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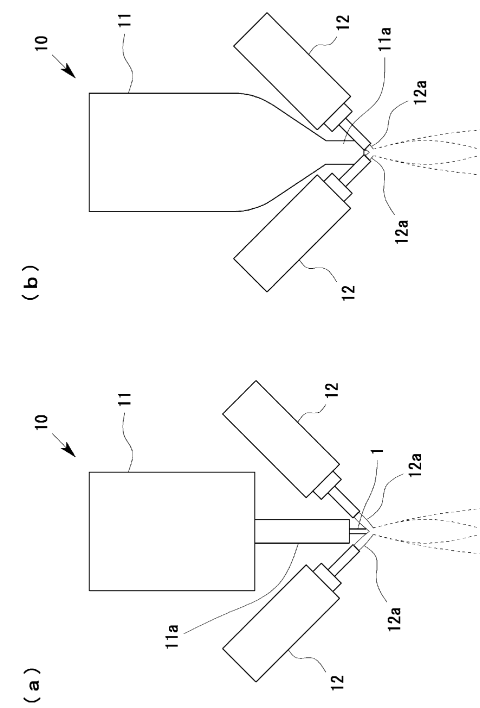
(54) **METALLIC POWDER PRODUCTION METHOD AND METALLIC POWDER PRODUCTION DEVICE**

(57) A metal powder production method and a metal powder production device capable of reducing the size of the device, reducing costs, and obtaining spherical metal powder are provided.

Supply means 11 supplies a downward flow 1 of molten metal, and a plurality of jet burners 12 emit flame jets 12a to the downward flow 1 of the molten metal supplied from the supply means 11. Each of the jet burners 12 is provided to emit the flame jet 12a from the same angle and from each of positions rotationally symmetrical with each other with respect to the downward flow 1 of the molten metal.

Fig.1



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Description

BACKGROUND OF INVENTION

Technical Field

[0001] The present invention relates to a metal powder production method and a metal powder production device.

Background Art

[0002] Conventionally, atomization methods have been widely used for producing metal powder (refer to, for example, MURAKAMI, Yotaro, "Method for producing high-quality metal powder", (online), September 2003, The New Materials Center, Osaka Science & Technology Center (searched on January 17, 2011), the Internet (URL: http://www.ostec.or.jp/nmc/TOP/nmc_news.htm)). Typical atomization methods include a water atomization method and a gas atomization method that produce powder by emitting a jet of water or gas to molten metal (metal melt), pulverizing the molten metal, and allowing it to be solidified as droplets (refer to, for example, Japanese Unexamined Patent Application Publication Numbers. 2006-63357, 2005-139471, and 2004-183049). In addition, the typical atomization methods also include a disk atomization method that produces the powder by allowing the molten metal to be dropped on a rotating disk, and pulverizing it by applying a shear force in a tangential direction, and a plasma atomization method that allows a fine wire of Ti or the like to become particles by heat of plasma and kinetic energy.

SUMMARY OF INVENTION

Technical Problem

[0003] However, the water atomization method has the problem of increased equipment costs, because a high-pressure pump for emitting a jet of water at high speed is expensive. In addition, the water atomization method has such a problem that the shape of the produced powder is irregular. The gas atomization method has such a problem that material costs, equipment costs and other costs are high because high-pressure gas production equipment is required in order to use high-pressure gas, and the gas to be used is expensive. The disk atomization method has such a problem that equipment costs are high, because it is necessary to increase a rotation rate of the disk in order to produce the fine metal powder, and such a problem that technology for increasing the rotation rate of the disk has already reached the limit. The plasma atomization method has such a problem that a plasma torch is expensive. In addition, the plasma atomization method also has the problem of an increase in size of the device, because the plasma torch is used.

[0004] The present invention is made in view of the above-described problems, and an object of the present invention is to provide a metal powder production method and a metal powder production device capable of reducing the size of the device, reducing the costs, and obtaining spherical metal powder.

Solution to Problem

[0005] In order to achieve the above-described object, a metal powder production method according to the present invention obtains metal powder by emitting a flame jet to molten metal or a metal wire.

[0006] A metal powder production device according to the present invention includes supply means for supplying molten metal or a metal wire, and a jet burner for emitting a flame jet to the molten metal or the metal wire supplied from the supply means.

[0007] It is possible for the metal powder production device of the present invention to preferably implement the metal powder production method according to the present invention. The metal powder production method and the metal powder production device according to the present invention can obtain the metal powder by using the principle of an atomization method. By emitting the high-temperature flame jet to the molten metal, the molten metal can be pulverized. Further, by emitting the high-temperature flame jet to the metal wire, the metal wire is melted and its molten metal can be pulverized. As the temperature of the flame jet at this time is higher than those of high-pressure water of a water atomization method and high-pressure gas of a gas atomization method, flow velocity of blowing fluid can be increased to be higher than those of the water atomization method and the gas atomization method. Due to its high temperature, it is not necessary to cool the molten metal for atomization, nor to increase the temperature of the molten metal more than necessary. Therefore, the molten metal can be finely pulverized. Thus-pulverized molten metal is allowed to fall or scatter in an atmosphere and statically supercooled, so as to enable vitrification and to obtain fine metal powder with ease. In addition, it is possible to obtain the metal powder that is finer than those obtained by the water atomization method and the gas atomization method.

[0008] According to the metal powder production method and the metal powder production device of the present invention, it is possible to obtain the spherical metal powder. The jet burners used in the metal powder production method and the metal powder production device according to the present invention are relatively inexpensive and small-sized as compared with a high-pressure pump used in the water atomization method, high-pressure gas production equipment used in the gas atomization method, a plasma torch used in a plasma atomization method and the like, and therefore, it is possible to reduce the size of the device and to reduce the costs including equipment costs, material costs and the like.

[0009] It is preferable that the metal powder production method and the metal powder production device of the present invention are configured to be able to emit the flame jet to the molten metal or the metal wire at a speed faster than the speed of sound. In this case, the the molten metal can be finely pulverized by a shock wave emitted by the flame jet, and the fine metal powder can be obtained. According to the metal powder production method and the metal powder production device of the present invention, the atomization method to the molten metal or the metal wire may be a free fall type or may be a confined type. According to the metal powder production method and the metal powder production device of the present invention, it is preferable that the flame jet is emitted to obliquely intersect a flow direction of the molten metal or an extending direction of the metal wire. In this case, the fine metal powder can be produced efficiently.

[0010] According to the metal powder production method of the present invention, it is preferable that the flame jet is emitted from a periphery of the molten metal or the metal wire so that the flame jet collides against the molten metal or the metal wire with an almost equal jet pressure and without leaving any space along an outer periphery of the molten metal or the metal wire. According to the metal powder production device of the present invention, it is preferable that the jet burner emits the flame jet from a periphery of the molten metal or the metal wire so that the flame jet collides against the molten metal or the metal wire with an almost equal jet pressure and without leaving any space along an outer periphery of the molten metal or the metal wire. This makes it possible to prevent the molten metal or the metal wire from scattering to escape from the flame jet at the position where the flame jet collides against the molten metal or the metal wire. Therefore, the uniform atomization to the molten metal or the metal wire is possible, and the fine and uniform spherical metal powder can be obtained. It is also possible to improve production efficiency of the metal powder.

[0011] According to the metal powder production method of the present invention, a circular jet orifice for emitting the flame jet may be provided, and the flame jet may be emitted by arranging the molten metal or the metal wire on an inner side of the flame jet emitted from the jet orifice. According to the metal powder production device of the present invention, the jet burner may include a circular jet orifice for emitting the flame jet, and the molten metal or the metal wire may be arranged on an inner side of the flame jet emitted from the jet orifice. In this case, the flame jet can be made to collide against the molten metal or the metal wire with an almost equal jet pressure and without leaving any space along an outer periphery of the molten metal or the metal wire, with relative ease. One jet burner and one combustion chamber will suffice, and therefore, the size of the device can be reduced further, and the production costs can be reduced.

[0012] According to the metal powder production method of the present invention, a plurality of flame jets may be emitted to the molten metal or the metal wire from positions rotationally symmetrical with each other with respect to the molten metal or the metal wire. According to the metal powder production device of the present invention, the jet burner may include a plurality of jet burners and may be provided to emit the flame jets to the molten metal or the metal wire from positions rotationally symmetrical with each other with respect to the molten metal or the metal wire. In this case, it is possible to pulverize the molten metal finely and to obtain the fine metal powder, by collisions between the plurality of flame jets.

[0013] Further, when there are plurality of jet burners, each of the jet burners may have an elongated jet orifice for emitting the flame jet, and a major axis direction of the jet orifice may be arranged to correspond to an outer periphery of the molten metal or the metal wire. In this case, the flame jet emitted from the jet orifice of each jet burner can be spread in a plane shape or devided into a plurality of jets, along the major axis direction of the jet orifice. When the flame jets are emitted from the plurality of jet burners so as to surround the molten metal or the metal wire, the uniform atomization to the molten metal or the metal wire is possible. It is preferable that there are three or more jet burners so as to surround the molten metal or the metal wire.

