ABSTRACT

To provide an abrasive water jet machining apparatus in which the machining accuracy and machining efficiency is improved by improving the flowability of an abrasive through a nozzle. An abrasive water jet machining apparatus performs machining by directing an abrasive water jet at a workpiece, the abrasive water jet being composed of a mixture of a high-pressure processing fluid with an abrasive. The machining apparatus includes: a nozzle that directs the abrasive water jet; a high-pressure water supply device that supplies the processing fluid to the nozzle; and an abrasive supply device that supplies the abrasive to the processing fluid. The abrasive is composed of a coated abrasive, the coated abrasive being produced by coating a surface of an abrasive material composed of abrasive grains with a water-repellent material or flow promoting material. The abrasive supply device supplies the coated abrasive to the nozzle.
APPARATUS AND METHOD FOR ABRASIVE WATER JET MACHINING

BACKGROUND

[0001] 1. Technical Field
[0002] The present invention relates to an apparatus and method for abrasive water jet machining, in which machining is performed by directing an abrasive water jet at a workpiece, the abrasive water jet being composed of a mixture of a high-pressure processing fluid and an abrasive.

[0003] 2. Related Art
[0004] As a machining apparatus for performing cutting on hard-to-machine workpieces of glass, stones, synthetic resin, composite materials such as carbon fiber reinforced plastic (CFRP), or the like, there is known an abrasive water jet machining apparatus in which a general abrasive (abrasive material), such as garnet, is mixed into high-pressure water.

[0005] A related art technology in which an abrasive (abrasive material) is improved in materials, surface shape, grain diameter, grain diameter distribution or the like in order to efficiently realize suitable cutting is disclosed, for example, in Japanese Unexamined Patent Application Publication No. H8-1515 (see paragraphs [0004] to [0008] and FIG. 1) and Japanese Patent No. 4653962 (see paragraphs [0041] to [0044] and FIG. 3).

[0006] The Japanese Unexamined Patent Application Publication No. H8-1515 discloses an abrasive (abrasive material) of ceramic fine grains each having an edge portion, each of the grains having a size in the range of 0.2 to 3 mm. The Japanese Patent No. 4653962 discloses an abrasive jet machining method using spherical zircon beads with a grain diameter in the range of 10 to 800 μm, the grain having a nearly spherical shape.

[0007] However, the Japanese Unexamined Patent Application Publication No. H8-1515 and Japanese Patent No. 4653962 do not disclose an effective technology for preventing the abrasive from clogging a nozzle. Especially in recent years, in order to perform accurate cutting of workpieces of different materials, shapes, and thicknesses, it is necessary to perform a machining with the optimum jet diameter as appropriate on the workpieces different in final cutting width. Unfortunately, when the nozzle diameter is reduced in order to make the jet diameter smaller, the nozzle diameter is brought close to the grain diameter of the abrasive, causing clogging of the nozzle with the abrasive more likely to occur.

[0008] Furthermore, if the abrasive is non-water-repellent (non-hydrophobic), an abrasive material adheres to a wall surface of an abrasive material passage with water adhering thereto as a contact body, and further, the subsequent abrasive material adheres to the abrasive material with the water as a contact body, leading to chained agglomeration of the abrasive materials, thereby causing the problems of a reduction in the inner diameter (airway) of the abrasive material passage and a decrease in flowability.

[0009] In this case, the problem is that the abrasive materials adhering to an inner wall of the abrasive material passage cause a blockage in a flow passage and cut off the air pulled in by a jet, resulting in feed failure of the abrasive materials.

SUMMARY

[0010] Accordingly, the present invention has been made under such circumstances, and an object of the present invention is to provide an apparatus and method for abrasive water jet machining, in which the machining accuracy and machining efficiency is improved by improving the flowability of an abrasive through a nozzle.

[0011] In order to address the above-mentioned problems, a first aspect of the present invention provides an abrasive water jet machining apparatus that performs machining by directing an abrasive water jet at a workpiece, the abrasive water jet being composed of a mixture of a high-pressure processing fluid with an abrasive. The abrasive water jet machining apparatus includes: a nozzle that directs the abrasive water jet; a processing fluid supply portion that supplies the processing fluid to the nozzle; and an abrasive supply portion that supplies the abrasive to the processing fluid. The abrasive is composed of a coated abrasive, the coated abrasive being produced by coating a surface of an abrasive material composed of abrasive grains with a water-repellent material or flow promoting material. The abrasive supply portion supplies the coated abrasive to the nozzle.

[0012] With this construction, the abrasive supply portion for supplying the abrasive to the processing fluid supplies the coated abrasive produced by coating the surface of the abrasive material composed of abrasive grains with the water-repellent material or flow promoting material. Thus, the coated abrasive repels the processing fluid or promotes flowability by surface tension acting on the processing fluid existing among the grains of the coated abrasive, thereby preventing the abrasive material from adhering to the wall surface of an abrasive material passage and always establishing an open airway that allows air to flow. Consequently, the flowability of the abrasive through the nozzle can be improved.

[0013] Thus, in the abrasive water jet machining apparatus, the abrasive in the processing fluid at the time of machining the workpiece with the abrasive water jet is uniformly dispersed and smoothly flows without agglomeration. Therefore, during a machining work, interruption of the work due to clogging of the nozzle, etc. with the abrasive can be prevented.

[0014] Furthermore, because the coated abrasive is less likely to cause clogging and has excellent fluidity, the amount of the abrasive in the abrasive water jet can be increased so as to improve machinability. It is therefore possible to shorten cutting time and speed up the processing, and, at the time of machining, provide smooth finishing of the machining surface as compared with the machining with the related art abrasive material.

[0015] Also, preferably, the coated abrasive has a property of floating in the processing fluid.

[0016] With this construction, because the coated abrasive has a property of floating, the sinking and deposition of the abrasive grains of the coated abrasive in the nozzle can be reduced, thereby it is possible to prevent the coated abrasive from clogging the nozzle.

[0017] Furthermore, preferably, the abrasive supply portion includes: an abrasive material supply portion that supplies the abrasive material to the processing fluid; a coated abrasive supply portion that supplies the coated abrasive to the processing fluid; and switching unit for selectively supplying the abrasive material supplied from the abrasive material supply portion or the coated abrasive supplied from the coated abrasive supply portion.

[0018] With this construction, the abrasive to be supplied into the nozzle can be selectively changed between the abrasive material and the coated abrasive by switching the switch-
ing unit. Therefore, the abrasive water jet machining apparatus can machine the workpiece by effectively utilizing the property of the abrasive material that is more excellent in machinability and the property of the coated abrasive that is more excellent in non-agglomerating property or flowability.

[0019] A second aspect of the present invention provides an abrasive water jet machining apparatus that performs machining by directing an abrasive water jet at a workpiece, the abrasive water jet being composed of a mixture of a high-pressure processing fluid with an abrasive. The abrasive water jet machining apparatus includes: a nozzle that directs the abrasive water jet; a processing fluid supply portion that supplies the processing fluid to the nozzle; an abrasive supply portion that supplies the abrasive to the processing fluid; and a liquid supply portion that supplies a water-repellent material or flow promoting material to the processing fluid or the abrasive.

[0020] With this construction, because the liquid supply portion supplies the water-repellent material or flow promoting material to the processing fluid or abrasive, the water-repellent material having surface tension or the flow promoting material having the function of promoting the flowability is mixed into the processing fluid or abrasive, thereby improving the flowability of the processing fluid or the abrasive. Consequently, a trouble due to deterioration in flowability can be avoided.

[0021] Moreover, preferably, the water-repellent material or flow promoting material is composed of any one of a fluorine-based material, silicon-based material, a coating material composed of a mixture of a fluorine-based material or a silicon-based material and an oily raw material, paraffin, and fats.

