions show holes and filled resin parts.

The two types of powder samples obtained by inoculating the aforementioned A-25 alloys with phosphorus and with no phosphorus were cold-formed at pressure with no classification. These compacts were degassed and heated at a temperature of 450 °C for 30 minutes. The compacts were preheated at the same temperature, thereafter forged/formed at a surface pressure of 6 ton/cm², and subjected to T6 heat treatment.

Mechanical properties-of solidified bodies of the as-obtained powder samples were measured. The results of the measurement are shown in Table 6.

Table 6

P Inoculation	Tensile Strength (MPa)	Elongation (%)
no	400	0.5
yes	500	2.0

The hyper-eutectic aluminum-silicon alloy powder samples obtained in relation to the aforementioned A-25 alloy were classified through the maximum particle sizes of silicon primary crystals D_{Si} . The respective classified powder samples were subjected to measurement of tensile strength of solidified bodies of the respective powder samples prepared under the same conditions as the above at the room temperature. The results of the measurement are shown in Fig. 6.

As understood from the aforementioned results, it is possible to control sizes of silicon primary crystals contained in powder to be small in an extremely narrow range according to the inventive preparation method, whereby it is possible to remarkably reduce rupture caused from starting points of coarse silicon crystals and to improve mechanical strength of consolidates of the powder. Also in cutting of the as-obtained consolidates, it is possible to attain such effects that chipping and wear of a cutting tool are stabilized and can be controlled.

Industrial Availability

As hereinabove described, a consolidate or hot worked product prepared from the inventive hyper-eutectic aluminum-silicon alloy powder has extremely superior machinability and mechanical strength. Thus, it is usefully applied to various parts for machine structural use. According to the inventive method of preparing hyper-eutectic aluminum-silicon alloy powder, further, it is possible to refine and homogenize primary crystal silicon contained in the hyper-eutectic aluminum-silicon alloy powder, thereby remarkably reducing dependency of the particle size of the primary crystal silicon on the powder grain size as compared with the prior art. As the result, it is possible to prepare consolidates of powder which is improved in mechanical properties as compared with the prior art with a high yield.

Claims

1. A hyper-eutectic aluminum-silicon alloy powder comprising at least 12 percent by weight and not more than 50 percent by weight of silicon, and at least 0.0005 percent by weight and not more than 0.1 percent by weight of phosphorus.
2. A hyper-eutectic aluminum-silicon alloy powder in accordance with claim 1, containing at least 0.0005 percent by weight and not more than 0.05 percent by weight of phosphorus.
3. A hyper-eutectic aluminum-silicon alloy powder in accordance with claim 1, containing at least 0.02 percent by weight and not more than 0.1 percent by weight of phosphorus.
4. A hyper-eutectic aluminum-silicon alloy powder in accordance with claim 1, wherein the crystal grain size of primary crystal silicon is not more than 10 μm in said alloy powder.
5. A hyper-eutectic aluminum-silicon alloy powder in accordance with claim 1, containing at least 2.0 percent by weight and not more than 3.0 percent by weight of copper, at least 0.5 percent by weight and not more than 1.5 percent by weight of magnesium, at least 0.2 percent by weight and not more than 0.8 percent by weight of manganese and at least 0.0005 percent by weight and not more than 0.05 percent by weight of phosphorus, with a rest of aluminum and unavoidable impurities.
6. A method of preparing hyper-eutectic aluminum-silicon alloy powder, comprising:
 - a step of preparing a molten metal of a hyper-eutectic aluminum-silicon alloy containing phosphorus; and
 - a step of atomizing said molten metal with air or an inert gas and rapidly-solidifying the same.
7. A method of preparing hyper-eutectic aluminum-silicon alloy powder in accordance with claim 6, wherein said step of preparing a molten metal of an aluminum-silicon alloy includes a step of adding a

primary crystal silicon refiner containing phosphorus to the molten metal of the aluminum-silicon alloy.