[0014] According to the metal powder production device of the present invention, the jet burner may have a heat-resistant nozzle at its tip end, the heat-resistant nozzle having a through hole therein through which the molten metal or the metal wire passes, and the jet burner may be provided to be able to emit the flame jet to the molten metal or the metal wire passing through the through hole. In this case, the metal powder can be obtained by one jet burner. The heat-resistant nozzle may divide the flame jet in its inside into a plurality of jets, and may emit the divided jets to the molten metal or the metal wire, passing through the through hole, from positions rotationally symmetrical with each other. Any material, such as carbon or water-cooled copper, may be used to form the heat-resistant nozzle as long as the material is heat-resistant.

Advantageous Effects of Invention

[0015] According to the present invention, it is possible to provide the metal powder production method and the metal powder production device capable of reducing the size of the device, reducing the costs, and obtaining the spherical metal powder.

BRIEF DESCRIPTION OF DRAWINGS

[0016] Figs. 1(a) and 1(b) are side views illustrating a usage state of a metal powder production device according to a first embodiment of the present invention where (a) shows a free fall type, and (b) shows a confined type;

Fig. 2 is a side view illustrating a modification of the metal powder production device according to the first embodiment of the present invention, in which a metal wire is used;

Fig. 3 is a side view illustrating a modification of the metal powder production device according to the first embodiment of the present invention, in which jet burners are modified;

Fig. 4 is a vertical cross-sectional view illustrating the metal powder production device according to a second embodiment of the present invention;

Fig. 5(a) is a perspective view illustrating the metal powder production device according to a third embodiment of the present invention, and Fig. 5(b) is a perspective view illustrating its usage state;

Fig. 6(a) is a front view illustrating a jet orifice of the metal powder production device as in Figs. 5, and Fig. 6(b) is a side view illustrating the shape of an emitted flame jet;

Fig. 7(a) is an enlarged side view illustrating a state of the flame jets emitted from the metal powder production device as in Fig. 1(a), Fig. 7(b) is an enlarged side view near an emitting position of the flame jet, illustrating a state of atomization when molten metal is used in the metal powder production device as in Fig. 1(a), Fig. 7(c) is an electron micrograph of $Fe_{75}Si_{10}B_{15}$ amorphous powder obtained from Fe-Si-B based molten metal by the metal powder production device as in Fig. 1(a), and Fig. 7(d) is an electron micrograph illustrating enlarged particles of the powder;

Fig. 8(a) is an electron micrograph at 150-fold magnification and Fig. 8(b) is an electron micrograph at 1000-fold magnification of metal powder obtained by the metal powder production device as in Fig. 2 from a metal wire of stainless steel SUS420;

Fig. 9(a) is an electron micrograph at 1500-fold magnification and Fig. 9(b) is an electron micrograph at 2500-fold magnification of metal powder obtained by the metal powder production device as in Fig. 2 from a metal wire of a TIG welding rod (TGS50 manufactured by Kobe Steel, Ltd.);

Fig. 10(a) is an electron micrograph at 200-fold magnification and Fig. 10(b) is an electron micrograph at 1200-fold magnification of metal powder obtained by the metal powder production device as in Fig. 2 from a metal wire of SUS420 alloy; and

Figs. 11(a) to 11(c) are graphs illustrating particle size distribution of metal powder produced by emitting a flame jet to molten metal of $Fe\text{-}Si_{10}\text{-}B_{15}$ alloy by (a) the metal powder production device as in Fig. 1(a), (b) the metal powder production device as in Fig. 4, and (c) the metal powder production device as in Fig. 4 having a Laval nozzle type jet orifice.

DESCRIPTION OF EMBODIMENTS

[0017] Hereinafter, embodiments of the present invention will be explained with reference to the drawings.

[0018] Figs. 1 and Fig. 3 illustrate a metal powder production device according to a first embodiment of the present invention.

[0019] As illustrated in Figs. 1, a metal powder production device 10 has supply means 11 and a plurality of jet burners 12. In the following, an explanation will be mainly given to a free fall type that is illustrated in Fig. 1(a).

[0020] As illustrated in Fig. 1(a), the supply means 11 is formed by a container containing molten metal. The supply means 11 has, at the center of its bottom surface, a molten metal injection nozzle 11a that communicates with its inside. The supply means 11 is configured to be able to discharge the molten metal contained therein downward from the molten metal injection nozzle 11a.

[0021] Each of the plurality of jet burners 12 is able to emit a flame jet 12a at a speed faster than the speed of sound. Each of the jet burners 12 is arranged under the supply means 11 to be able to emit the flame jet 12a obliquely downward. Each of the jet burners 12 is provided to emit the jet to a downward flow 1 of the molten metal from the molten metal injection nozzle 11a in such a manner that the jet obliquely intersects the downward flow 1 at the same angle, from each of positions rotationally symmetrical with each other with respect to the downward flow 1. Thereby, the respective jet burners 12 are made to emit the flame jets 12a to one point of the downward flow 1 in a concentrated manner.

[0022] According to a specific example, the jet burner 12 is formed by a jet burner manufactured by Hard Industry Yugen Kaisha, which is small-sized, and is able to emit the flame jet 12a at the speed faster than the speed of sound. There are three jet burners 12 that are arranged at positions with the same distance from the downward flow 1 and at intervals of a central angle of 120 degrees, with the downward flow 1 of the molten metal serving as a central axis, and that emit the jets to the downward flow 1 from an obliquely upward direction at an angle of about 45 degrees. Further, each of the jet burners 12 are made to emit the flame jet 12a at the same pressure and speed.

[0023] It is possible for the metal powder production device 10 to preferably implement a metal powder production method according to the first embodiment of the present invention. The metal powder production device 10 can obtain metal powder by using the principle of an atomization method. By emitting the high-temperature flame jet 12a to the downward flow 1 of the molten metal, the molten metal can be pulverized. As the temperature of the flame jet 12a at this time is higher than those of high-pressure water of a water atomization method and high-pressure gas of a gas atomization method, flow velocity of blowing fluid can be increased to be higher than those of the water atomization method and the gas atomization method. Due to its high temperature, it is not necessary to cool the molten metal for atomization, nor to increase the temperature of the molten metal more than necessary. For example, the temperature of the molten metal may be set to be lower than those of the conventional water atomization method and the gas atomization method by about 50 to 100°C. Therefore, the molten metal can be finely pulverized under the condition in which the molten metal is amorphized more easily. Thus-pulverized molten metal is allowed to fall or scatter in an atmosphere and statically supercooled, so as to enable vitrification and to obtain fine metal powder with ease. In addition, it is possible to obtain the metal powder that is finer than those obtained by the water atomization method and the gas atomization method.

[0024] When each of jet burners 12 emits the flame jet 12a at the speed faster than the speed of sound, the metal powder production device 10 can finely pulverize the molten metal by a shock wave emitted by the flame jet 12a. Further, each of the jet burners 12 emits the flame jet 12a to one point of the the downward flow 1 in a concentrated manner from the same angle and from each of the positions rotationally symmetrical with each other with respect to the downward flow 1 of the molten metal, which makes it possible to pulverize the molten metal more finely and to obtain the finer metal powder, by collisions between the plurality of flame jets 12a. It should be noted that the obtained metal powder can be collected easily when a container or a chamber is provided under the supply means 11 in such a manner to cover peripheral portions and lower portions of the respective flame jets 12a.

[0025] As the jet burners 12 used in the metal powder production device 10 are relatively inexpensive and small-sized as compared with a high-pressure pump used in the water atomization method, high-pressure gas production equipment used in the gas atomization method, a plasma torch used in a plasma atomization method and the like, it is possible to reduce the size of the device and to reduce the costs including equipment costs, material costs and the like.

[0026] Incidentally, the metal powder production device 10 may be a confined type as illustrated in Fig. 1(b). With regard to the confined type, efficient atomization is possible without attenuating kinetic energy of the flame jets 12a of the respective jet burners 12, as the confined type can supply the molten metal directly to an atomizing zone, as well as the similar effects as those of the free fall type can be obtained. When the conventional gas atomization or the like is used in the confined type, there is such a problem that the molten metal is solidified and clogging of the molten metal injection nozzle 11a is easily caused as the molten metal injection nozzle 11a is cooled by the emitted gas and the like. On the contrary, with the metal powder production device 10 as illustrated in Fig. 1(b), it is possible to prevent the solidification of the molten metal and the occurrence of the clogging of the molten metal injection nozzle 11a because the high-temperature flame jets 12a are emitted from the respective jet burners 12 and the molten metal injection nozzle 11a is not cooled.

[0027] In the metal powder production device 10, as illustrated in Fig. 2, the supply means 11 may be provided to be able to supply a metal wire 2 continuously to a downward direction, and the respective jet burners 12 may be provided to emit the flame jets 12a to the metal wire 2. In this case, the high-temperature flame jets 12a are emitted to the metal wire 2, so as to melt the metal wire 2 and to pulverize the melted metal. Material of the metal wire 2 may be, for example, stainless steel or SUS420 alloy.