[0022] With this construction, because the water-repellent material or flow promoting material is composed of any one of a fluorine-based material, silicon-based material, a coating material composed of a mixture of a fluorine-based material or a silicon-based material and an oily raw material, paraffin, and fats, each of the abrasive grains has the function of promoting the water repellency or flowability. Therefore, the grains of the coated abrasive coated with the water-repellent material have the hydrophobic property of repelling the processing fluid with one another, and thus repel the processing fluid with one another in a state of being mixed in the water jet, thereby preventing agglomeration and eliminating a clogging of the nozzle. Furthermore, the grains of the coated abrasive coated with the flow promoting material are reduced in flow resistance during flowing, thereby allowing preventing agglomeration and eliminating a clogging of the nozzle.

[0023] It should be noted that the water-repellent material or flow promoting material may include any material other than the above if it has water repellency or flowability, and is not limited to the above-described coating material.

[0024] Also, preferably, the abrasive water jet machining apparatus further includes: a catcher tank that filled with liquid that receive and absorb water jet and its energy for machining the workpiece under the liquid; and a discharge port that discharges the liquid stored in the catcher tank. The coated abrasive floating in the liquid is discharged and recovered from the discharge port.

[0025] With this construction, the coated abrasive floating in the liquid stored in the catcher tank is discharged and recovered from the discharge port, thereby enabling recycled use thereof. Furthermore, the non-water-repellent abrasive material sinks to an inner bottom of the catcher tank in the liquid and therefore can be recovered separately from the floating coated abrasive.

[0026] Preferably, the abrasive water jet machining apparatus further includes a liquid level adjusting device that adjusts a liquid level of the liquid by adjusting a height of the discharge port.

[0027] With this construction, by raising the height of the discharge port with the liquid level adjusting device, the liquid level inside the catcher tank can be raised. Also, by lowering the height of the discharge port with the liquid level adjusting device, the liquid level inside the catcher tank can be lowered and adjusted as appropriate according to the thickness of the workpiece.

[0028] In addition, a third aspect of the present invention provides an abrasive water jet machining method in which machining is performed by directing an abrasive water jet at a workpiece, the abrasive water jet being composed of a mixture of a high-pressure processing fluid with an abrasive. The method includes producing a coated abrasive as the abrasive by coating a surface of an abrasive material composed of abrasive grains with a water-repellent material or flow promoting material.

[0029] With this construction, the coated abrasive produced by coating the surface of the abrasive material composed of abrasive grains with the water-repellent material or flow promoting material is supplied to the processing fluid. Thus, in the case of the coated abrasive coated with the water-repellent material, the coated abrasives repel the processing fluid with one another by surface tension acting on the processing fluid existing among the abrasive grains. Furthermore, in the case of the coated abrasive coated with the flow promoting material, each of the abrasive grains is improved in flowability. Therefore, with the coated abrasive coated with the water-repellent material or flow promoting material, agglomeration in the nozzle or the like or clogging can be eliminated. As a result, the abrasive water jet machining method allows uniform dispersion and smooth flow of the grains of the coated abrasive in the water jet at the time of abrasive water jet machining.

[0030] Also, a fourth aspect of the present invention provides an abrasive water jet machining method in which machining is performed by directing an abrasive water jet at a workpiece, the abrasive water jet being composed of a mixture of a high-pressure processing fluid with an abrasive. The method includes supplying a water-repellent material or flow promoting material to the processing fluid or the abrasive.

[0031] With this construction, by using the coated abrasive having a property of floating, the sinking and deposition of the grains of the coated abrasive in the nozzle can be reduced, thereby allowing preventing the coated abrasive from clogging the nozzle.

[0032] According to the present invention, the present invention is to provide an apparatus and method for abrasive water jet machining, in which the machining accuracy and machining efficiency is improved by improving the flowability of an abrasive through a nozzle.

BRIEF DESCRIPTION OF THE DRAWINGS

[0033] Embodiments of the present invention will be described in detail based on the following drawings, in which:
FIG. 1 is a perspective view of the essential parts of an abrasive water jet machining apparatus according to an embodiment of the present invention;

FIG. 2 is a schematic view of the essential parts of the abrasive water jet machining apparatus according to the embodiment of the present invention;

FIG. 3 is an enlarged longitudinal sectional view of a nozzle shown in FIG. 2;

FIGS. 4A to 4C are enlarged views of the essential parts of a carrier rotor of the abrasive supply device of the abrasive water jet machining apparatus according to the embodiment of the present invention, wherein FIG. 4A is a longitudinal sectional view, FIG. 4B is a side view, and FIG. 4C is a longitudinal sectional view showing the state when the carrier rotor is rotated;

FIG. 5 is a schematic view of a catcher tank of the abrasive water jet machining apparatus according to the embodiment of the present invention;

FIGS. 6A and 6B are schematic views showing a state actually seen with an electron microscope, wherein FIG. 6A is an enlarged schematic view showing abrasive grains of an non-coated abrasive material, and FIG. 6B is an enlarged schematic view showing abrasive grains of a coated abrasive coated with a water-repellent material;

FIG. 7A is a perspective view showing a state in which a water droplet is put onto a pile of coated abrasive with abrasive grains of garnet having a grain diameter of #200 coated with a water-repellent material; FIG. 7B is a perspective view showing a state in which a water droplet is put onto a pile of coated abrasive with abrasive grains of garnet having a grain diameter of #360 coated with a water-repellent material; and FIG. 7C is a perspective view showing a state in which a water droplet is put onto a pile of non-coated abrasive grains of garnet having a grain diameter of #360;

FIG. 8 is a perspective view of the essential parts of an abrasive water jet machining apparatus according to a modification of the embodiment of the present invention; and

FIG. 9 is a schematic view of the essential parts of the abrasive water jet machining apparatus according to the modification of the embodiment of the present invention.

DETAILED DESCRIPTION

Hereinafter, an apparatus and method for abrasive water jet machining according to an embodiment of the present invention will be described with reference to the accompanying drawings. Before an explanation of an abrasive water jet machining apparatus 100, a workpiece W to be used therein will be explained.

<Construction of Workpiece>

Although the material and shape of the workpiece W is not particularly limited, a hard-to-machine material, such as glass, stones, synthetic resin, or composite materials including carbon fiber reinforced plastic (CFRP), is most suitable as the workpiece W to be used in the abrasive water jet machining apparatus 100. Hereinafter, a description will be given using a generally elongated, substantially planar thick plate as an example of the workpiece W.

<Construction of Abrasive Water Jet Machining Apparatus>

As shown in FIG. 1, the abrasive water jet machining apparatus 100 is a machining apparatus that performs cutting of the workpiece W by directing an abrasive water jet AWJ with an abrasive G (an abrasive material G1 or a coated abrasive G3) mixed into processing fluid Q supplied at a high pressure of 200 to 400 Mpa. Furthermore, the abrasive water jet machining apparatus 100 can eject the abrasive water jet AWJ at a high speed equal to or above the speed of sound, and thus can cut the workpiece W into a shape of high quality even if the workpiece W is a hard material such as glass or metal, a relatively soft material such as synthetic resin, or a composite material composed of various kinds of materials such as a hard material and a soft material.

As shown in FIG. 1, the abrasive water jet machining apparatus 100 is composed mainly of: a nozzle 1 that ejects the abrasive water jet AWJ mixed with the abrasive G; a high-pressure water supply device 101 (processing fluid supply portion) that supplies the processing fluid Q from a high-pressure pipe 102 to the nozzle 1; an abrasive supply device 8 (abrasive supply portion) that supplies an appropriate amount of the abrasive G to the nozzle 1; a catcher tank 2 that stores liquid 6; and a liquid level adjusting device 5 (see FIG. 5) that adjusts a liquid level of the liquid 6.