- 5 8. A method of preparing hyper-eutectic aluminum-silicon alloy powder in accordance with claim 6, wherein said step of preparing a molten metal of an aluminum-silicon metal includes a step of melting a solid body of an aluminum-silicon alloy previously containing a primary crystal silicon refiner containing phosphorus.
- 10 9. A method of preparing hyper-eutectic aluminum-silicon alloy powder in accordance with claim 6, wherein said step of atomizing said molten metal and quench-solidifying the same includes a step of atomizing said molten metal in a state being held at a temperature of at least a level exceeding the liquidus temperature of the aluminum-silicon alloy by 100 °C and not more than 1300 °C.
- 15 10. A method of preparing hyper-eutectic aluminum-silicon alloy powder in accordance with claim 9, wherein said step of atomizing said molten metal and quench-solidifying the same includes a step of atomizing said molten metal after holding the same at a temperature of at least a level exceeding the liquidus temperature of the aluminum-silicon alloy by 100 °C and not more than 1300 °C.
- 20 11. A method of preparing hyper-eutectic aluminum-silicon alloy powder, comprising:
a step of preparing a molten metal of a hyper-eutectic aluminum-silicon alloy containing phosphorus;
a step of preparing hyper-eutectic aluminum-silicon alloy powder by atomizing said molten metal with air and quench-solidifying the same; and
a step of selecting said alloy powder of not more than 400 μm in particle size.
- 25 12. A method of preparing hyper-eutectic aluminum-silicon alloy powder in accordance with claim 11, wherein said step of selecting said alloy powder includes a step of selecting said alloy powder of not more than 200 μm in particle size.
- 30 13. A method of preparing hyper-eutectic aluminum-silicon alloy powder in accordance with claim 11, wherein said step of selecting said alloy powder includes a step of selecting said alloy powder of not more than 100 μm in particle size.
- 35 14. A method of preparing hyper-eutectic aluminum-silicon alloy powder in accordance with claim 11, wherein said step of selecting said alloy powder includes a step of selecting said alloy powder of not more than 50 μm in particle size.