[0028] Further, the metal powder production device 10 may include one jet burner 12 having a heat-resistant nozzle at its tip end. The heat-resistant nozzle may be configured to include a through hole therein, through which the molten metal or the metal wire passes, divide the flame jet 12a in its inside into a plurality of jets, and emit the divided jets to the molten metal or the metal wire, passing through the through hole, from positions rotationally symmetrical with each other and from the same angle with respect to the molten metal or the metal wire. In this case, it is possible to obtain the metal powder by one jet burner 12. The heat-resistant nozzle may be obtaibed by forming the nozzle used in the water atomization method or the gas atomization method by heat-resistant material such as carbon or water-cooled copper.

[0029] Further, in the metal powder production device 10, as illustrated in Fig. 3, a jet nozzle 12c of each of the jet burners 12 may be bent so that an emitting direction of the flame jet 12a has a specified angle with respect to a longitudinal direction of a body 12b of the jet burner 12. In this case, the jet nozzle 12c can be easily brought closer to the molten metal injection nozzle 11a of the supply means 11. This is effective especially when the metal powder production device 10 is the confined type.

[0030] Fig. 4 illustrates the metal powder production device and the metal powder production method according to a second embodiment of the present invention.

[0031] As illustrated in Fig. 4, a metal powder production device 20 is the confined type, and has the supply means 11 and the jet burner 12.

[0032] Incidentally, in the following explanation, the same numerals and symbols will be used to designate the same components as those in the metal powder production device 10 according to the first embodiment of the present invention, and the repeated explanation will be omitted.

[0033] The supply means 11 has a container 21 containing the molten metal, and a supply hole 21a that communicates with the outside at the center of the bottom of the container 21. Further, the supply means 11 has the molten metal injection nozzle 11a that communicates with the supply hole 21a and is attached to the center of the bottom surface of the container 21 via a heat insulating plate 22 (an alumina plate, for example). The molten metal injection nozzle 11a has a tapered shape, whose tip end has such an external form that is gradually thinnes downward. The supply means 11 can supply the molten metal that is contained in the container 21 through the molten metal injection nozzle 11a.

[0034] The jet burner 12 has a combustion chamber (not illustrated) and a circular jet orifice 24 for emitting the flame jet. The jet burner 12 is provided under the container 21 of the supply means 11 in such a manner that the molten metal injection nozzle 11a is arranged on an inner side of the jet orifice 24. The jet burner 12 is formed in such a manner that the jet orifice 24 corresponds to the tapered shape of the tip end of the molten metal injection nozzle 11a.

[0035] The jet burner 12 is configured to be able to emit the flame jet from the jet orifice 24 toward a forward inner side and along the circumference of the jet orifice 24 without leaving any space. Thereby, the jet burner 12 is able to emit the flame jet concentrically on one point of the molten metal, from the periphery of the molten metal supplied from the molten metal injection nozzle 11a, in such a manner that the flame jet obliquely intersects a flow direction of the molten metal. Further, with the jet burner 12, the flame jet is made to collide against the molten metal along the outer periphery of the molten metal supplied from the molten metal injection nozzle 11a with an almost equal jet pressure and without leaving any space.

[0036] The jet burner 12 also has a water cooling unit 25 that circulates water in the periphery of the jet orifice 24 and cools the jet orifice 24. Incidentally, the jet burner 12 can also emit the flame jet at the speed faster than the speed of sound. In the specific example, the jet burner 12 is made to emit the jet to the molten metal supplied downward from the molten metal injection nozzle 11a, from the obliquely upward direction at an angle of about 40 degrees.

[0037] It is possible for the metal powder production device 20 to preferably implement the metal powder production method according to the second embodiment of the present invention. With the metal powder production device 20 and the metal powder production method according to the second embodiment of the present invention, the flame jet that is emitted from the periphery of the molten metal is made to collide against the molten metal along the outer periphery of the molten metal with the almost equal jet pressure and without leaving any space, which makes it possible to prevent the molten metal from scattering to escape from the flame jet at the colliding position. Therefore, uniform atomization to the molten metal is possible, and fine and uniform spherical metal powder can be obtained. It is also possible to improve production efficiency of the metal powder. According to the specific example, the diameter of the produced metal powder is about 5 μm.

[0038] With the metal powder production device 20 and the metal powder production method according to the second embodiment of the present invention, one jet burner 12 and one combustion chamber will suffice, and therefore, the size of the device can be reduced further, and the production costs can also be reduced further. Incidentally, it is also possible for the metal powder production device 20 and the metal powder production method according to the second embodiment of the present invention to emit the high-temperature flame jet to the metal wire, not to the molten metal.

[0039] Figs. 5 and Figs. 6 illustrate the metal powder production device and the metal powder production method according to a third embodiment of the present invention.

[0040] As illustrated in Figs. 5 and Figs. 6, a metal powder production device 30 has the supply means 11 and the jet burners 12.

[0041] Incidentally, in the following explanation, the same numerals and symbols will be used to designate the same components as those in the metal powder production device 10 according to the first embodiment of the present invention and the metal powder production device 20 according to the second embodiment of the present invention, and the repeated explanation will be omitted.

[0042] In the metal powder production device 30, there are three jet burners 12, each of which has an elongated jet orifice 24 for emitting the flame jet 12a. Each of the jet burners 12 is arranged in such a manner that a major axis direction of the jet orifice 24 corresponds to the outer periphery of the downward flow 1 of the molten metal. Each of the jet burners 12 is provided to be able to emit the flame jet 12a at the same pressure and the same speed to the downward flow 1, from each of the positions rotationally symmetrical with each other and from the same angle with respect to the downward flow 1.

[0043] In the specific example illustrated in Figs. 5 and Figs. 6, each jet orifice 24 has a gourd shape in which two circles are connected. Further, the respective jet burners 12 are arranged at the positions with the same distance from the downward flow 1 and at the intervals of the central angle of 120 degrees, with the downward flow 1 of the molten metal serving as the central axis, and the respective jet burners 12 emit the jets to the downward flow 1 from the obliquely upward direction at the angle of about 40 degrees.

[0044] It is possible for the metal powder production device 30 to preferably implement the metal powder production method according to the third embodiment of the present invention. With the metal powder production device 30 and the metal powder production method according to the third embodiment of the present invention, the flame jet 12a emitted from the jet orifice 24 of each jet burner 12 can be spread in a plane shape or devided into a plurality of jets, along the major axis direction of the jet orifice 24, as illustrated in Fig. 6(b). Therefore, the flame jets 12a are emitted from the respective jet burners 12 so as to surround the downward flow 1 of the molten metal, and thus, the flame jets 12a are made to collide against the downward flow 1 of the molten metal along the outer periphery of the downward flow 1 of the molten metal with the almost equal jet pressure and without leaving any space. This makes it possible to prevent the molten metal from scattering to escape from the flame jet 12a at the colliding position. Therefore, the uniform atomization to the molten metal is possible, and the fine and uniform spherical metal powder can be obtained. It is also possible to improve the production efficiency of the metal powder.

[0045] Incidentally, it is also possible for the metal powder production device 30 and the metal powder production method according to the third embodiment of the present invention to emit the high-temperature flame jets 12a to the metal wire, not to the molten metal.

[Example 1]

[0046] The state of the flame jets 12a emitted from the metal powder production device 10 as illustrated in Fig. 1(a) is illustrated in Fig. 7(a). A convergence of the plurality of flame jets can be confirmed as in Fig. 7(a). This metal powder production device 10 was used to emit the flame jets 12a to Fe-Si-B based molten metal, and then fine spherical $Fe_{75}Si_{10}B_{15}$ amorphous powder was obtained. Fig. 7(b) to Fig. 7(d) illustrate the state of the flame jet 12a near the emitting position at this time, and electron micrographs of the obtained powder.

[Example 2]

[0047] The metal powder production device 10 as illustrated in Fig. 2 was used to emit the flame jets 12a to the metal wire 2 of stainless steel SUS420, and then fine spherical metal powder was obtained. Electron micrographs of the obtained metal powder are illustrated in Figs. 8.

[Example 3]

[0048] The metal powder production device 10 as illustrated in Fig. 2 was used to emit the flame jets 12a to the metal wire 2 of a TIG welding rod TGS50 (manufactured by Kobe Steel, Ltd.), and then fine and spherical metal powder was obtained. Electron micrographs of the obtained metal powder are illustrated in Figs. 9.

[Example 4]

[0049] The metal powder production device 10 as illustrated in Fig. 2 was used to emit the flame jets 12a to the metal wire 2 of SUS420 alloy, and then fine and spherical metal powder was obtained. Electron micrographs of the obtained metal powder are illustrated in Figs. 10.

[Example 5]

[0050] The metal powder production device 10 as illustrated in Fig. 1(a), the metal powder production device 20 as illustrated in Fig. 4, and the metal powder production device 20 as illustrated in Fig. 4 having a Laval nozzle type jet orifice 24 were used to emit the flame jets to the molten metal of $Fe\text{-}Si_{10}\text{-}B_{15}$ alloy, so as to produce the metal powder. Particle size distribution of the metal powder produced in the respective devices is illustrated in Figs. 11.