It should be noted that although in this embodiment FIG. 1, shows the abrasive water jet machining apparatus 100 with an ejection direction of the abrasive water jet AWJ directed downward, the present invention is not limited thereto, but also can include an abrasive water jet machining apparatus that has a nozzle mounted to a tip of a robot arm capable of freely changing its directions, and a portable abrasive water jet machining apparatus that an operator holds in his/her hand to perform machining.

<Construction of Abrasive>

As shown in FIG. 2, the abrasive G is abrasive grains to be mixed into a water jet W3 when machining the workpiece W (see FIG. 1) with the abrasive water jet machining apparatus 100. In the abrasive water jet machining apparatus 100, two types of abrasives are used as the abrasive G, as appropriate. The abrasive G to be used as appropriate includes the following two types of abrasives: the abrasive material G1 that is the same as that used in the related art apparatus; and the coated abrasive G3 that is a water-repellent abrasive or flowable abrasive composed of abrasive grains in which the abrasive material G1 is coated with a water-repellent material or a flow promoting material G2. That is, the abrasive material G1 not subjected to water-repellent processing or the coated abrasive G3 is used as the abrasive G according to the kind, intended use, machining conditions of the workpiece W.

<Construction of Abrasive Material>

Referring mainly to FIGS. 6A, 6B, and 7A to 7C, the abrasive material G1, the water-repellent material or flow promoting material G2, and the coated abrasive G3 composed of a water-repellent abrasive will be described.

As shown in FIG. 6A, the abrasive material G1 is the abrasive G which is composed of non-coated abrasive grains, the abrasive grains having a so-called angular shape with acute-angle corners. As the abrasive material G1, a common material, such as garnet, sapphire, or a cemented carbide, can be used appropriately according to the kind or the like of the workpiece W.

FIG. 7C is a perspective view showing the state at the time of an experiment in which a droplet of the processing fluid Q (tap water) supplied from the high-pressure water supply device 101 is put onto the abrasive material G1 com-
posed of abrasive grains made of garnet having a grain diameter of #360. As shown in FIG. 7C, when a drop of water is put on the abrasive material G1, the water sinks into the abrasive material G1, and therefore the abrasive material G1 is non-water-repellent and has hydrophilicity.

<Construction of Water-Repellent Material or Flow Promoting Material>

[0052] The water-repellent material or flow promoting material G2 is a coating material for coating the abrasive material G1 to cause it to have the function of promoting water repellency or flowability, and composed of, for example, a fluorine-based material, silicon-based material, a coating material composed of a mixture of a fluorine-based material or silicon-based material and an oily raw material, paraffin, Teflon (R), or an oily raw material. It should be noted that, more specifically, the fluorine-based material or silicon-based material includes a common material, such as fluorine, silicon, and silica, or a compound of a material, such as fluorine, silicon, and silica, and silane or a silane derivative. Furthermore, the oily raw material includes alcohol, ethanol, and various kinds of wax.

[0053] FIG. 7A is a perspective view showing the state at the time of an experiment in which a droplet of the processing fluid Q (tap water) used in the high-pressure water supply device 101 is put onto the coated abrasive G3 composed of a water-repellent abrasive in which abrasive grains made of garnet having a grain diameter of #220 are coated with a coating material of 0.2 mass %.

[0054] FIG. 7B is a perspective view showing the state at the time of an experiment in which a droplet of the processing fluid Q (tap water) used in the high-pressure water supply device 101 is put onto the coated abrasive G3 (water-repellent abrasive) in which abrasive grains made of garnet having a grain diameter of #360 are coated with a coating material of 0.3 mass %.

[0055] In the experiments shown in FIGS. 7A and 7B, a water droplet with a large contact angle in the range of 150° to 180° was formed, and therefore it has been confirmed that the coated abrasive G3 (water-repellent abrasive) has super water-repellency to strongly repel a water droplet and is hard to get wet and has small surface tension. It has been also confirmed that the coated abrasive G3 (water-repellent abrasive) has buoyancy to float on water when dropped and has a property of floating.

[0056] Furthermore, in an experiment conducted by actually using the coated abrasive G3 (water-repellent abrasive) in the nozzle 1 as shown in FIGS. 2 and 3, it has been confirmed that, even if the coated abrasive G3 (water-repellent abrasive) is mixed with the water jet WJ at a high pressure in the range of 200 to 400 MPa, peeling off of a coating due to the pressure is not caused. That is, the nozzle 1 has durability in which the water repellency can be maintained even under a pressure in the range of at least 200 to 400 MPa.

[0057] As shown in FIG. 6B, the coated abrasive G3 (water-repellent abrasive) is composed of the abrasive grains having a so-called blocky shape with obtuse angle corners because the whole surface of the abrasive material G1 is coated with the water-repellent material (G2). The coated abrasive G3 is inferior in cutting quality as compared with the abrasive material G1 which is composed of the unprocessed abrasive grains having the angular shape with acute-angle corners, but has a property of floating in the processing fluid Q and water repellency.

[0058] It should be noted that examples of the method for producing the coated abrasive G3 include, but are not particularly limited to, a method in which the coated abrasive G3 is produced byputting the abrasive material G1 and the coating material (water-repellent material (G2)) into a general mixer, agitating and then drying them, and a method in which the coated abrasive G3 is produced by spraying the coating material (water-repellent material (G2)) on the abrasive material G1 and then drying it. Examples of other methods for producing the coated abrasive G3 include a method for producing a metal composite body in which a silica layer made of silica serving as the water-repellent material (G2) is formed on surfaces of abrasive grains (metal grains) of the abrasive material G1 or the like, as disclosed in Japanese Patent Nos. 3906137 and 3906138.

<Construction of Nozzle>

[0059] As shown in FIG. 2, the nozzle 1 includes a nozzle body 10, a mixing chamber 13 that is formed within the nozzle body 10, a water nozzle 14 that is formed with an introducing port 14a to eject the processing fluid Q (water jet WJ), and an abrasive nozzle 15 that produces the water jet AW mixed with the abrasive G (hereinafter, simply referred to as the water jet AW) by mixing the abrasive G (the abrasive material G1 or the coated abrasive G3) into the water jet WJ ejected from the water nozzle 14 and ejects the abrasive water jet AWJ for machining the workpiece W.

[0060] It should be noted that in FIG. 2, for example, the relationship between the diameter of the water nozzle 14 and the diameter of the water jet WJ is visually simplified for convenience of explanation, and it is generally assumed that the diameter of the jet ejected is smaller than the nozzle diameter. Furthermore, in FIGS. 1 and 2, the grain diameter of the abrasive G (the abrasive material G1 or the coated abrasive G3) is drawn by magnifying its size, and there are shown a state in which the abrasive G flows while floating in air within the mixing chamber 13 and a state in which the abrasive G flows within the abrasive supply device 8.

[0061] The nozzle body 10 is a member that is composed of an upper body 11 and a lower body 12 and designed to position with high accuracy and dispose the components including the water nozzle 14. The mixing chamber 13 is formed in a central portion of the nozzle body 10. It should be noted that although in this embodiment, the nozzle body 10 has a structure separated into the upper body 11 and the lower body 12, the upper body 11 and the lower body 12 may be integrated.

[0062] The mixing chamber 13 forms a space of a nearly columnar shape. In a central portion of the mixing chamber 13, the water jet WJ ejected from the water nozzle 14 passes through the inside of the mixing chamber 13 to be introduced into the abrasive nozzle 15.