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FIG. 1

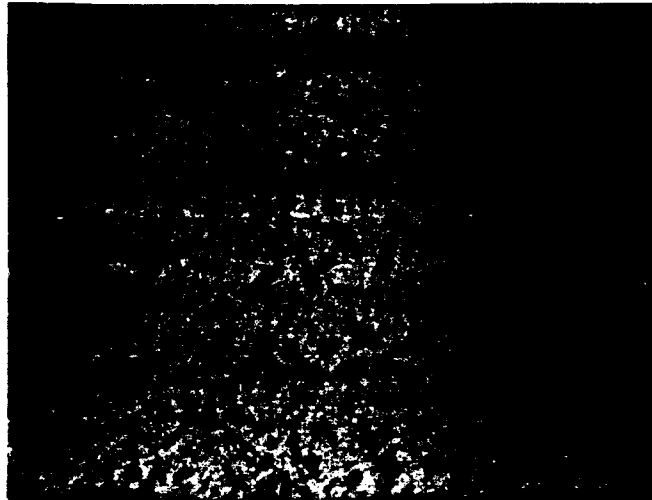


FIG. 2

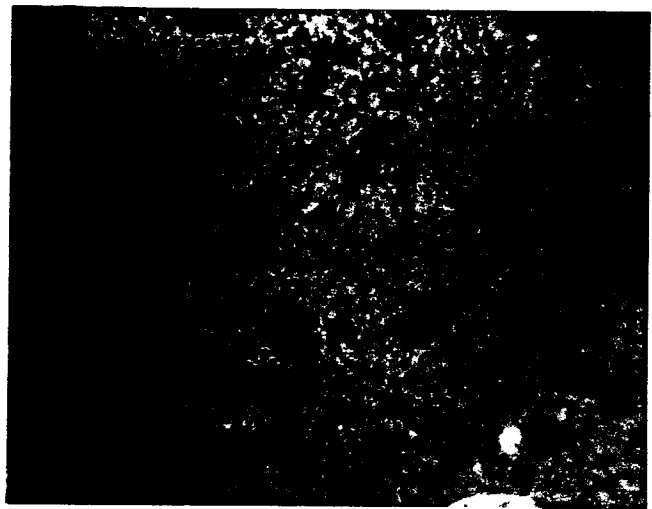


FIG. 3

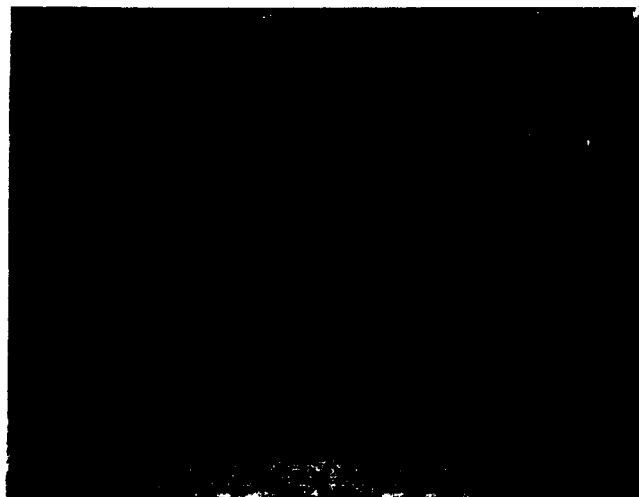


FIG. 4

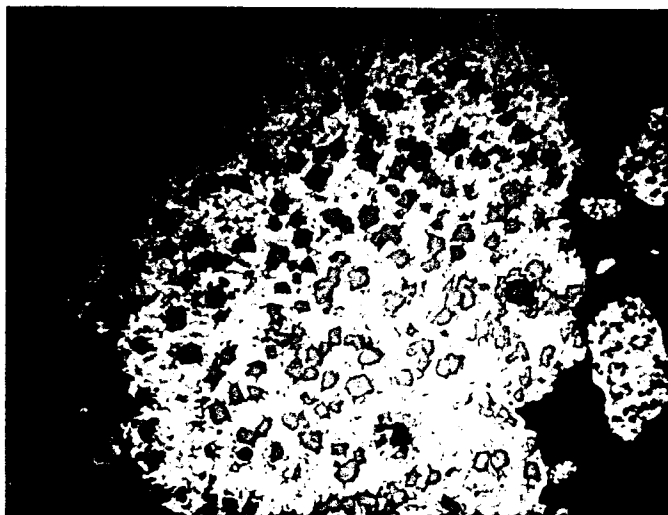


FIG. 5

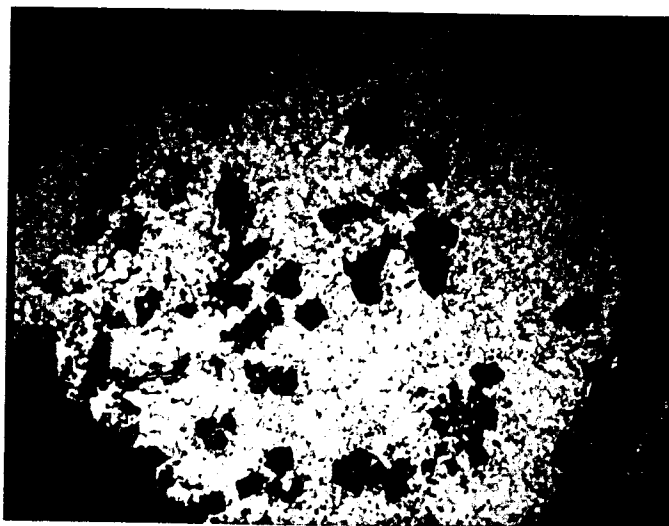
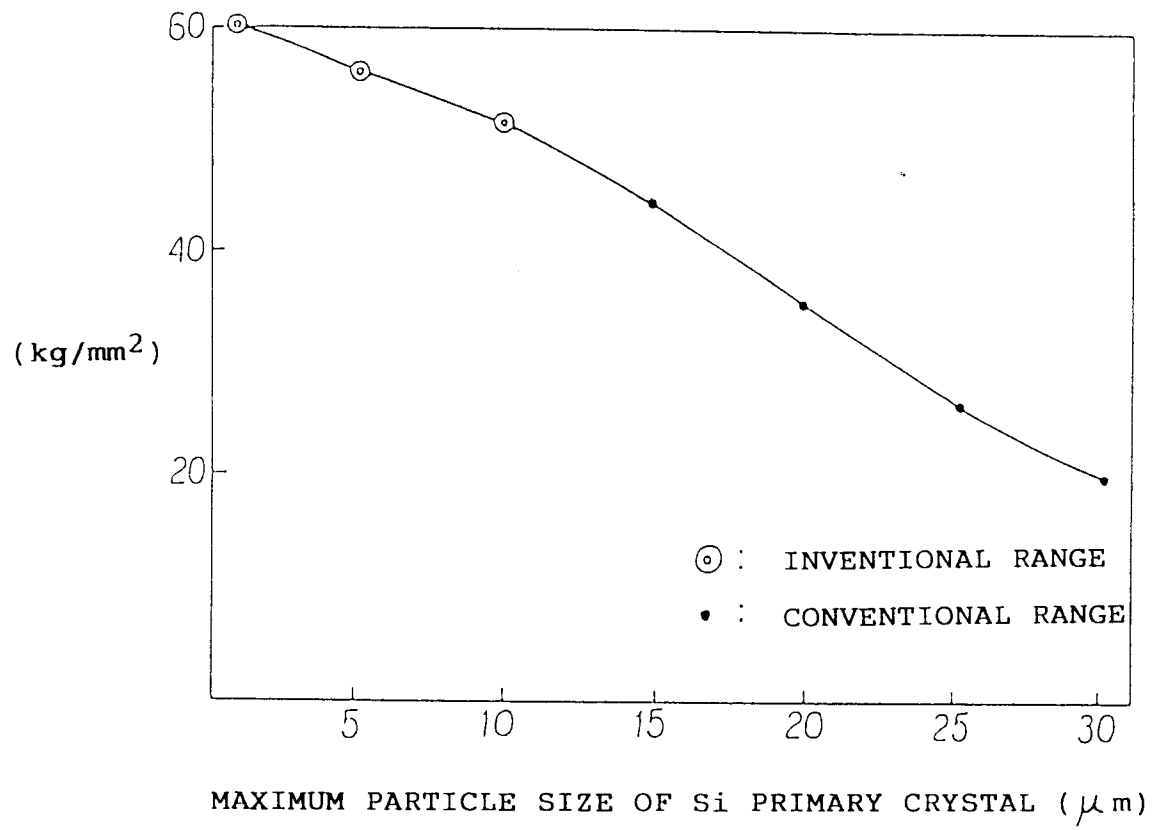