[0051] Incidentally, in the metal powder production device 10 as illustrated in Fig. 1(a), the four jet burners 12 were arranged at the intervals of the central angle of 90 degrees, with the downward flow 1 of the molten metal serving as the central axis, and the respective jet burners 12 emitted the flame jets to the downward flow 1 from the obliquely upward direction at the angle of about 15 degrees (vertex angle of 30 degrees). With regard to combustion parameters per one jet burner 12, air volume is 700 L/min and fuel (kerosene) is 130 mL/min. With regard to the combustion parameters of the metal powder production device 20 as illustrated in Fig. 4, the air volume is 3000 L/min and the fuel (kerosene) is 550 mL/min. With regard to the combustion parameters of the Laval nozzle type, the air volume is 3000 L/min and the fuel (kerosene) is 550 mL/min.

[0052] With regard to the metal powder produced by the metal powder production device 10 as illustrated in Fig. 1(a) and by the metal powder production device 20 as illustrated in Fig. 4, the most common diameter was 40 to 70 μm, and the diameter was 100 μm or less for the most part, as illustrated in Figs. 11(a) and 11(b). With regard to the metal powder produced by the Laval nozzle type, the diameter was 50 μm or less for the most part. From these results, it was confirmed that the fine powder can be obtained by the emission of the flame jet. As the diameter of the produced metal powder is smaller in the Laval nozzle type, it is found that the diameter of the produced metal powder is reduced as the speed of the flame jet is increased.

Reference Signs List

[0053]

1	downward flow
2	metal wire
10	metal powder production device
11	supply means
11(a)	molten metal injection nozzle
12	jet burner
12a	flame jet

Claims

1. A metal powder production method comprising obtaining metal powder by emitting a flame jet to molten metal or a metal wire.

2. The metal powder production method according to claim 1,
wherein the flame jet is emitted from a periphery of the molten metal or the metal wire so that the flame jet collides against the molten metal or the metal wire with an almost equal jet pressure and without leaving any space along an outer periphery of the molten

metal or the metal wire.

3. The metal powder production method according to claim 1 or claim 2,
wherein a circular jet orifice for emitting the flame jet is provided, and the flame jet is emitted by arranging the molten metal or the metal wire on an inner side of the flame jet emitted from the jet orifice.

4. The metal powder production method according to claim 1 or claim 2,
wherein a plurality of flame jets are emitted to the molten metal or the metal wire from positions rotationally symmetrical with each other with respect to the molten metal or the metal wire.

5. A metal powder production device comprising:

    supply means for supplying molten metal or a metal wire; and
    a jet burner for emitting a flame jet to the molten metal or the metal wire supplied from the supply means.

6. The metal powder production device according to claim 5,
wherein the jet burner emits the flame jet from a periphery of the molten metal or the metal wire so that the flame jet collides against the molten metal or the metal wire with an almost equal jet pressure and without leaving any space along an outer periphery of the molten metal or the metal wire.

7. The metal powder production device according to claim 5 or claim 6,
wherein the jet burner comprises a circular jet orifice for emitting the flame jet, and the molten metal or the metal wire is arranged on an inner side of the flame jet emitted from the jet orifice.

8. The metal powder production device according to claim 5 or claim 6,
wherein the jet burner comprises a plurality of jet burners that are provided to emit the flame jets to the molten metal or the metal wire from positions rotationally symmetrical with each other with respect to the molten metal or the metal wire.

9. The metal powder production device according to claim 8,
wherein each of the jet burners has an elongated jet orifice for emitting the flame jet, and a major axis direction of the jet orifice is arranged to correspond to an outer periphery of the molten metal or the metal wire.

10. The metal powder production device according to claim 5 or claim 6,
wherein the jet burner has a heat-resistant nozzle at its tip end, the heat-resistant nozzle having a through hole therein through which the molten metal or the metal wire passes, and the jet burner is provided to be able to emit the flame jet to the molten metal or the metal wire passing through the through hole.