[0063] The mixing chamber 13 includes a supply port 13a allowing the abrasive G (the abrasive material G1 or the coated abrasive G3) to be introduced therein. The abrasive G discharged from the abrasive supply device 8 (see FIG. 1) is sucked together with air from the supply port 13a and introduced into the mixing chamber 13. Thus, the abrasive G introduced into the mixing chamber 13 is mixed into the water jet WJ to produce the abrasive water jet AW mixed with the abrasive G. The abrasive supply device 8 (see FIG. 1) is designed to discharge an appropriate amount of the abrasive G to the supply port 13a.
Within the mixing chamber 13, the supply port 13a is disposed toward the introducing port 14a of the water nozzle 14 with respect to an upper end of the abrasive nozzle 15. That is, the supply port 13a prevents the abrasive G from entering the water jet WJ and clogging an upstream opening end of the abrasive nozzle 15 within the mixing chamber 13.

In this manner, when the water jet WJ ejected from the water nozzle 14 passes through the inside of the mixing chamber 13, an appropriate amount of the abrasive G (the abrasive material G1 or the coated abrasive G3) is suitably sucked together with air from the supply port 13a by a negative pressure generated by the high-speed water jet WJ. Therefore, clogging with the abrasive G near the supply port 13a can be effectively avoided. Furthermore, the abrasive G sucked from the supply port 13a is drawn and mixed into the water jet WJ within the mixing chamber 13 while floating together with an air current and accumulating to produce the water jet AW mixed with an appropriate amount of the abrasive material G1 or the coated abrasive G3.

As shown in FIG. 3, the water nozzle 14 is a member that includes: a body portion 14b disposed by being embedded in an upstream portion (upper portion in FIG. 2) of the upper body 11; and a nozzle portion 14c embedded in the body portion 14b, to inject, into the mixing chamber 13 from the nozzle portion 14c, the processing fluid Q supplied from the high-pressure pipe 102 to the introducing port 14a. Therefore, a hole diameter D1 of the water nozzle 14 (the nozzle portion 14c) is set smaller than an inner diameter D3 of the body portion 14b and a hole diameter D2 of the abrasive nozzle 15.

As shown in FIG. 3, the abrasive nozzle 15 is installed within the cylindrical lower body 12. The abrasive nozzle 15 is a member designed to introduce the water jet AW mixed with the abrasive G and direct the abrasive water jet AWJ at the workpiece W.

Furthermore, the hole diameter D2 of the abrasive nozzle 15 is set, for example, in the range of about 0.2 to 0.7 mm and, preferably, set larger than the hole diameter D1 of the water nozzle 14.

That is, an advantageous effect of preventing clogging of the abrasive nozzle 15 with the abrasive G can be expected by setting the hole diameter D2 of the abrasive nozzle 15 to be larger than the hole diameter D1 of the water nozzle 14.

<Construction of Abrasive Supply Device>

As shown in FIG. 2, the abrasive supply device 8 (abrasive supply portion) is a device for supplying, as appropriate, the abrasive G composed of the abrasive material G1 or the coated abrasive G3 to the nozzle 1. The abrasive supply device 8 is composed mainly of: a first abrasive supply device 8A (abrasive material supply portion) that supplies abrasive grains of the unprocessed abrasive material G1 to the processing fluid Q in the nozzle 1; a second abrasive supply device 8B (coated abrasive supply portion) that supplies abrasive grains of the coated abrasive G3 to the processing fluid Q in the nozzle 1; a switching unit 88 for selecting the abrasive G to be supplied to the nozzle 1 between the abrasive material G1 and the coated abrasive G3; and an abrasive suction pipe 89 that couples the switching unit 88 and the nozzle 1.

The first abrasive supply device 8A for supplying the non-coated abrasive material G1 and the second abrasive supply device 8B for supplying the coated abrasive G3 have the same structure. Therefore, the first abrasive supply device 8A will be mainly described and description of the other device will not be given accordingly.

The first abrasive supply device 8A (second abrasive supply device 8B) includes: an abrasive material supply pipe 80a (coated abrasive supply pipe 80b) that supplies the abrasive material G1 (coated abrasive G3) stored in an abrasive material supply tank (not shown); a storage portion 81 that stores the abrasive material G1 (coated abrasive G3); an outlet hole 82 that is disposed at a lower portion of the storage portion 81; a carrier rotor 83 that is disposed below the outlet hole 82 with a predetermined gap δ (see FIG. 4) and driven to rotate around a rotating shaft 83a in a horizontal direction; a motor 84 that rotationally drives the carrier rotor 83; a control unit (not shown) that controls the rotation of the motor 84; a receiving portion 85 that is disposed below the carrier rotor 83; a discharge port 86 that is formed in the receiving portion 85; and an abrasive material suction pipe 87A (coated abrasive suction pipe 87B) that sucks the abrasive material G1 (coated abrasive G3) discharged from the discharge port 86 by the negative pressure generated by high-pressure water to supply it to the nozzle 1.

As shown in FIG. 4, the carrier rotor 83 includes a projection portion 83b serving as a projecting-recessed portion formed at an outer periphery thereof, and a wall portion 83c circumferentially formed. The projection portion 83b is formed linearly along an axial direction, and a plurality of the projection portions 83b are formed at equally spaced circumferential points like blades of a water wheel. The wall portion 83c is formed like a flange to project radially from both edge portions of an outer peripheral portion of the carrier rotor 83.

With this construction, the carrier rotor 83 is designed to hold the abrasive material G1 (coated abrasive G3) flowing from the outlet hole 82 so as to prevent it from being scattered, and carry a required amount of the abrasive material G1 (coated abrasive G3) to the receiving portion 85 with proper timing.

It should be noted that although in this embodiment, the projection portion 83b is provided at the outer peripheral portion of the carrier rotor 83, the projection portion 83b is not particularly limited if it has a shape that allows a predetermined amount of the abrasive material G1 (coated abrasive G3) to accumulate therein for a predetermined time, but may include a recessed portion or may be composed of a recessed portion and a projecting portion, or may be formed without such recessed and projecting portions.

As shown in FIG. 2, the first abrasive supply device 8A (second abrasive supply device 8B) is a device that causes a predetermined amount of the abrasive material G1 (coated abrasive G3) to flow downstream from the outlet hole 82 disposed at a lower portion of the storage portion 81 and carries the abrasive material G1 (coated abrasive G3) from the outlet hole 82 to the receiving portion 85 with the carrier rotor 83, and supplies the abrasive material G1 (coated abrasive G3) to the supply port 13a of the mixing chamber 13 from the discharge port 86 formed in the receiving portion 85 through the abrasive material suction pipe 87A (coated abrasive suction pipe 87B), the switching unit 88, and the abrasive suction pipe 89.

As shown in FIG. 4A, the first abrasive supply device 8A (second abrasive supply device 8B) is provided with the predetermined gap δ between the outlet hole 82 and the carrier rotor 83. Thus, in a state in which the carrier rotor 83 is stopped, the abrasive material G1 (coated abrasive G3)
can be held in an accumulated state in the predetermined gap δ by frictional resistance among the grains.

[0078] On the other hand, when the carrier rotor 83 is rotated, the first abrasive supply device 8A (second abrasive supply device 8B) carries the abrasive material G1 (coated abrasive G3) accumulated in the gap 8 along an outer peripheral surface of the carrier rotor 83 to thereby cause the subsequent abrasive material G1 (coated abrasive G3) to flow again into the gap 8 from the outlet hole 82 (see FIG. 4C).

[0079] The switching unit 88 is a switching valve having two input ports and a single output port, and the input ports may be switched manually or automatically by electromagnetic force.