FIG. 6

TENSILE STRENGTH



INTERNATIONAL SEARCH REPORT

International Application No PCT/JP91/01488

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) ⁶		
According to International Patent Classification (IPC) or to both National Classification and IPC		
Int. Cl ⁵ B22F1/00, 9/08		
II. FIELDS SEARCHED		
Minimum Documentation Searched ⁷		
Classification System	Classification Symbols	
IPC	B22F1/00, 9/08	
Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched ⁸		
Jitsuyo Shinan Koho 1926 - 1991 Kokai Jitsuyo Shinan Koho 1971 - 1991		
III. DOCUMENTS CONSIDERED TO BE RELEVANT ⁹		
Category ⁹	Citation of Document, ¹¹ with indication, where appropriate, of the relevant passages ¹²	Relevant to Claim No. ¹³
X	JP, B2, 59-37339 (Showa Denko K.K.), September 8, 1984 (08. 09. 84), Lines 11 to 35, column 2, line 41, column 4 to line 13, column 5, lines 29 to 38, column 8 (Family: none)	1-14
Y	JP, B1, 45-1538 (Daihatsu Motor Co., Ltd.), January 19, 1970 (19. 01. 70), Lines 23 to 26, column 2 (Family: none)	1-14
Y	JP, A, 02-213401 (Toyota Motor Corp.), August 24, 1990 (24. 08. 90), Line 5, lower left column to line 7, lower right column, page 1 (Family: none)	1-5
Y	JP, A, 63-266004 (Showa Denko K.K.), November 2, 1988 (02. 11. 88), Lines 5 to 15, lower left column, page 1 & EP, A2, 100470	1, 5
* Special categories of cited documents: ¹⁰ "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier document but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step "Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
IV. CERTIFICATION		
Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report	
January 10, 1992 (10. 01. 92)	February 4, 1992 (04. 02. 92)	
International Searching Authority	Signature of Authorized Officer	
Japanese Patent Office		

FURTHER INFORMATION CONTINUED FROM THE SECOND SHEET

Y JP, A, 01-147038 (Honda Motor Co., Ltd.),
June 8, 1989 (08. 06. 89),
Lines 1 to 18, lower right column, page 1
(Family: none)

6-10

V. ☐ OBSERVATIONS WHERE CERTAIN CLAIMS WERE FOUND UNSEARCHABLE

This international search report has not been established in respect of certain claims under Article 17(2) (a) for the following reasons:

1. ☐ Claim numbers, because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claim numbers _____, because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claim numbers _____, because they are dependent claims and are not drafted in accordance with the second and third sentences of PCT Rule 6.4(a).

VI. ☐ OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING ²

This International Searching Authority found multiple inventions in this international application as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims of the international application.

2. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims of the international application for which fees were paid, specifically claims:

3. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claim numbers:

4. ☐ As all searchable claims could be searched without effort justifying an additional fee, the International Searching Authority did not invite payment of any additional fee.

Remark on Protest

- ☐ The additional search fees were accompanied by applicant's protest.
- ☐ No protest accompanied the payment of additional search fees.