Fig.1

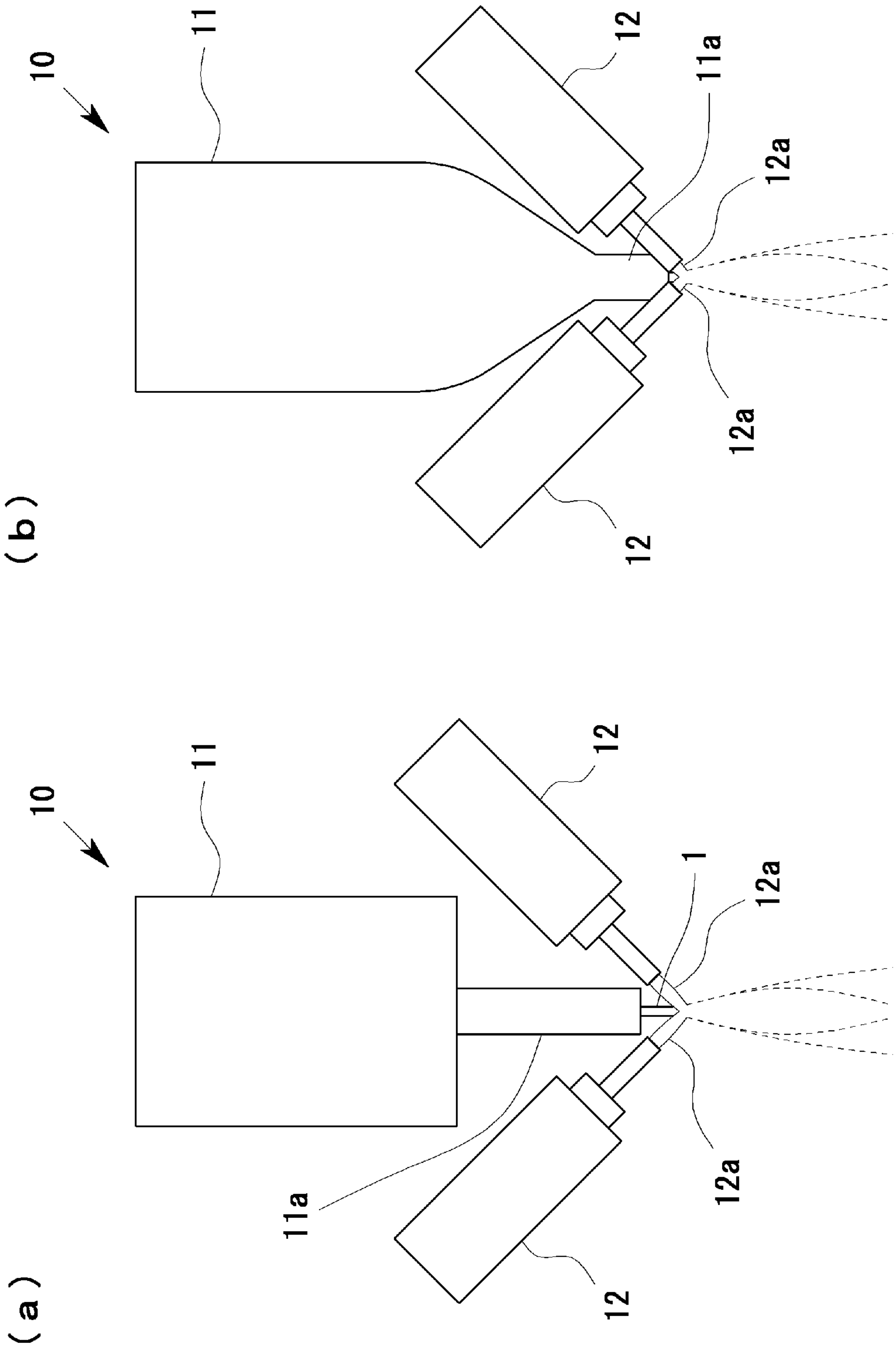


Fig.2

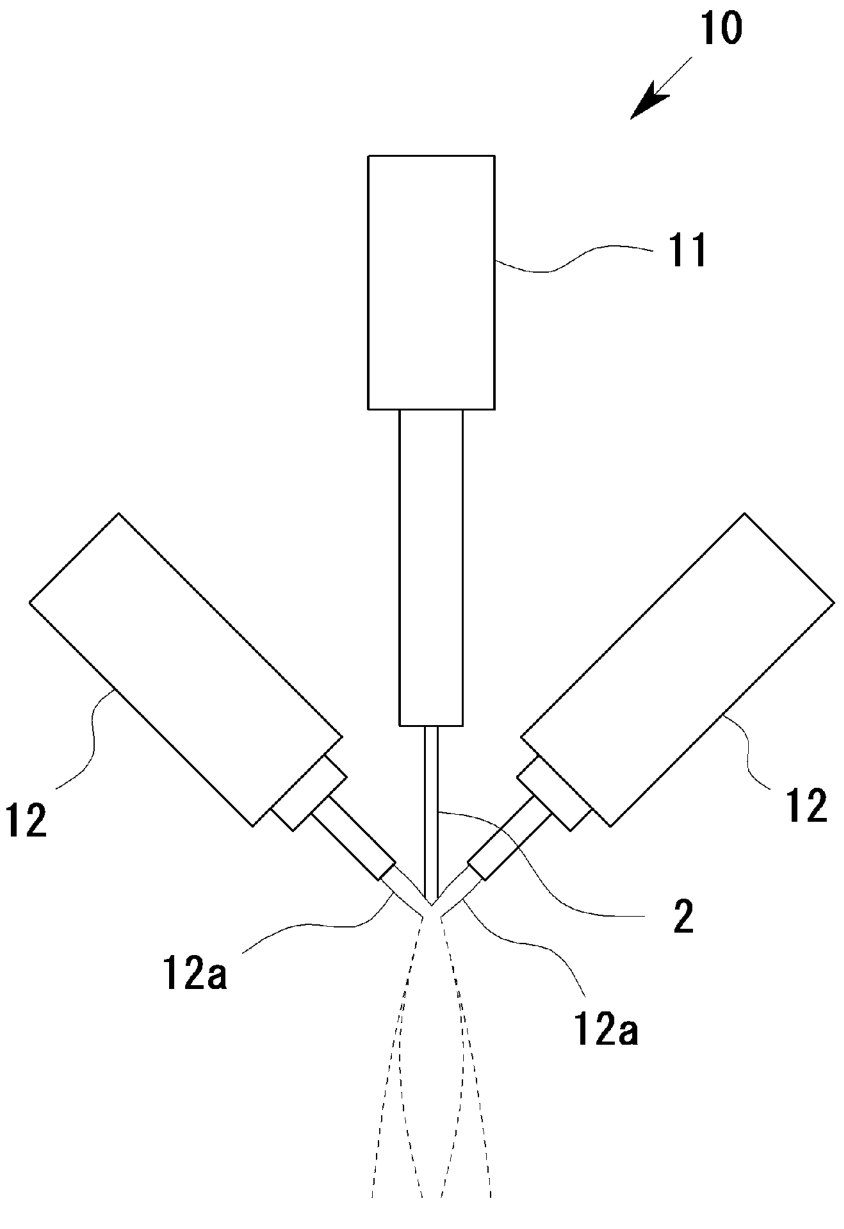


Fig.3

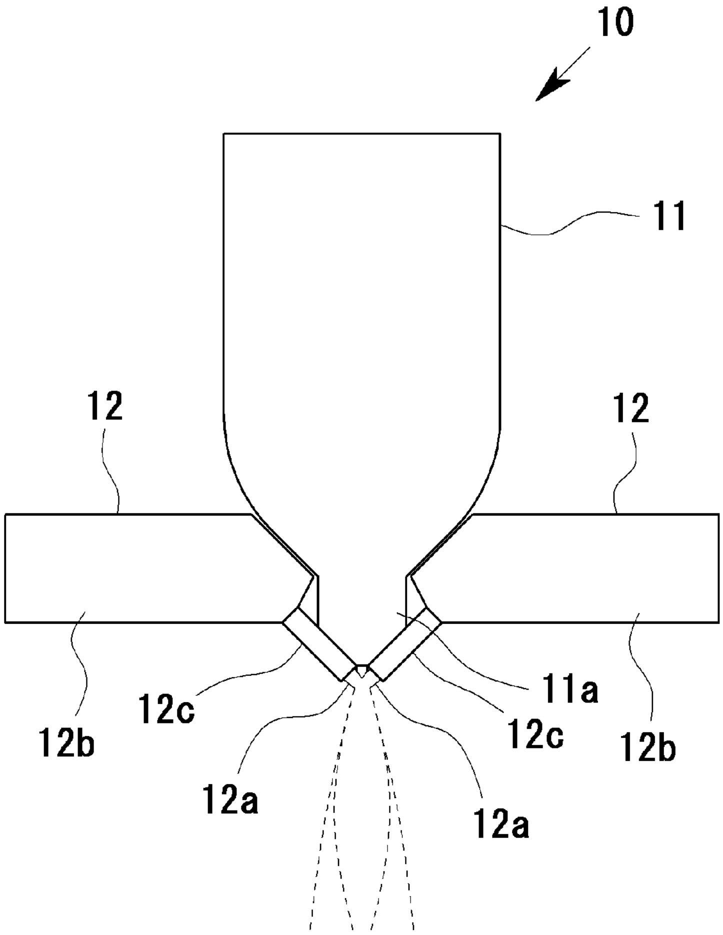


Fig.4

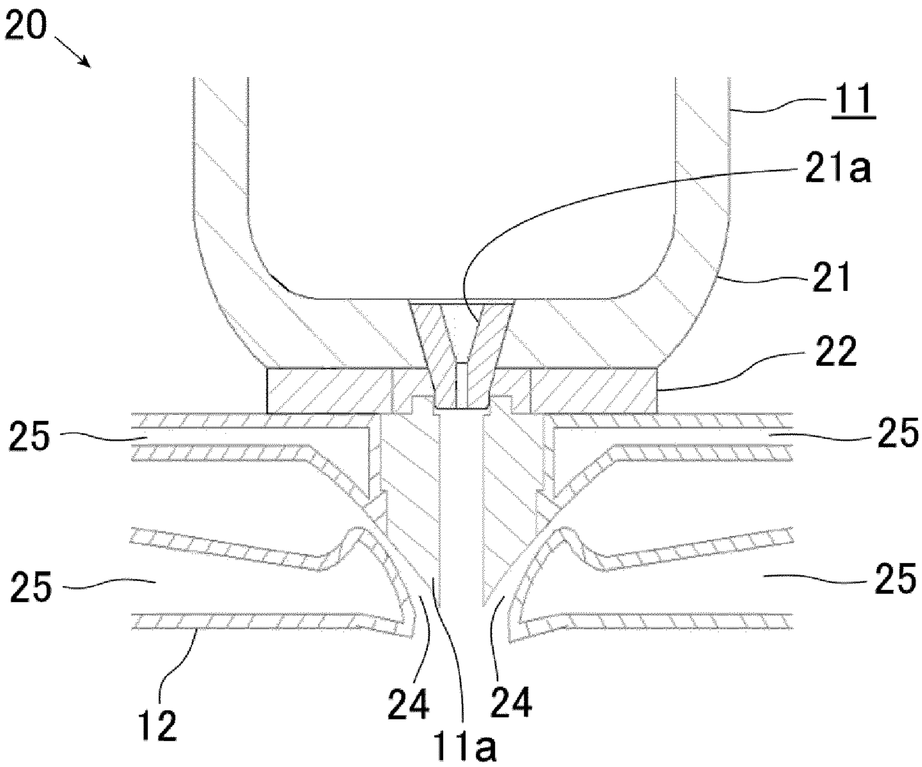
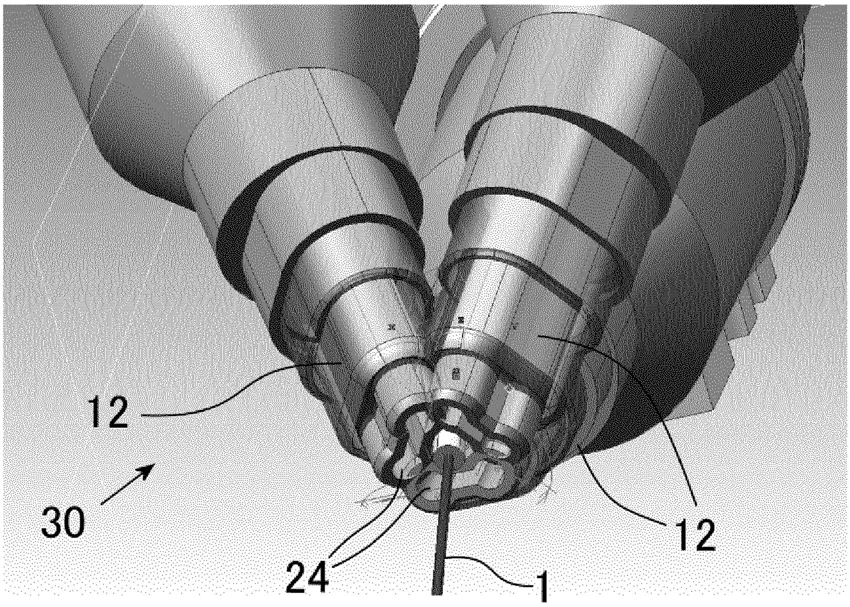


Fig.5

(a)



(b)