[0080] In this manner, as shown in FIG. 1, in response to the rotation of the carrier rotor 83, the first abrasive supply device 8A (second abrasive supply device 8B) of the abrasive supply device 8 carries the abrasive material G1 (coated abrasive G3) flowing into the gap 8 along the outer peripheral surface of the carrier rotor 83 according to rotational speed of the carrier rotor 83, and receives the abrasive material G1 (coated abrasive G3) in the receiving portion 85 for the abrasive material G1 (coated abrasive G3) disposed below the carrier rotor 83, and supplies the abrasive material G1 (coated abrasive G3) to the supply port 13a of the mixing chamber 13 from the discharge port 86 formed in the receiving portion 85.

[0081] The abrasive supply device 8 appropriately controls the rotational speed of the carrier rotor 83 with the control unit (not shown), thereby allowing uniform and smooth supply of an appropriate amount of the abrasive material G1 (coated abrasive G3) to the mixing chamber 13 with proper timing, or allowing supply of the abrasive G by causing the switching unit 88 to operate and automatically select the abrasive material G1 or the coated abrasive G3 with proper timing according to the workpiece W, or allowing alternate supply of the abrasive material G1 and the coated abrasive G3 with proper timing.

<Construction of Catcher Tank>

[0082] As shown in FIG. 5, the catcher tank 2 is a tank that stores the liquid 6 for receiving abrasive water jet AWJ with the workpiece W sunk in the liquid 6. The catcher tank 2 is provided with: a water level adjusting tank 3 for adjusting a liquid level of the liquid 6 in the catcher tank 2; a pedestal 4 like a table for placing and holding the workpiece W; the liquid level adjusting device 5 that varies a liquid level of the liquid 6 in the catcher tank 2; a coated abrasive recovery device 7 that recovers the coated abrasive G3 discharged from an discharge pipe 52; and an abrasive material recovery device 9 that recovers the abrasive material G1 contained in the liquid 6 inside the catcher tank 2.

<Construction of Water Level Adjusting Tank>

[0083] The water level adjusting tank 3 is a tank of an inverted container shape with a bottom opening. The water level adjusting tank 3 is provided with: an airtight chamber 3a that is formed in a ceiling portion inside the water level adjusting tank 3; a partition wall 3b that partitions the water level adjusting tank 3 and the catcher tank 2; a lower trough portion 3c that is formed below the partition wall 3b to communicate with a region filled with water inside the catcher tank 2; a pump P1 that leads air into and out of an upper portion inside the airtight chamber 3a; and a water level adjusting pipe 51 that is vertically disposed inside the airtight chamber 3a.

[0084] The airtight chamber 3a is an air pocket formed in the ceiling portion inside the water level adjusting tank 3 having an inverted container shape. The amount of air in the airtight chamber is adjusted by the pump P1 to be described later so that the water level of the liquid 6 in the water level adjusting tank 3 is adjusted.

[0085] The partition wall 3b is a wall for partitioning the water level adjusting tank 3 and the catcher tank 2 and forming the lower trough portion 3c therebelow so that the water level of the liquid 6 in the water level adjusting tank 3 and the water level of the liquid 6 in the catcher tank 2 are linked together.

[0086] The lower trough portion 3c is a portion for forming a flow passage allowing the liquid 6 to flow between the water level adjusting tank 3 and the catcher tank 2 according to the fluctuation in the water level of the liquid 6 in the water level adjusting tank 3.

[0087] The pump P1 is a pump to lower the water level of the liquid 6 in the water level adjusting tank 3, with increases in the air pressure in the airtight chamber 3a, by sending air into the airtight chamber 3a and force the liquid 6 into the catcher tank 2 through the lower trough portion 3c to raise the water level of the liquid 6 in the catcher tank 2. Furthermore, when discharging air to the inside of the airtight chamber 3a, the pump P1 is designed to, for example, with the pump P1 in its OFF position, discharge the air in the airtight chamber 3a to the outside and reduce the internal air pressure of the airtight chamber 3a to cause the liquid 6 in the catcher tank 2 to flow into the water level adjusting tank 3 so as to lower the water level of the catcher tank 2.

[0088] The water level adjusting pipe 51 is a tubular member that is provided within the water level adjusting tank 3 for water level adjustment, which constitutes a portion of the liquid level adjusting device 5 to be described later. The water level adjusting pipe 51 is designed to adjust the water level so that the water level matches the thickness of the workpiece W to be cut, by adjusting its longitudinal position and changing the position of an opening edge of a lower end thereof. The lower end of the water level adjusting pipe 51 has an opening at the same level as the minimum water level in which the water level in the water level adjusting tank 3 is the lowest, and an upper end of the water level adjusting pipe 51 penetrates the water level adjusting tank 3 and has an external opening in an open state.

<Construction of Liquid Level Adjusting Device>

[0089] As shown in FIG. 5, the liquid level adjusting device 5 is a device that adjusts the liquid level of the liquid 6 by adjusting heights H1 and H2 of a discharge port 52a provided within the catcher tank 2. The liquid level adjusting device 5 includes the water level adjusting pipe 51, and the discharge pipe 52 for discharging the liquid 6 stored in the catcher tank 2 and the coated abrasive G3 floating on the liquid surface of the liquid 6.

[0090] The discharge pipe 52 has a lower end 52a turnably (tiltably) mounted on a side wall of the catcher tank 2, and is provided so that the discharge port 52a at an upper end thereof can be displaced with respect to the liquid surface of the liquid 6 by causing the discharge pipe 52 to pivot about the lower end 52a. The discharge pipe 52 is composed of a cylindrical overflow pipe that has: the discharge port 52a formed in the
upper opening end; and the lower end 52b formed by bending in an L-shape and journaled to the side wall in the vicinity of an inner bottom of the catcher tank 2.

[0091] The discharge port 52a is an opening for discharging the liquid 6 and the coated abrasive G3 floating on the liquid 6 to the outside of the catcher tank 2, and formed by the upper opening of the discharge pipe 52. In the case where the discharge pipe 52 is disposed vertically as shown by the solid line in FIG. 5, the discharge port 52a also serves as an overflow discharge port that adjusts an upper limit water level for keeping the water level of the catcher tank 2 to a maximum water level 6a and discharging the liquid 6 and the coated abrasive G3 exceeding the maximum water level 6a to the outside of the catcher tank 2. Furthermore, in the case where the discharge pipe 52 is disposed in a tilted position as shown by the two-dot chain line in FIG. 5, the discharge port 52a also serves as an overflow discharge port that adjusts the lower limit water level for, for example, changing the water level of the catcher tank 2 to a minimum water level 6b and discharging the liquid 6 and the coated abrasive G3 exceeding the minimum water level 6b to the outside of the catcher tank 2.

[0092] For example, at the time of cutting the workpiece W using the coated abrasive G3, when the abrasive water jet AWJ ejected from the abrasive nozzle 15 shown in FIG. 5 is dropped into the catcher tank 2, the amount of water in the catcher tank 2 increases, and therefore the water level in the catcher tank 2 exceeds the maximum water level 6a preliminarily set, so that the liquid 6 and the coated abrasive G3 are discharged from the discharge port 52a.

[0093] The position of the discharge port 52a (i.e. the water level of the liquid 6) can be adjusted as appropriate by adjusting a tilt angle α of the discharge pipe 52 according to the height of the workpiece W. The excess liquid 6 in the catcher tank 2 and the coated abrasive G3 floating on the liquid 6 can be discharged to the outside of the catcher tank 2 by tilting the discharge pipe 52 and thereby lowering the heights H1 and H2 of the discharge port 52a.

[0094] Furthermore, when air is sent into the air intake chamber 3a by the pump P1, the water level of the liquid 6 in the catcher tank 2 increases, so that the liquid 6 and the coated abrasive G3 floating on the liquid 6 can be discharged from the discharge port 52a to the outside of the catcher tank 2.

[0095] The coated abrasive recovery device 7 is a separation device that is disposed below the lower opening end of the discharge pipe 52 to separate and recover the used liquid 6 and coated abrasive G3 discharged from the discharge pipe 52. The coated abrasive recovery device 7 includes: a separator 71 that separates a turbid liquid composed of a mixture of the immersion liquid 6 and the coated abrasive G3 into the immersion liquid 6 and the coated abrasive G3; an used coated abrasive discharge pipe 72 that supplies the used coated abrasive G3, etc. discharged from the discharge pipe 52; an used coated abrasive recovery pipe 73 that receives the used coated abrasive G3 having undergone the separator 71; and an used liquid recovery pipe 74 that receives the used liquid 6 having undergone the separator 71.

[0096] The separator 71 is a device that separates the used liquid 6 and coated abrasive G3 overflowing and entering the discharge port 52a of the catcher tank 2, into the liquid 6 and the coated abrasive G3 for recycled use thereof. The separator 71 is, for example, a centrifugal machine that centrifugally separates the turbid liquid into the liquid 6 and the coated abrasive G3 by gravity difference.

[0097] The used coated abrasive discharge pipe 72 is a pipe for sending, to the separator 71, the turbid liquid composed of a mixture of the used coated abrasive G3 and liquid 6. The used coated abrasive discharge pipe 72 is connected to the discharge pipe 52 at its upstream side and connected to an upper end of the separator 71 at its downstream side.

[0098] The used coated abrasive recovery pipe 73 is a pipe that is connected to an upper end of a side surface of the separator 71 at its upstream side and connected to the coated abrasive supply pipe 80b at its downstream side to return the used coated abrasive G3 to the coated abrasive supply pipe 80b and circulate it, thereby enabling recycled use thereof.

[0099] The used liquid recovery pipe 74 is a pipe that is connected to a lower end of the separator 71 at its upstream side and connected to the high-pressure water supply device 101 (see FIG. 1) at its downstream side to return the filtered liquid 6 to the high-pressure water supply device 101 for recycled use thereof in the nozzle 1.

[0100] It should be noted that the coated abrasive recovery device 7 may have any structure that can recover the used coated abrasive G3 in the catcher tank 2, and its structure or the like is not particularly limited. For example, the coated abrasive recovery device 7 may include a coated abrasive recovery filter or filtering device that separates, into the liquid 6 and the coated abrasive G3, the used liquid 6 and coated abrasive G3 overflowing and entering the discharge port 52a.

[0101] Furthermore, as shown in FIG. 5, the coated abrasive recovery device 7 has been described using as an example the case where the used coated abrasive discharge pipe 72 located at an upper portion of the separator 71 is coupled to the discharge pipe 52 provided at a side wall of the catcher tank 2. However, a coupler between the liquid level adjusting device 5 and the coated abrasive recovery device 7 may be changed as appropriate.

[0102] For example, the coated abrasive recovery device 7 may be such that the discharge pipe 52 of the liquid level adjusting device 5 extends directly downward of the catcher tank 2 and penetrates an inner bottom of the catcher tank 2 to be connected in communication to the separator 71, thereby recovering the coated abrasive G3 or the like.

[0103] Alternatively, the coated abrasive recovery device 7 may be an external device that is installed outside the catcher tank 2, such as disposing it outside the side wall of the catcher tank 2.

<Construction of Abrasive Material Recovery Device>

[0104] The abrasive material recovery device 9 is a device that separately recovers the liquid 6, abrasive material G1, and sludge-like chips in the catcher tank 2 so as to enable recycled use of the used liquid 6 and abrasive material G1 in the catcher tank 2. For example, the abrasive material recovery device 9 is a classifying machine that separates liquid 6, the abrasive material G1, and chips according to gravity and grain diameter by centrifugal force. The abrasive material recovery device 9 includes: an abrasive material discharge pipe 91 for recovering the abrasive material G1 settling at the inner bottom of the catcher tank 2; a suction pump P2 that is provided in the abrasive material discharge pipe 91; a classifier 92 that separates the liquid 6, abrasive material G1, and chips sucked by the suction pump P2; a chip recovery pipe 93 that receives the chips having undergone the classifier 92; an abrasive material recovery pipe 94 that receives the abrasive
material G1 having undergone the classifier 92; and an liquid recovery pipe 95 for discharging the liquid 6 having undergone the classifier 92.

[0105] As shown in FIG. 5, the abrasive material discharge pipe 91 has a lower opening end disposed in the vicinity of the inner bottom of the catcher tank 2 and an upper opening end connected to an upper side surface of the classifier 92.

[0106] The suction pump P2 is a pump that is disposed on the way of the abrasive material discharge pipe 91 to suck the abrasive material G1 sinking in the liquid 6 together with the immersion liquid 6 and send it to the classifier 92. The suction pump P2 is driven by an electric motor (not shown).

[0107] The chip recovery pipe 93 is a pipe for discharging the chips having undergone the classifier 92. The chip recovery pipe 93 is connected to a lower end of the classifier 92 at its upstream side and disposed, for example, on a disposal tank (not shown) at its downstream side.

[0108] The abrasive material recovery pipe 94 is a pipe for discharging the abrasive material G1 having undergone the classifier 92. The abrasive material recovery pipe 94 is connected to an upper side surface of the classifier 92 at its upstream side and connected to the abrasive material supply pipe 80a (see FIG. 2) at its downstream side so as to enable recycled use of the abrasive material G1.

[0109] The liquid recovery pipe 95 is a pipe for discharging the liquid 6 having undergone the classifier 92. The liquid recovery pipe 95 is connected to an upper end of the classifier 92 at its upstream side and connected to the liquid supernatant recovery device 101 (see FIG. 2) at its downstream side so as to enable recycled use of the liquid 6.

[0110] It should be noted that the abrasive material recovery device may have any structure that can recover the used abrasive material G1 in the catcher tank 2, and its structure or the like is not particularly limited. For example, the abrasive material recovery device may include an abrasive material recovery filter or filtering device that recovers the used abrasive material G1 settling at the inner bottom of the catcher tank 2 and separates the abrasive material G1 from the chips and the liquid 6.

<Construction of Pedestal>

[0111] As shown in FIG. 5, the pedestal 4 is a workpiece supporting base that receives the workpiece W with a number of thin plates 4a horizontally arranged in parallel at an appropriate spacing.

[0112] Each of the thin plates 4a, with a plane of a thin horizontally long flat member in a vertical position, is extended in a width direction of the catcher tank 2, and a number of the thin plates 4a are arranged in parallel with slit spaces thereamong along the liquid surface of the liquid 6 in the catcher tank 2 so that the workpiece W is placed thereon for underwater cutting.

<Operation>

[0113] Next, referring mainly to the accompanying drawings, an apparatus and method for abrasive water jet machining according to the embodiment of the present invention will be described in the order of an operation process.

[0114] As shown in FIG. 5, before the start of operation, the pump P1 is in the OFF position. Because the pump P1 is in the OFF position, air in the airtight chamber 3a is discharged into the atmosphere from the pump P1, so that the internal pressure of the airtight chamber 3a is same as atmosphere. Thus, the liquid 6 in the catcher tank 2 flows into the water level adjusting tank 3, and the water level of the liquid 6 in the catcher tank 2 is reduced to a predetermined water level. With the water level in the catcher tank 2 reduced in this manner, firstly, the workpiece W is mounted on the pedestal 4 inside the catcher tank 2.