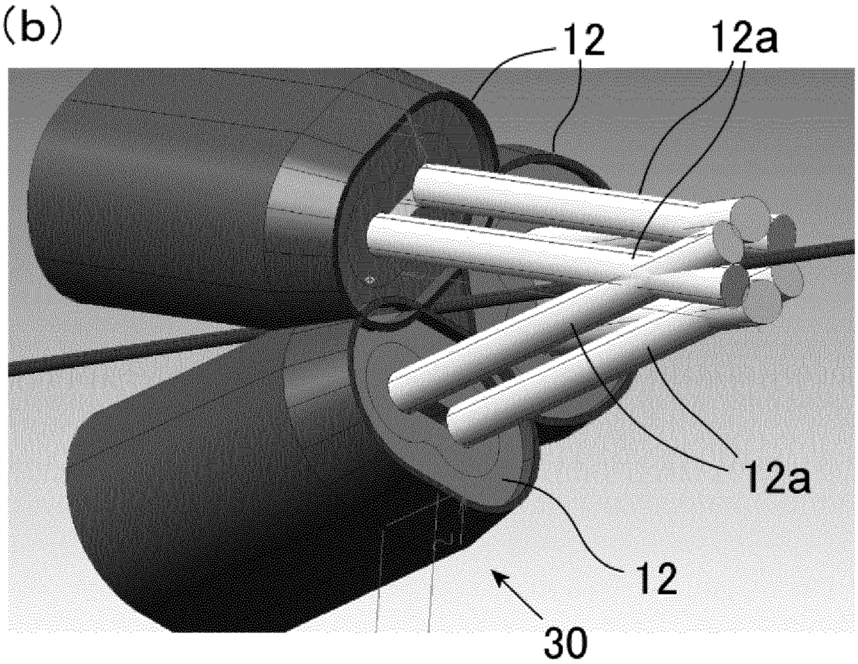


Fig.6

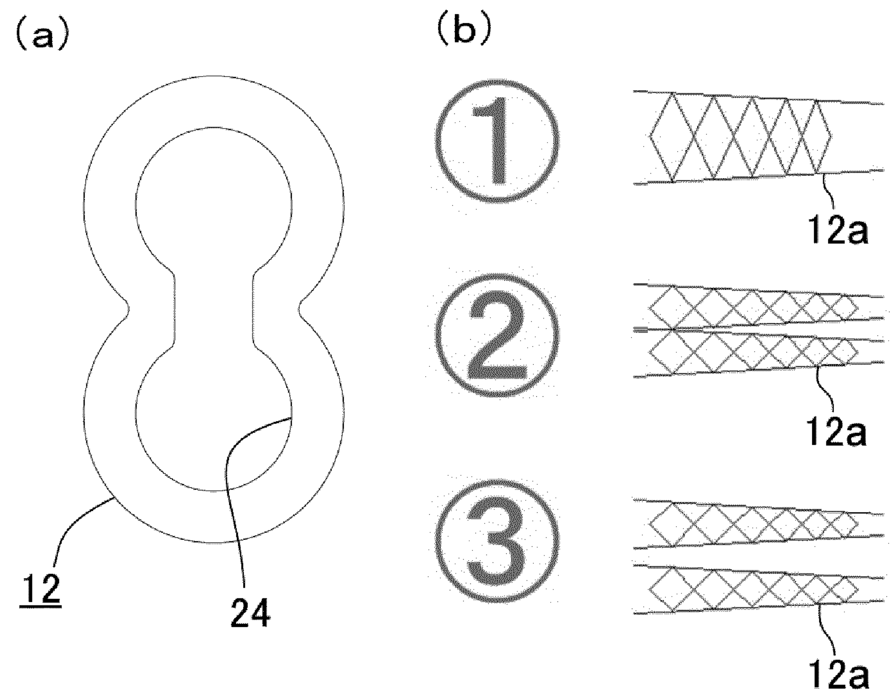


Fig.7

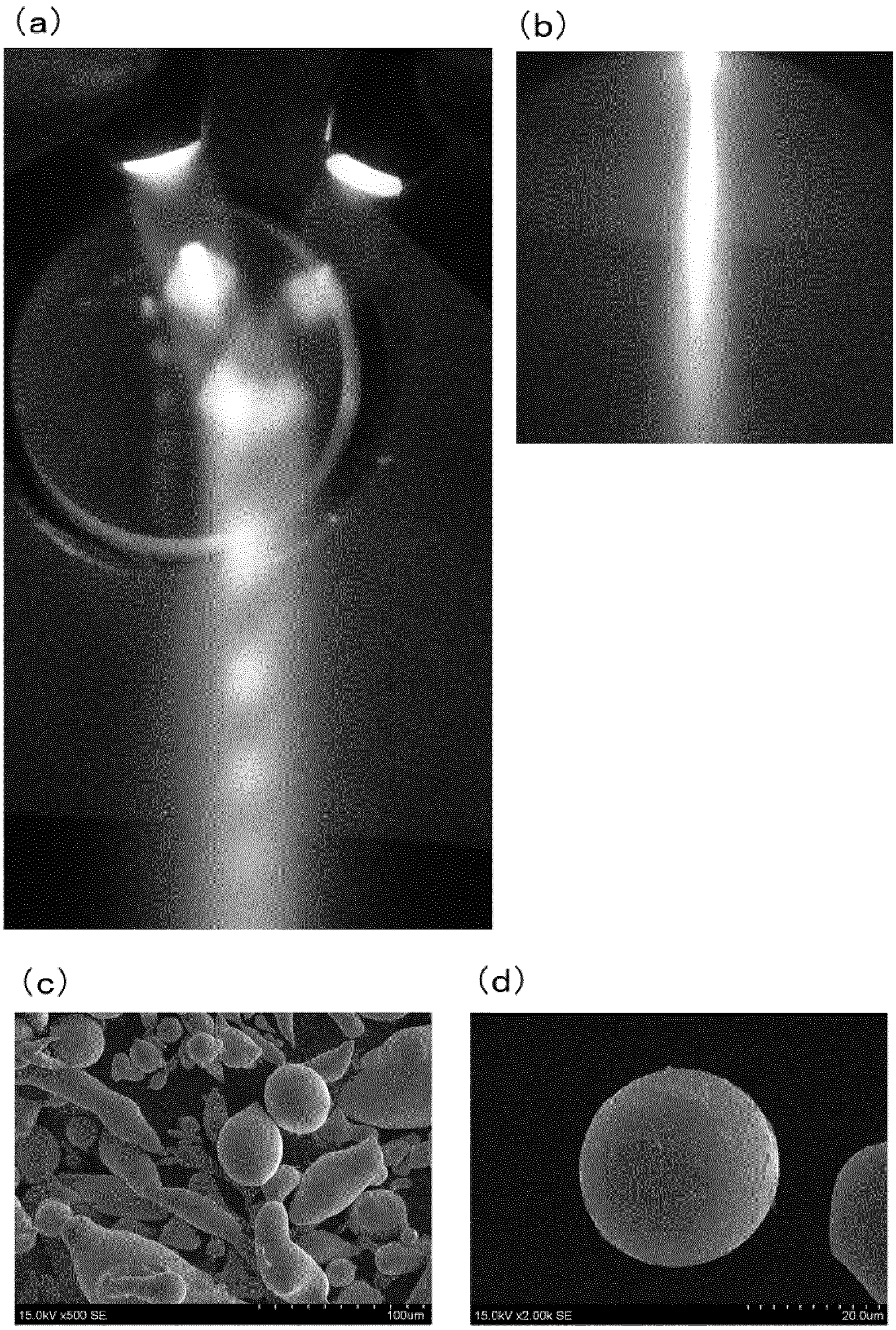
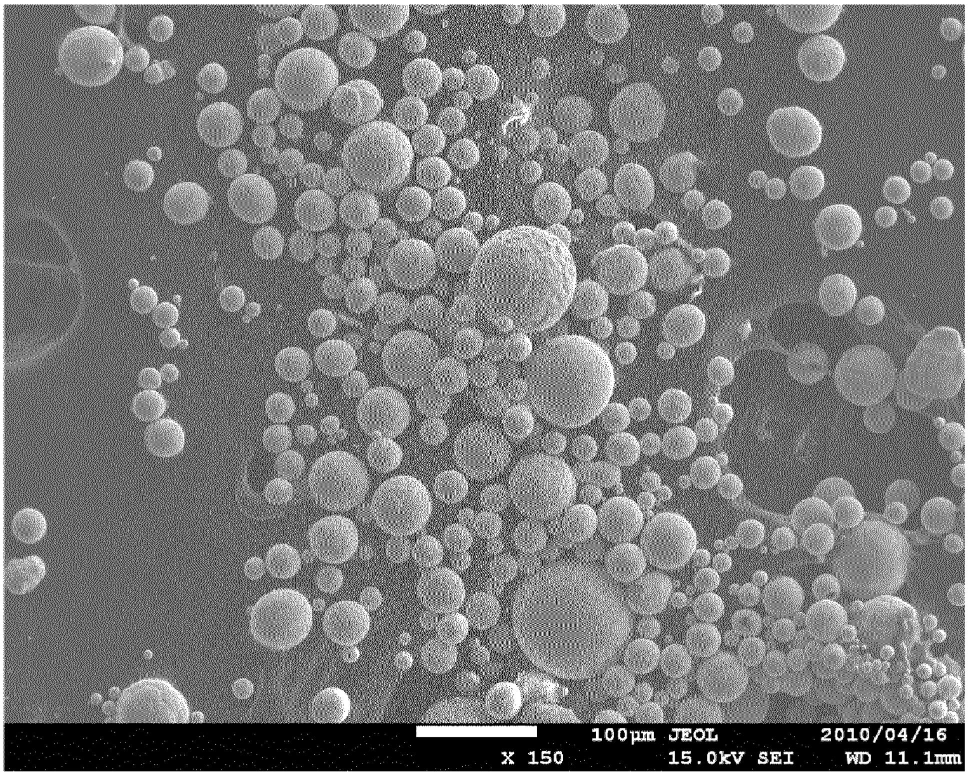


Fig.8

(a)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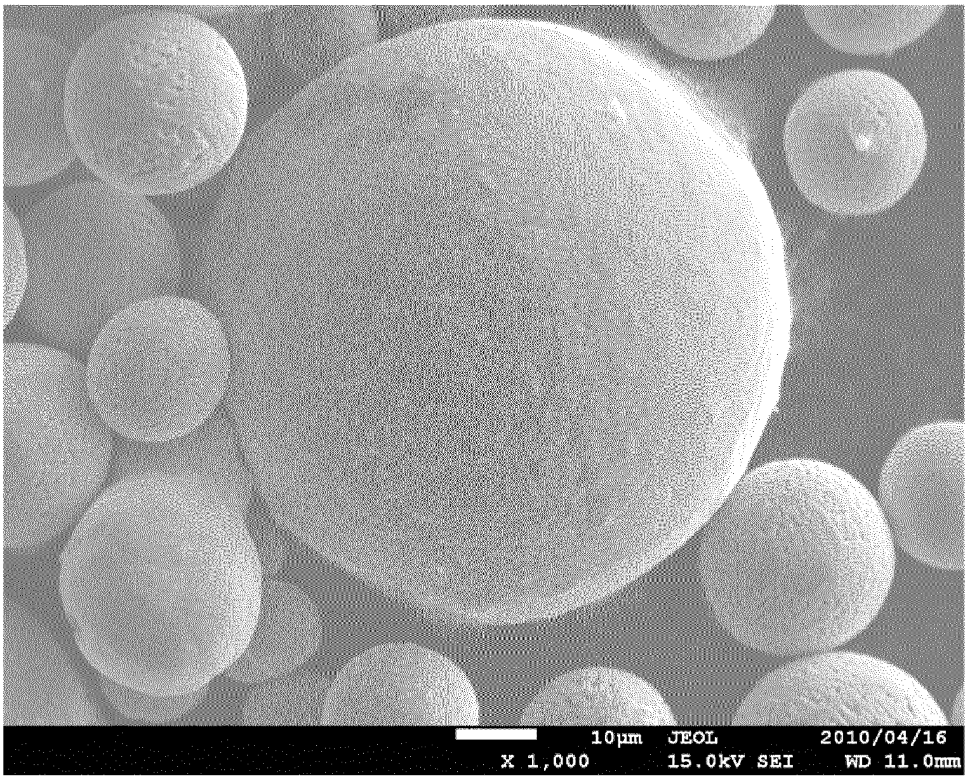
2010/04/16
X 150
15.0kV SEI
WD 11.1mm

(b)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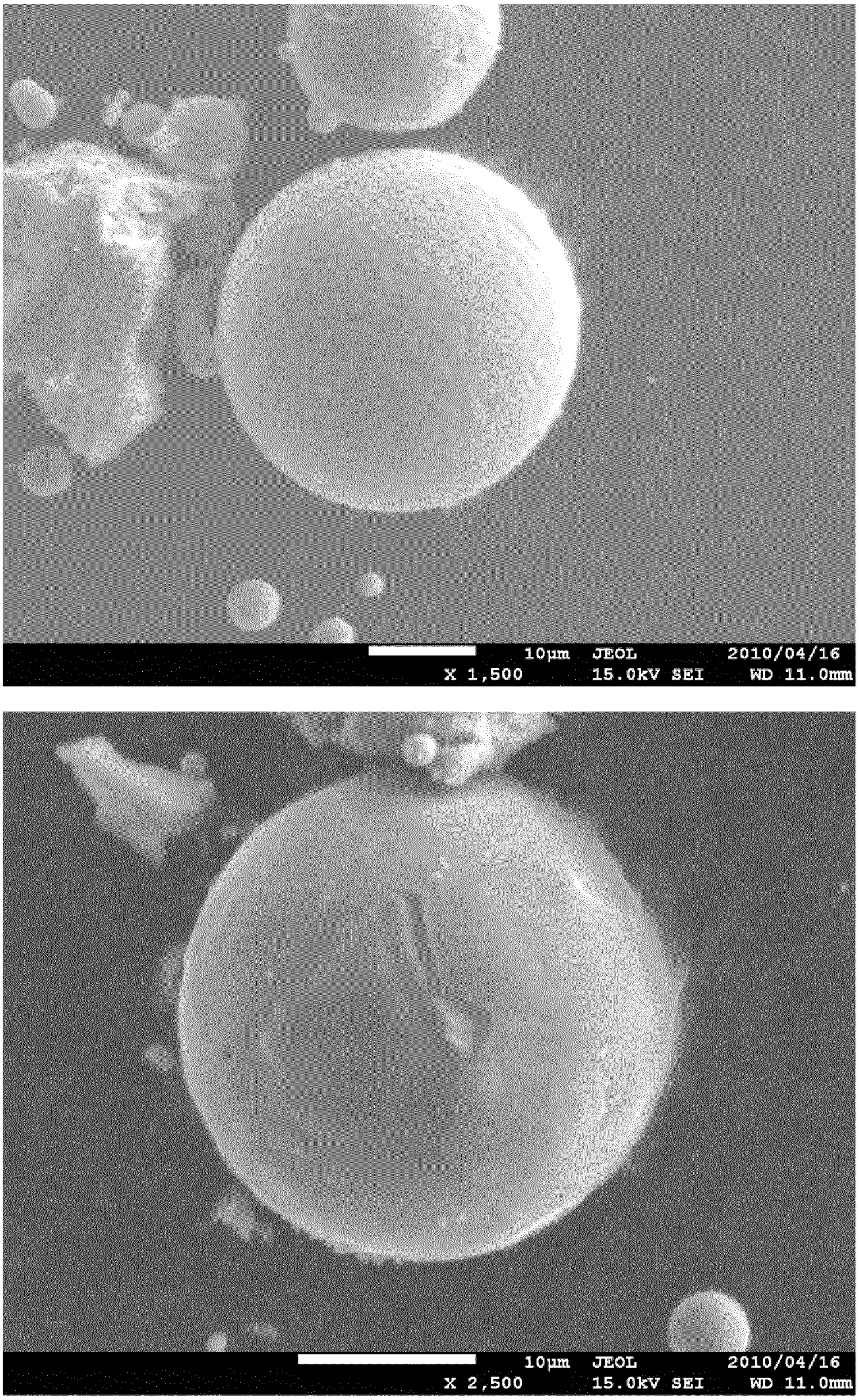
2010/04/16
X 1,000
15.0kV SEI
WD 11.0mm

Fig.9

(a)

(b)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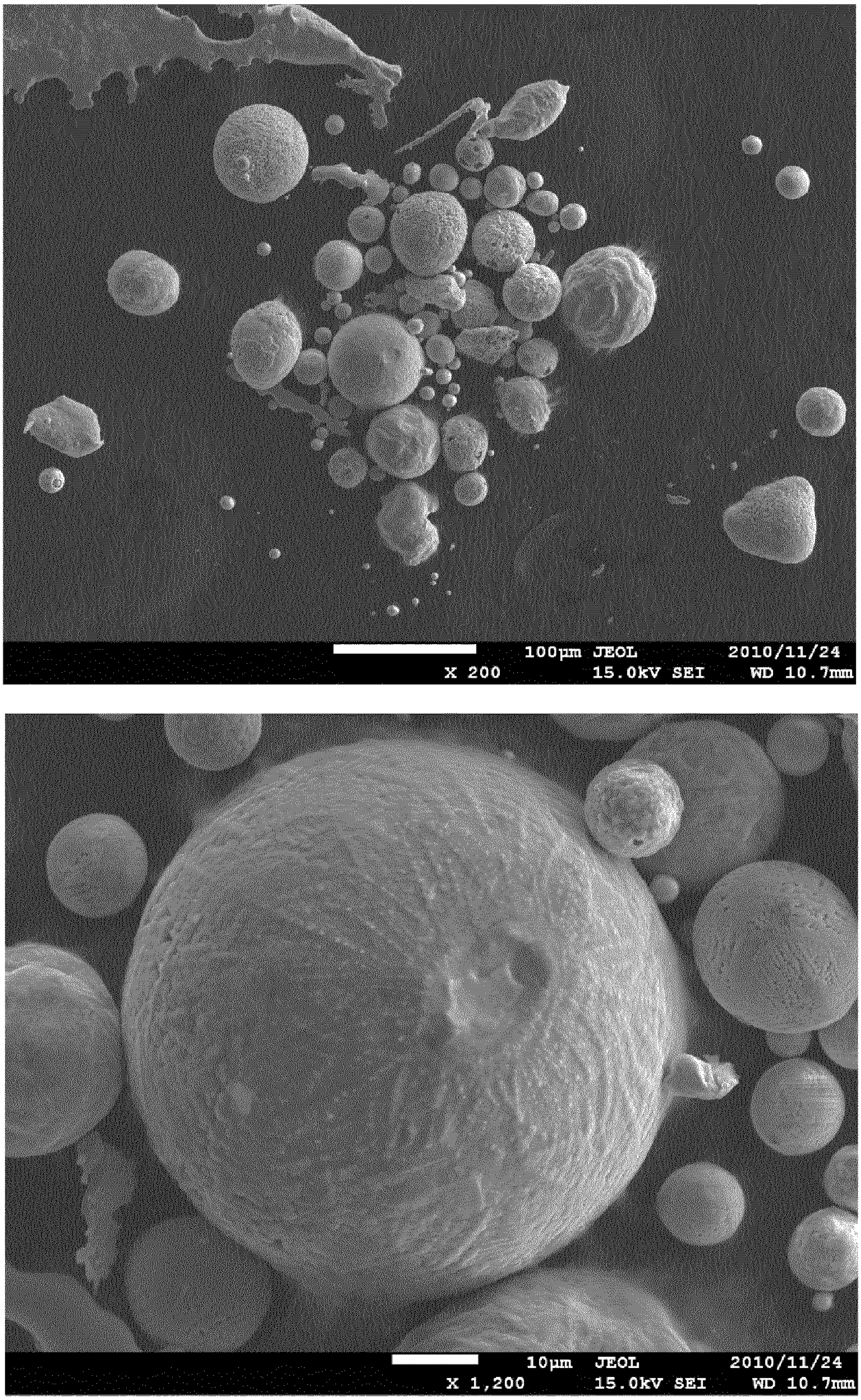
X 1,500 15.0kV SEI WD 11.0mm
10μm JEOL 2010/04/16
X 2,500 15.0kV SEI WD 11.0mm

Fig.10

(a)

(b)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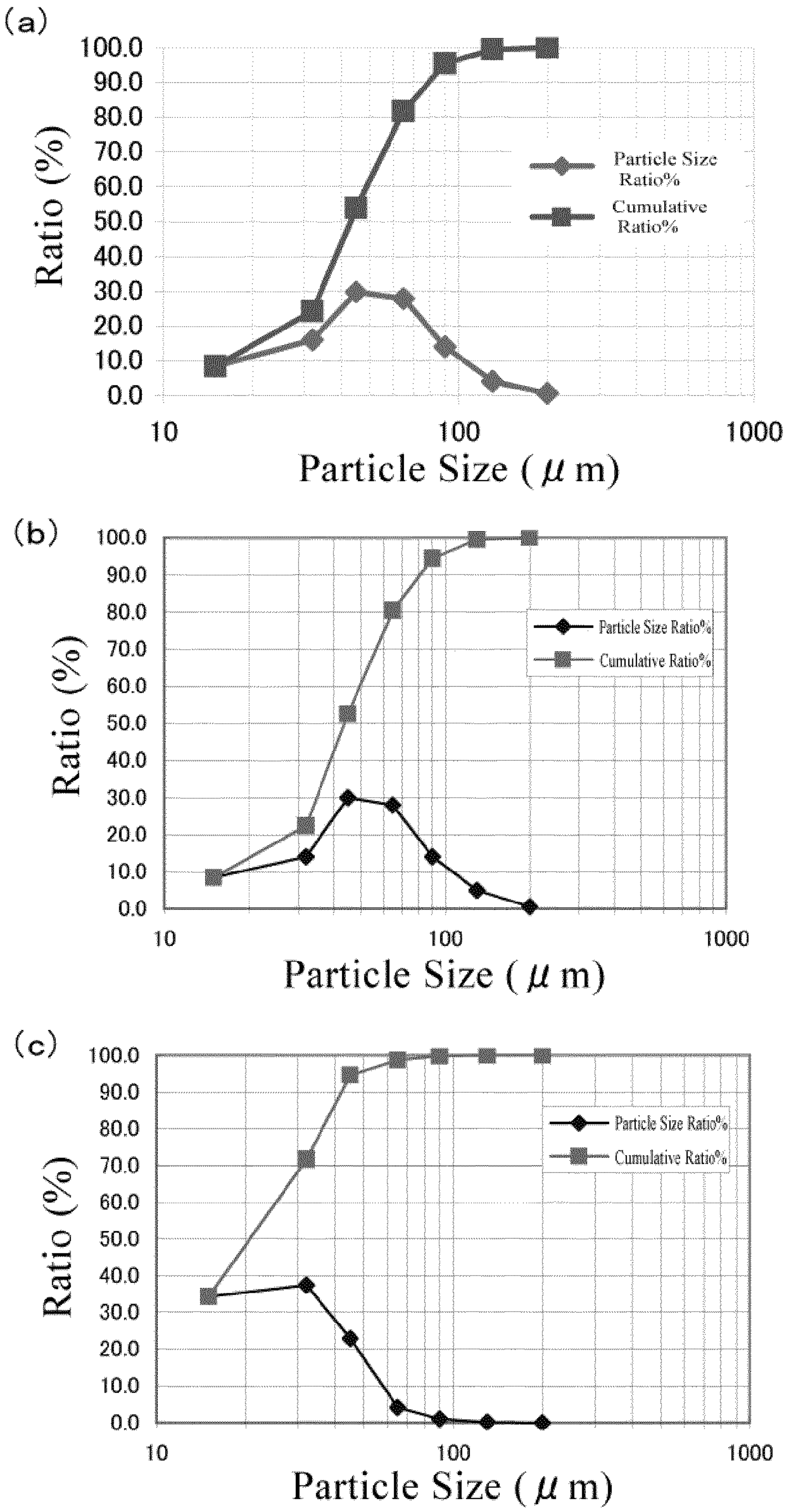
X 200 15.0kV SEI WD 10.7mm
10μm JEOL 2010/11/24
X 1,200 15.0kV SEI WD 10.7mm

Fig.11


(a)
Ratio (%)
Particle Size Ratio%
Cumulative Ratio%
Particle Size (μ m)
(b)
Ratio (%)
Particle Size Ratio%
Cumulative Ratio%
Particle Size (μ m)
(c)
Ratio (%)
Particle Size Ratio%
Cumulative Ratio%
Particle Size (μ m)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2012/062736

A. CLASSIFICATION OF SUBJECT MATTER
B22F9/08(2006.01)i, *B22F9/02*(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
B22F9/08, B22F9/02

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

Jitsuyo Shinan Koho	1922-1996	Jitsuyo Shinan Toroku Koho	1996-2012
Kokai Jitsuyo Shinan Koho	1971-2012	Toroku Jitsuyo Shinan Koho	1994-2012

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	JP 10-176206 A (Akihisa INOUE), 30 June 1998 (30.06.1998), paragraphs [0001] to [0013]; fig. 1, 2 (Family: none)	1,2,5,6,10 3,4,7-9
Y	JP 2003-530679 A (Tetronics Ltd.), 14 October 2003 (14.10.2003), paragraphs [0024] to [0025] & US 2003/0160033 A1 & GB 8797 D & EP 1281296 A & RU 2267239 C & WO 2001/078471 A1 & DE 60201387 D & AU 9335001 A & IL 152119 A & CA 2405743 A & IL 152119 D & AT 278314 T & CN 1422510 A	1-10

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

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent 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 when the document is taken alone
"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

Date of the actual completion of the international search	Date of mailing of the international search report
26 July, 2012 (26.07.12)	07 August, 2012 (07.08.12)

Name and mailing address of the ISA/	Authorized officer
Japanese Patent Office	
Facsimile No.	Telephone No.

Form PCT/ISA/210 (second sheet) (July 2009)

INTERNATIONAL SEARCH REPORT

International application No. PCT/JP2012/062736

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y A	JP 11-257615 A (Kabushiki Kaisha Daio), 21 September 1999 (21.09.1999), paragraphs [0001] to [0020]; fig. 1, 4 (Family: none)	3,7 1,2,4-6,8-10
Y A	JP 2006-241562 A (Daido Steel Co., Ltd.), 14 September 2006 (14.09.2006), entire text; all drawings (Family: none)	4,8,9 1-3,5-7,10
A	JP 05-271719 A (Teikoku Piston Ring Co., Ltd.), 19 October 1993 (19.10.1993), entire text; all drawings (Family: none)	1-10
A	JP 60-211005 A (General Electric Co.), 23 October 1985 (23.10.1985), page 8, upper right column, line 1 to page 9, upper right column, line 10 & US 4631013 A & GB 2155048 A & DE 3505660 A & FR 2560086 A & SE 8500969 A & IL 74266 A & IT 1184334 B & SE 464173 B & IT 8519673 D0	1-10

Form PCT/ISA/210 (continuation of second sheet) (July 2009)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2012/062736

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

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

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

2. ☐ Claims Nos.:
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. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

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

The search revealed that the invention of claim 1 is not novel, since the invention is relevant to the matter disclosed in the document 1 (JP 10-176206).

As a result, the invention of claim 1 does not have a special technical feature within the meaning of PCT Rule 13.2, second sentence, since the invention does not make a contribution over the prior art.

Consequently, the inventions of claims 1-10 have no same or corresponding special technical feature, and therefore do not comply with the requirement of unity.

Accordingly, in claims 1-10, at least five inventions, which are classified into claims [1], [2-4], [5], [6-9] and [10], are set forth.

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

2. ☒ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

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

4. ☐ 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 claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- JP 2006063357 A **[0002]**
- JP 2005139471 A **[0002]**
- JP 2004183049 A **[0002]**

Non-patent literature cited in the description

- **MURAKAMI, YOTARO.** *Method for producing high-quality metal powder,* September 2003 **[0002]**