[0115] Next, the pump P1 is switched to the ON position, and the position of the discharge port 52a is adjusted by setting the discharge pipe 52 to the desired angle θ, thereby allowing machining with the water level of the liquid 6 in the catcher tank 2 at a position lower than the workpiece W or machining with the water level of the liquid 6 at a position (in water) higher than the workpiece W. For example, in the case of machining in liquid, as shown in FIG. 5, with the discharge pipe 52 in a vertical position, the pump P1 is switched to the ON position, and the water level of the liquid 6 is set to a position higher than the height of workpiece W.

[0116] Subsequently, the high-pressure water supply device 101 shown in FIG. 2 is driven to supply the water jet WJ to the nozzle 1, and the abrasive supply device is driven to supply the abrasive G to the nozzle 1 so that cutting of the workpiece W is performed by the abrasive water jet AWJ.

[0117] At the time of the cutting, firstly, piercing of the workpiece W is performed by the low-pressure abrasive water jet AWJ. Then, after the pressure of the abrasive water jet AWJ is increased, the cutting is performed starting from a hole formed by piercing. It should be noted that machining is performed while adjusting a machining condition in accordance with the material of the workpiece W because there is a difference in feed speed, tilt angle, etc., between the case where the workpiece W is glass which is hard to cut and the case where the workpiece W is a relatively easy-to-cut material, such as aluminum or stainless steel.

[0118] Furthermore, at the time of machining, either the abrasive material G1 of the first abrasive supply device 8A or the coated abrasive G3 of the second abrasive supply device 8B is selected as appropriate by selecting the switching unit 88 and supplied to the nozzle 1.

[0119] In this case, agglomeration of the abrasive G in the nozzle 1, etc. or clogging with the abrasive G can be eliminated especially by selecting the switching unit 88 to the second abrasive supply device 8B and supplying the coated abrasive G3 to the nozzle 1. This is because, as shown in FIG. 3, the abrasive grains of the coated abrasive G3 coated with the water-repellent material or flow-promoting material G2, in liquid, such as in the water jet AWJ, repel one another by the super water-repellency and are stably dispersed without approaching one another or agglomerating, and also can promote the flowability of the abrasive material G1.

[0120] Furthermore, at the time of cutting the workpiece W, the abrasive material G1 is composed of abrasive grains having an angular shape with acute-angle corners and superior in cutting quality as compared with the abrasive grains of the coated abrasive G3.

[0121] Thus, at the time of machining with the abrasive water jet machining apparatus 100, cutting is performed while selecting the abrasive G between the abrasive material G1 and the coated abrasive G3 or alternately supplying the abrasive material G1 and the coated abrasive G3 with proper timing by switching the switching unit 88 of the abrasive supply device 8 as appropriate according to a machining condition, such as the shape, material, thickness, or finishing of the workpiece W. Thus, even if the abrasive material G1 agglomerates, the abrasive material G1 can be dispersed
separately and stabilized by the action of the super water-repellency of the coated abrasive G3.

As shown in FIG. 5, the coated abrasive G3 ejecting from the nozzle 15 into the catcher tank 2 floats on a liquid surface of the liquid 6 in the catcher tank 2 and overflows and enters the discharge pipe 52 to be separated by the coated abrasive recovery device 7 so that it can be recycled, and then is recirculated into the coated abrasive supply pipe 80b of the second abrasive supply device 83.

Furthermore, the abrasive material G1 ejecting from the nozzle and chips falling into the catcher tank 2 by cutting sinks to the inner bottom of the catcher tank 2 and is sucked into the abrasive material discharge pipe 91 by the suction pump P2 to be separated by the abrasive material recovery device 9 so that it can be recycled, and then is recirculated into the abrasive material supply pipe 80a of the first abrasive supply device 8a, and the chips are discarded through the chip recovery pipe 93.

It should be noted that the abrasive material G1 and chips sinking to the inner bottom of the catcher tank 2 may be recovered from the catcher tank 2 by the abrasive material recovery device 9 or the like and then discarded without being recycled.

After the machining of the workpiece W is finished, the pump P1 is turned OFF to cause the air in the airtight chamber 3a to be discharged to the outside, and the water in the catcher tank 2 with the water level raised by the machining is moved by its own weight to the water level adjusting tank 3 with the water level lowered, thereby lowering the water level in the catcher tank 2. In this state, the machined workpiece W is removed from the pedestal 4 located inside the catcher tank 2, and machining work is completed.

<Modification>

It should be noted that the present invention is not limited to the above-described embodiment, and various modifications and changes may be made without departing from the technical idea of the present invention. The present invention, of course, also extends to alternative embodiments which incorporate these modifications and changes, and a modification will be described referring mainly to FIGS. 8 to 10. It should be noted that the same elements as those already described are designated by the same reference signs and a description thereof will not be repeated.

FIG. 8 is a perspective view of the essential parts of an abrasive water jet machining apparatus according to a modification of the embodiment of the present invention. FIG. 9 is a schematic view of the essential parts of the abrasive water jet machining apparatus according to the modification of the embodiment of the present invention.

In the above-described embodiment, as an example of the abrasive water jet machining apparatus 100, as shown in FIG. 2, the abrasive supply device 8 (abrasive supply portion) for supplying the coated abrasive G3 coated with the water-repellent material or flow promoting material G2 to the nozzle 1 has been described. However, the present invention is not limited thereto. For example, as shown in FIGS. 8 and 9, an abrasive water jet machining apparatus 100 may include a liquid supply portion 8C that supplies the water-repellent material or flow promoting material G2 to the processing fluid Q and the abrasive G. In this case, the liquid supply portion 8C is composed of a device that supplies, to the nozzle 1 supplied with the processing fluid Q and the abrasive G, the water-repellent material or flow promoting material G2 composed of any one of liquids of a fluorine-based material, silicon-based material, a coating material composed of a mixture of a fluorine-based material or silicon-based material and an oily raw material, paraffin, and fats. The liquid supply portion 8C includes: a liquid supply pipe 80c that supplies the water-repellent material or flow promoting material G2 stored in a storage tank not shown; a storage portion 81C that is composed of a tank temporarily storing the water-repellent material or flow promoting material G2 and having a discharge port 86C, and a liquid suction pipe 87C that couples to the storage portion 81C and the switching unit 88.

For example, in order to supply the water-repellent material or flow promoting material G2 to the processing fluid Q supplied from the high-pressure pipe 102 to the nozzle 1, the switching unit 88 is switched so that the water-repellent material or flow promoting material G2 flows from the storage portion 81C to the nozzle 1, and the supply of the abrasive G from the abrasive material suction pipe 87A is stopped. Thus, the processing fluid Q and the water-repellent material or flow promoting material G2 can be supplied to the nozzle 1 and mixed together.

Furthermore, in order to supply the abrasive G and the water-repellent material or flow promoting material G2 to the nozzle 1, the high-pressure water supply device 101 is stopped to stop the supply of the processing fluid Q, and the switching unit 88 is switched so as to enable the supply from both the abrasive material suction pipe 87A and the liquid suction pipe 87C. Thus, the abrasive G is supplied to the abrasive suction pipe 89 from the abrasive material suction pipe 87A through the switching unit 88, and the water-repellent material or flow promoting material G2 is supplied to the abrasive suction pipe 89 from the liquid suction pipe 87C through the switching unit 88, so that the abrasive G and the water-repellent material or flow promoting material G2 are mixed to be supplied to the nozzle 1.

In this manner, the water-repellent material or flow promoting material G2 in the liquid supply portion 8C is supplied to the nozzle 1 to be mixed into the processing fluid Q or abrasive G, thereby improving the fluidity of the processing liquid Q or abrasive G with the water-repellent material or flow promoting material G2 so that it can smoothly flow through the nozzle 1.

<Another Modification>

For example, although in the above-described embodiment, the description has been made using, as an example, the abrasive supply device 8 which includes the first abrasive supply device 8A and the second abrasive supply device 8B, the arrangement may be such that the abrasive supply device 8 includes only the second abrasive supply device 8B to supply only the coated abrasive G3 to the nozzle 1.

Furthermore, in the above-described embodiment, the case where the supply port 13a is provided at one place of the mixing chamber 13 has been described. However, the supply port 13a may be provided at a plurality of places, and a plurality of the abrasive supply devices 8 may be provided corresponding to the plurality of supply ports 13a.

EXAMPLES

Next, referring mainly to tables 1 and 2, examples will be described.
[0136] In the examples, two kinds of related art abrasive materials with different grain sizes and the coated abrasive G3 (water-repellent abrasive) of the present invention are supplied to the nozzles 1 having two different nozzle diameters, and it has been confirmed that the coated abrasive G3 (water-repellent abrasive) has the function of eliminating clogging.

<table>
<thead>
<tr>
<th>Abrasive grain ejection amount: (g/min)</th>
<th>Abrasive grain ejection amount: (g/min)</th>
<th>Abrasive grain ejection amount: (g/min)</th>
<th>Abrasive grain ejection amount: (g/min)</th>
<th>Abrasive grain ejection amount: (g/min)</th>
<th>Abrasive grain ejection amount: (g/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>40</td>
<td>60</td>
<td>80</td>
<td>100</td>
<td>120</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Related art abrasive material with grain size of #120</th>
<th>Good</th>
<th>Good</th>
<th>Good</th>
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<th>Good</th>
<th>Good</th>
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<th>Good</th>
</tr>
</thead>
<tbody>
<tr>
<td>Related art abrasive material with grain size of #220</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>Water-repellent abrasive of present invention with grain size of #220</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
</tr>
</tbody>
</table>

[0137] Table 1 shows a result of a first experiment in which, using the abrasive waterjet machining apparatus 100 according to the embodiment of the present invention, each of a related art abrasive material with a grain size of #120, a related art abrasive material with a grain size of #220, and the coated abrasive G3 (water-repellent abrasive) of the present invention with a grain size of #220 is supplied to the nozzle 1 having the abrasive nozzle 15 with a pressure of 300 MPa and an inner diameter of φ0.5 mm. The result is represented as “Good” if the abrasive G is not agglomerated, as “Fair” if the abrasive G is slightly agglomerated but does not cause clogging, as “Poor” if the abrasive G is agglomerated and causes clogging.

<table>
<thead>
<tr>
<th>Experimental Result 1 (in case of nozzle with inner diameter of φ0.5 mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abrasive grain ejection amount: (g/min)</td>
</tr>
<tr>
<td>20</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Related art abrasive material with grain size of #120</th>
<th>Good</th>
<th>Good</th>
<th>Good</th>
<th>Good</th>
<th>Good</th>
<th>Good</th>
<th>Good</th>
<th>Good</th>
</tr>
</thead>
<tbody>
<tr>
<td>Related art abrasive material with grain size of #220</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>Water-repellent abrasive of present invention with grain size of #220</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
</tr>
</tbody>
</table>

[0138] As shown in Table 1, in the case of the abrasive nozzle 15 with an inner diameter of φ0.5 mm, as for any of the related art abrasive material with a grain size of #120, the related art abrasive material with a grain size of #220, and the coated abrasive G3 (water-repellent abrasive) of the present invention with a grain size of #220, agglomeration of the abrasive G and clogging did not occur. Consequently, all the results were “Good”.

Table 2

<table>
<thead>
<tr>
<th>Experimental Result 2 (in case of nozzle with inner diameter of φ0.3 mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abrasive grain ejection amount: (g/min)</td>
</tr>
<tr>
<td>20</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Related art abrasive material with grain size of #120</th>
<th>Good</th>
<th>Fair</th>
<th>Poor</th>
<th>Poor</th>
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<tbody>
<tr>
<td>Related art abrasive material with grain size of #220</td>
<td>Poor</td>
<td>Poor</td>
<td>Poor</td>
<td>Poor</td>
<td>Poor</td>
<td>Poor</td>
<td>Poor</td>
<td>Poor</td>
</tr>
<tr>
<td>Water-repellent abrasive of present invention with grain size of #220</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
</tr>
</tbody>
</table>
Table 2 shows a result of a second experiment in which, using the abrasive water jet machining apparatus 100 according to the embodiment of the present invention, each of a related art abrasive material with a grain size of #120, a related art abrasive material with a grain size of #220, and the coated abrasive G3 (water-repellent abrasive) of the present invention with a grain size of #220 is supplied to the nozzle 1 having the abrasive nozzle 15 with a pressure of 300 MPa and an inner diameter of 40.3 mm.

As shown in Table 2, in the case of the abrasive nozzle 15 with an inner diameter of 40.3 mm, as for both the related art abrasive material with a grain size of #120 and the related art abrasive material with a grain size of #220, clogging occurred entirely, except that the related art abrasive material with a grain size of #120 did not cause clogging when the abrasive grain ejection amount is 20 and 40 (g/min).

On the other hand, as for the coated abrasive G3 (water-repellent abrasive) of the present invention with a grain size of #220, it has been confirmed that, in any case, the abrasive G does not agglomerate and the inside of the nozzle 1 is not clogged.

1. An abrasive water jet machining apparatus that performs machining by directing an abrasive water jet at a workpiece, the abrasive water jet being composed of a mixture of a high-pressure processing fluid with an abrasive, comprising:
   a nozzle that directs the abrasive water jet;
   a processing fluid supply portion that supplies the processing fluid to the nozzle;
   an abrasive supply portion that supplies the abrasive to the processing fluid; and
   a liquid supply portion that supplies a water-repellent material or flow promoting material to the processing fluid or the abrasive.

5. The abrasive water jet machining apparatus according to claim 1, wherein the water-repellent material or flow promoting material is composed of any one of a fluorine-based material, silicon-based material, a coating material composed of a mixture of a fluorine-based material or a silicon-based material and an oily raw material, paraffin, and fats.

6. The abrasive water jet machining apparatus according to claim 1, further comprising:
   a catcher tank that stores liquid for machining the workpiece under liquid; and
   a discharge port that discharges the liquid stored in the catcher tank, wherein the coated abrasive floating on the liquid is discharged and recovered from the discharge port.

7. The abrasive water jet machining apparatus according to claim 6, further comprising a liquid level adjusting device that adjusts a liquid level of the liquid by adjusting a height of the discharge port.

8. An abrasive water jet machining method in which machining is performed by directing an abrasive water jet at a workpiece, the abrasive water jet being composed of a mixture of a high-pressure processing fluid with an abrasive, the method comprising:
   producing a coated abrasive as the abrasive by coating a surface of an abrasive material composed of abrasive grains with a water-repellent material or flow promoting material.

9. An abrasive water jet machining method in which machining is performed by directing an abrasive water jet at a workpiece, the abrasive water jet being composed of a mixture of a high-pressure processing fluid with an abrasive, the method comprising:
   supplying a water-repellent material or flow promoting material to the processing fluid or the abrasive.

10. The abrasive water jet machining apparatus according to claim 2, wherein the abrasive supply portion includes:
    an abrasive material supply portion that supplies the abrasive material to the processing fluid;
    a coated abrasive supply portion that supplies the coated abrasive to the processing fluid; and
    a switching unit for selectively supplying the abrasive material supplied from the abrasive material supply portion or the coated abrasive supplied from the coated abrasive supply portion.

4. An abrasive water jet machining apparatus that performs machining by directing an abrasive water jet at a workpiece, the abrasive water jet being composed of a mixture of a high-pressure processing fluid with an abrasive, comprising: