Provided is an abrasive water jet nozzle comprising a mixing chamber for absorbing the abrasives with air through a supply port; a water nozzle; a mixing nozzle disposed on the downstream side against the water nozzle, to mix the abrasives in a water jet jetted out of the water nozzle, and to jet the water jet into the mixing chamber out of a through hole of the mixing nozzle; and an abrasive nozzle disposed on the downstream side against the mixing nozzle, to introduce the water jet thereinto to jet an abrasive water jet. A diameter of the through hole is larger than that of the water nozzle so that the abrasives in the mixing chamber are absorbed with air in a clearance between the through hole and the water jet passing through the through hole to mix the abrasives in the water jet.
FIG. 3

Processing Time for Piercing (s)

D3/D1

0 5 10 15 20 25
0 5 10 15 20 25 30
ABRASIVE WATER JET NOZZLE AND ABRASIVE WATER JET MACHINE

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the foreign priority benefit under Title 35, United States Code, 119 (a)-(d) of Japanese Patent Application No. 2012-089748, filed on Apr. 10, 2012 in the Japan Patent Office, the disclosure of which is herein incorporated by reference in its entirety.

BACKGROUND OF THE INVENTION

[0002] 1. Technical Field
[0003] The present invention relates to an abrasive water jet nozzle comprising a mixing nozzle to absorb abrasives in a through hole thereof to mix the abrasives in a water jet, and an abrasive water jet machine including the abrasive water jet nozzle.

[0004] 2. Description of Background Art
[0005] An abrasive water jet machine is known as a machine to cut a workpiece having a thickness to some extent or made of hard material. In general, like glass, stone, a synthetic resin, and a composite material like a carbon fiber reinforced plastic (CFRP) are included in the hard material. The abrasive water jet machine improves cutting efficiency by jetting an abrasive water jet to the workpiece. The abrasive water jet is a water jet supplied at high pressure of 200 to 400 MPa in which abrasives are mixed.

[0006] Various means for mixing an adequate quantity of abrasives in the water jet are adopted in the prior abrasive water jet machine in order to prevent a nozzle from being damaged due to the abrasives and to improve the cutting efficiency (for example, patent documents 1, 2).

[0007] An abrasive nozzle described in the patent document 1 is a nozzle which generates a swirl flow of super high pressure fluid within a nozzle main body by including a swirl generating device. The swirl generating device has a swirl groove to feed abrasives toward a center of the nozzle main body so that the abrasives are mixed more densely in a center part of a water jet than in the other.

[0008] An abrasive nozzle described in the patent document 2 is a nozzle which jets a water jet supplied from the water jet supply part 11 into spherical-zircon beads ZB and water mixed with spherical-zircon beads so that the spherical-zircon beads are mixed in the water jet. The spherical-zircon beads ZB are supplied from a spherical-zircon-bead-supply part 12a, and the water mixed with spherical-zircon beads are supplied from a recycled-spherical-zircon-bead-supply part 12b.


BRIEF SUMMARY OF THE INVENTION

[0011] However, in the prior abrasive nozzle, the abrasives supplied to a mixing chamber are directly involved and absorbed in the water jet by jetting the water jet into the mixing chamber. Hence, there are problems to cause the abrasive nozzle to be filled with and/or to be worn by the abrasives because the abrasives are concentrated at an inlet port of the abrasive nozzle. Especially, when an inner diameter of the abrasive nozzle is made small in order to improve the precision of the cutting process, the quantity of abrasives is saturated in the abrasive nozzle so that the abrasive nozzle tends to be further filled with the abrasives.

[0012] On the other hand, there is another problem to cause the precision or the quality of the cutting process to be uneven in a case that the cutting process is done by using the abrasive water jet containing an inadequate quantity of abrasives. Furthermore, the abrasive nozzle may be worn further when the abrasives unevenly enter and are mixed in the abrasive nozzle.

[0013] The present invention has been created in view of such a technical background. It is an object of the present invention to provide an abrasive water jet nozzle and an abrasive water jet machine which are capable of mixing an adequate quantity of abrasives in a water jet, are capable of reducing a degree of filling the interior of the abrasive nozzle with the abrasives, are capable of reducing a degree of the abrasion of the abrasive nozzle, and are capable of improving the precision and efficiency of the cutting process.

[0014] To solve the above problems, the present invention provides an abrasive water jet nozzle for jetting an abrasive water jet to a workpiece to process the workpiece, the abrasive water jet being a water jet supplied to an inlet hole and mixed with abrasives, comprising:

[0015] a mixing chamber for absorbing the abrasives therein together with air through a supply port, the mixing chamber being composed as an air chamber;

[0016] a water nozzle having the inlet hole and to jet the water jet;

[0017] a mixing nozzle disposed on a downstream side against the water nozzle, to mix the abrasives in the water jet jetted out of the water nozzle, and to jet the water jet mixed with the abrasives into the mixing chamber out of a through hole of the mixing nozzle; and

[0018] an abrasive water jet nozzle disposed on a downstream side against the mixing nozzle, to introduce the water jet mixed with the abrasives thereinto, and to jet the abrasive water jet to the workpiece,

[0019] wherein a diameter of the through hole of the mixing nozzle is larger than a diameter of an inlet port of the inlet hole of a nozzle part of the water nozzle so that the abrasives stayed in the mixing chamber are absorbed together with air in a clearance formed between an inner surface defining the through hole and the water jet passing through the through hole to mix the abrasives in the water jet in the through hole.

[0020] The abrasive water jet nozzle according to the present invention comprises the mixing chamber as a kind of air chamber in which the abrasives are absorbed together with air through the supply port. When the water jet jetted out of the water nozzle passes through the mixing chamber composed as an air chamber, a negative pressure is generated by the water jet passing through at a high speed. Therefore, the abrasives are absorbed together with air to be stayed in the mixing chamber due to the negative pressure, and the abrasives stayed in the mixing chamber are efficiently mixed in the water jet.

[0021] Furthermore, wording of “water” or “water jet” is used in the explanation of the present invention in an idiomatic manner. However, the present invention is not limited to “water”. Fluid used in the present invention widely includes water and other kind of fluid for processing.

[0022] The abrasive water jet nozzle according to the present invention comprises the mixing nozzle for jetting the water jet passed through the through hole into the mixing
chamber. Therefore, the abrasives are absorbed together with air in a clearance formed between the water jet passing through the through hole and an inner surface defining the through hole of the mixing nozzle such that the abrasives are forced to be mixed in the water jet in the through hole of the mixing nozzle by absorbing the abrasives in the water jet.

[0023] That is, in the present invention, the abrasives introduced into the mixing chamber are not directly mixed in the water jet within the mixing chamber as in the prior art. But in the present invention, the abrasives are absorbed and mixed in the water jet in the through hole of the mixing nozzle while the abrasives are being stirred up and absorbed together with air in the through hole of the mixing nozzle in a direction opposite to the flow direction of the water jet. Therefore, an adequate quantity of abrasives can be mixed in the water jet.

[0024] Furthermore, there are two mixing routes to mix the abrasives introduced into the mixing chamber in the water jet because the abrasive water jet nozzle according to the present invention comprises the mixing nozzle. The first mixing route is a route to absorb the abrasives in the mixing nozzle in the direction opposite to the flow direction of the water jet, through an outlet port of the mixing nozzle, that is, through an outlet port positioned at a front end of the through hole, to mix the abrasives in the water jet. The second mixing route is a route to mix the abrasives in the water jet jetted downward out of the outlet port of the mixing nozzle.

[0025] Thus, the abrasives are mixed in the water jet through the two separate routes in the present invention. Therefore, the abrasives in the mixing chamber are not forced to concentrate at an inlet port of the abrasive nozzle to be absorbed in, so that the abrasives are uniformly mixed in the water jet and the interior of the abrasive nozzle is efficiently prevented from being filled with the abrasives.

[0026] The abrasive water jet nozzle according to the present invention prevents the abrasive nozzle from being filled with the abrasives, so that an inner diameter of the abrasive nozzle can be formed smaller to smoothly enhance the flow speed of the abrasive water jet. Therefore, abrasive consumption can be economized, and the precision and efficiency of the cutting process can be improved by using the abrasive water jet nozzle with a small inner diameter.

[0027] It is preferable that the diameter of the through hole of the mixing nozzle is 5 to 25 times as large as the diameter of the inlet port of the nozzle hole of the water nozzle.

[0028] The abrasives can be efficiently absorbed in a clearance formed between the water jet and the inner surface defining the through hole of the mixing nozzle to be mixed in the water jet by using the abrasive water jet nozzle comprising the mixing nozzle having the through hole whose diameter is 5 to 25 times as large as that of the inlet port of the inlet hole of the nozzle part of the water nozzle.

[0029] That is, in a case that the clearance is too small, the quantity of the abrasives to be absorbed becomes few. Also, in a case that the clearance is too big, the degree of the negative pressure becomes low, so that the quantity of the abrasives to be absorbed is decreased. For this reason, it is desirable that the diameter of the through hole of the mixing nozzle is properly set within the range of 5 to 25 times as large as the diameter of the inlet port of the nozzle hole of the water nozzle because the quantity of the abrasives to be absorbed becomes peak in a case that the diameter of the through hole of the mixing nozzle is 5 to 25 times as large as the diameter of the inlet port of the nozzle hole of the nozzle part of the water nozzle.

[0030] And it is preferable that a length of the through hole of the mixing nozzle is longer than a distance from an outlet port positioned at a front end of the through hole to the abrasive nozzle.

[0031] In this case, a length of the second mixing route can be set short by using the abrasive water jet nozzle in which the length of the through hole of the mixing nozzle is longer than the distance from the outlet port positioned at the front end of the through hole to the abrasive nozzle. Therefore, the abrasives in the mixing chamber are prevented from concentrating at the inlet port of the abrasive nozzle to be absorbed in the abrasive nozzle, so that the abrasive nozzle is efficiently prevented from being filled with the abrasives and an adequate quantity of abrasives can be steadily mixed in the water jet.

[0032] In other words, in the second mixing route for mixing the abrasives in the water jet jetted downward out of the outlet port of the mixing nozzle, the abrasives introduced into the mixing chamber is forced to be absorbed in the abrasive nozzle through the inlet port of the abrasive nozzle. Therefore, in the second mixing route, the abrasives tend to concentrate at the inlet port of the abrasive nozzle, thus filling the inlet port with the abrasives tends to be induced. Because of this, it is preferable that the length of the second mixing route is set shorter and the length of the first mixing route is set longer as much as the second mixing route is shortened.

[0033] Furthermore, it is preferable that a diameter of a through hole of the abrasive nozzle is smaller than the diameter of the through hole of the mixing nozzle, and is larger than the diameter of the inlet port of the inlet hole of the nozzle part of the water nozzle.

[0034] The precision and efficiency of the cutting process can be improved by using the abrasive water jet nozzle in which the diameter of the through hole of the abrasive nozzle is smaller than the diameter of the through hole of the mixing nozzle. And filling with the abrasives can be prevented by using the abrasive water jet nozzle in which the diameter of the through hole of the abrasive nozzle is larger than the diameter of the inlet port of the inlet hole of the nozzle part of the water nozzle.

[0035] And furthermore, it is preferable that the mixing nozzle has an approximately cylindrical shape and has a tapered part formed on an outer surface thereof, the tapered part being configured to decrease a diameter toward the abrasive nozzle. The tapered part is formed from a position facing the supply port to a front tip of the mixing nozzle.

[0036] The abrasives introduced into the mixing chamber together with air through the supply port smoothly flow along the outer surface of the mixing nozzle to the tip thereof and are absorbed in the mixing nozzle by using the abrasive water jet nozzle in which the mixing nozzle has the tapered part formed on the front port of the outer surface thereof. Thus the abrasives are efficiently absorbed together with air in the clearance formed in the through hole through the outlet port for the water jet positioned at the tip of the mixing nozzle. Therefore, the abrasives can be absorbed to be mixed in the water jet within the through hole.

[0037] Furthermore, the present invention provides an abrasive water jet machine including the abrasive water jet nozzle described in the foregoing and an abrasive supply apparatus for supplying a predetermined quantity of abrasives to the mixing chamber.
[0038] wherein the abrasive supply apparatus comprises:
[0039] a reservoir for reserving the abrasives therein;
[0040] a flow-out hole formed in a lower part of the reservoir;
[0041] a conveyance rotor disposed so as to define a predetermined gap below or on the downstream side of the flow-out hole, and capable of rotating around a horizontal axis;
[0042] a receiver disposed below or on the downstream side of the conveyance rotor; and
[0043] an exhaust port formed in the receiver.

[0044] Abrasives which flew out of the flow-out hole are conveyed by the conveyance rotor rotating in a case of using the abrasive water jet machine in which the conveyance rotor is disposed so as to define a predetermined gap below or on the downstream side of the flow-out hole.

[0045] That is, since the predetermined gap is provided between the flow-out hole and the conveyance rotor, the abrasives are kept staying in the gap because of friction between each of the abrasives when the conveyance rotor is in a stopped condition. On the other hand, when the conveyance rotor is in a rotating condition, since the abrasives stayed in the gap are conveyed along the outer surface of the conveyance rotor, further abrasives flow out of the flow-out hole into the gap. Thus the abrasives which flowed into the gap are conveyed along the outer surface of the conveyance rotor in accordance with the rotational speed of the conveyance rotor by the conveyance rotor rotating, so that the abrasives are accumulated in the receiver disposed below or on the downstream side of the conveyance rotor, and then are sent through the exhaust port.

[0046] Thereby, an adequate quantity of abrasives can be smoothly and uniformly supplied to the mixing chamber by the conveyance rotor rotating when the abrasive water jet machine is used. Therefore, the abrasives can be uniformly mixed in a water jet, the degree of filling the interior of the abrasive nozzle with the abrasives can be reduced, the degree of abrasion of the abrasive nozzle can be reduced, and the precision and efficiency of the cutting process can be improved.

[0047] It is preferable that the conveyance rotor in the abrasive water jet machine according to the present invention has a concavo-convex part formed on an outer surface thereof.

[0048] Abrasives which flow into the gap can be kept staying there to be prevented from dropping freely, and can be smoothly conveyed along the outer surface of the conveyance rotor by using the abrasive water jet machine in which the conveyance rotor has the concavo-convex part on the outer surface thereof.

[0049] The present invention can provide an abrasive water jet nozzle and an abrasive water jet machine which are capable of uniformly mixing abrasives in a water jet, are capable of reducing the degree of filling the interior of the abrasive nozzle with the abrasives, are capable of reducing the degree of the abrasion of the abrasive nozzle, and are capable of improving the precision and efficiency of the cutting process.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

[0050] FIG. 1 is a schematic sectional view of an abrasive water jet machine of a present embodiment according to the present invention;

[0051] FIG. 2 is a schematic sectional view of an abrasive water jet nozzle of the present embodiment according to the present invention;

[0052] FIG. 3 is a graph chart to explain an operation of the mixing nozzle shown in FIG. 2;

[0053] FIG. 4A is an enlarged partial view mainly showing a conveyance rotor in FIG. 1 when the conveyance rotor stops;

[0054] FIG. 4B is a side view viewed from a side of the conveyance rotor in FIG. 4A, and

[0055] FIG. 4C is another view corresponding to FIG. 4A when the conveyance rotor is rotating.

DETAILED DESCRIPTION OF THE INVENTION

[0056] An embodiment of an abrasive water jet machine 100 according to the present invention will be described in detail with reference to the attached drawings.

[0057] The abrasive water jet machine 100 is a machine for mixing abrasives G in a water jet Q supplied at high pressure of 200 to 400 MPa, and for jetting an abrasive water jet AWJ to cut a workpiece (not shown). And the abrasive water jet machine 100 can jet the abrasive water jet AWJ at high speed over the speed of sound. Therefore, the cutting process can be done with high precision even if the workpiece is made of one of a hard material like glass, a relatively soft material like a synthetic resin, and a composite material consisting of a plurality of materials. For example, the composite material consists of the hard material, the soft material.

[0058] The abrasive water jet machine 100 comprises an abrasive water jet nozzle 1 for jetting the abrasive water jet AWJ mixed with the abrasives G, a water jet supply apparatus 10 for supplying a water jet Q through a high pressure pipe 102 to the abrasive water jet nozzle 1, and an abrasive supply apparatus 8 for supplying an adequate quantity of abrasives G to the abrasive water jet nozzle 1, as shown in FIG. 1.

[0059] Furthermore, the abrasive water jet machine 100 is shown so that a jet direction of the abrasive water jet AWJ is a downward direction in FIG. 1 in the present embodiment. However, the present invention is not limited to this direction. The jet direction may be a horizontal direction. Also, the abrasive water jet machine or the abrasive water jet nozzle may be attached to the tip of a robot arm. And the abrasive water jet machine or the abrasive water jet nozzle may be attached to a portable abrasive water jet machine, and in this case, an operator can handle the portable abrasive water jet machine with his hand(s) for the cutting process. Hence, the jet direction of the abrasive water jet AWJ can be freely changeable.

[0060] In the present invention, a general abrasive including at least one of a garnet, a sapphire, and Cemented Carbide can be properly used for the abrasives G in accordance with a kind of and/or a use of a workpiece. The grain size of the abrasives G is properly set in accordance with the kind of and/or the use of the workpiece. Minute grains and coated grains can also be used.

[0061] The abrasive water jet nozzle 1 comprises a nozzle main body 2, a mixing chamber 3 formed in the nozzle main body 2, a water nozzle 4 having an inlet hole 41 formed through the water nozzle in order to jet a water jet W3 through the inlet hole 41, a mixing nozzle 5 for mixing the abrasives G in the water jet W3 jetted out of the water nozzle 4 to generate a water jet AW mixed with the abrasives G (hereinafter, this is called a water jet AW), and an abrasive nozzle 6 for jetting an abrasive water jet AWJ to process a workpiece (not shown), as shown in FIG. 2.
Furthermore, FIG. 2 is a schematic view in view of visibility. For example, a relation between a hole diameter of the water nozzle 4 and a diameter of the water jet WJ is simplified, and this relation is not strictly correct in FIG. 2. That is, in general, it is assumed that the diameter of the water jet WJ jetted out of the water nozzle 4 is smaller than the hole diameter of the water nozzle 4. And the grain size of the abrasives G is exaggeratedly shown in FIGS. 1 and 2. FIGS. 1 and 2 show that the abrasives G are floating and flowing in the air in the mixing chamber 3, and also show that the abrasives G are flowing as grains to be conveyed in the abrasive supply apparatus 8.

The nozzle main body 2 has an upper body 21 and a lower body 22. The nozzle main body 2 is a member for fixing members of the water nozzle 4, the mixing nozzle 5, and so on at each predetermined position with high precision. The mixing chamber 3 is formed in the middle of the nozzle main body 2. That is, the space of the mixing chamber 3 is formed in the lower part of the upper body 21 and is closed by an upper surface of the lower body 22 from under the space.

Furthermore, for convenience of explanation, it is shown that the mixing nozzle 5 is an individual member different from the nozzle main body 2 in FIGS. 1 and 2, and is tightly inserted in the nozzle main body 2 (the upper body 21) to be fixed therein. But it is general that the mixing nozzle 5 is formed integrally with the nozzle main body 2 (the upper body 21) in views of manufacture and so on.

On the other hand, size and/or material of the mixing nozzle 5 can be easily changed in a case that the individual mixing nozzle 5 is inserted in the nozzle main body 2 (the upper body 21) to be removably fixed therein. And the nozzle main body 2 is formed by the two members of the upper body 21 and the lower body 22 in the present embodiment. But the upper body 21 and the lower body 22 may be formed integrally as one member.

The mixing chamber 3 has an approximately cylindrical shape, and the mixing nozzle 5 is disposed to be protruded into the central part of the mixing chamber 3. The mixing nozzle 5 is composed so that the water jet WJ jetted out of the water nozzle 4 passes through the mixing nozzle 5, and the water jet AW passes through the mixing chamber 3 to be introduced into the abrasive nozzle 6.

The mixing chamber 3 has a supply port 31 through which the abrasives G are introduced into the mixing chamber 3. The abrasives G sent from the abrasive supply apparatus 8 shown in FIG. 1 are absorbed together with air in the mixing chamber 3 through the supply port 31. The mixing chamber 3 is composed as an air chamber, so that the abrasives G introduced into the mixing chamber 3 can be enough decelerated to stay in the mixing chamber 3. Therefore, the abrasives G introduced into the mixing chamber 3 are mixed in the water jet WJ in order to generate the water jet AW. The abrasive supply apparatus 8 shown in FIG. 1 is configured to send an adequate quantity of abrasives G toward the supply port 31.

Furthermore, “the mixing chamber 3 is composed as an air chamber” means that the mixing chamber is a defined space capable of staying the abrasives therein. The mixing chamber 3 is not limited to an airtight space defined by some walls having no port through which the space is communicated with any attached device or instrument like a vacuum device which is used in order to generate an auxiliary negative pressure in the mixing chamber 3 during the processing for piercing.
The abrasives G. And the interior surface of the mixing nozzle 5 may be coated so that durability and wear resistance thereof are improved.

The outer shape of the mixing nozzle 5 is cylindrical in the present embodiment. However, the outer shape of the mixing nozzle 5 may be polygonal.

A negative pressure is generated in the through hole 51 of the mixing nozzle 5 when the water jet WJ jetted out of the water nozzle 4 passes through the through hole 51 to be jetted out of the outlet port 53 of the through hole 51. Therefore, a clearance δ1 is formed between the water jet WJ(AW) passing through the through hole 51 and the inner surface of the through hole 51, and the abrasives G are absorbed in the clearance δ1 together with air through the outlet port 53 (refer to an arrow R1 in FIG. 2).

The abrasives G are mixed in the water jet WJ within the through hole 51 of the mixing nozzle 5 while the abrasives G are absorbed up to a height H3 above the outlet port 53 in such a way (the first mixing route R1). In a case that the height H3 up to which the abrasives G can be absorbed above the outlet port 53 is high, the quantity of the abrasives G to be mixed in the water jet WJ tends to increase. However, the height H3 also relates to the size of the clearance δ1.

The mixing nozzle 5 has the tapered part 52 formed on the outer surface thereof. The tapered part 52 is configured to decrease a diameter toward the abrasive nozzle 6 so as for its cross section being smaller, and is formed from a position facing the supply port 31 to the front tip of the mixing nozzle 5.

Hereby, after the abrasives G are introduced into the mixing chamber 3 together with air through the supply port 31, the abrasives G are smoothly flowed along the tapered part 52 formed on the outer surface of the mixing nozzle 5 to the front tip and the abrasives G are absorbed in the clearance through the outlet port 53.

Furthermore, in the present embodiment, the tapered part 52 has a conical shape. However, the present invention is not limited to this shape. The tapered part may have a polygonal cross section, and may have an uneven surface which has a stair or stairs that become smaller gradually toward the tip of the mixing nozzle 5 in cross sectional sizes. And furthermore, the mixing nozzle 5 may have a straight cylindrical shape instead of the tapered part on the outer surface thereof. In the case of the straight cylindrical shape, after the abrasives G are introduced into the mixing chamber 3 together with air through the supply port 31, the abrasives G are smoothly flowed toward the outlet port 53 positioned at the front tip of the mixing nozzle 5 by reducing an outer diameter of the mixing nozzle 5.

Though, in the present invention, the tapered part 52 is formed on the outer surface of the mixing nozzle 5, it is feasible that the tapered part is formed on the inner surface of the mixing nozzle 5.

The abrasive water jet nozzle 1 can mix an adequate quantity of abrasives G in the water jet WJ by setting an adequate size of the clearance δ1 formed between the water jet WJ and the inner surface of the mixing nozzle 5 defining the through hole 51. The clearance δ1 will be described with reference to FIG. 3 in the following. FIG. 3 is a graph chart showing a relation between the clearance δ1 and a processing time (seconds) for piercing by taking the ratio of the inner diameter D3 of the mixing nozzle 5 to the diameter D1 of the inlet port 41A of the water nozzle 4, that is, D3/D1 on the abscissa and the processing time for piercing on the ordinate.

Furthermore, the processing for piercing is an abrasive water jet processing to be conducted previously to the cutting process in the abrasive water jet processing. The processing for piercing is selected as a standard processing to investigate processing efficiency in the abrasive water jet processing in order to verify whether the adequate quantity of abrasives G is mixed in the water jet WJ through measuring processing times for piercing under the condition of a constant pressure of the water jet WJ.

It is preferable that the diameter D3 of the through hole 51 of the mixing nozzle 5 is set to 5 to 25 or 5 to 20 times as large as the diameter D1 of the inlet port 41A of the nozzle part 43 of the water nozzle 4.

Here, the following equation is obtained.

\[ \delta_1 = \frac{(D3 - D1)}{2} \]

Therefore, in the case of D3/D1=5, the following equation is derived.

\[ \delta_1 = \frac{(5D1 - D1)}{2} = 2D1 \]

And, in the case of D3/D1=25, the following equation is derived.

\[ \delta_1 = \frac{(25D1 - D1)}{2} = 12D1 \]

That is, the clearance δ1 formed in the through hole 51 shown in FIG. 2 is set to be 2 to 12 times as large as the diameter D1 of the inlet port 41A of the inlet hole 41 of the nozzle part 43 of the water nozzle 4.

The clearance δ1 relates also to the speed and the pressure of the water jet WJ and the diameter D1. However, in general, the quantity of the abrasives G to be absorbed tends to decrease in a case that the clearance δ1 is too small. And, the quantity of the abrasives G to be absorbed tends to decrease also in a case that the clearance δ1 is too large so that degree of negative pressure decreases. And the quantity of the abrasives G to be mixed tends to increase in a case that the height H3 up to which the abrasives G are absorbed in the upstream is high as can be seen in FIG. 2.

The relation between processing time for piercing and the clearance δ1 will be explained with reference to FIG. 3 in order to verify that the quantity of the abrasives G absorbed and mixed in the water jet WJ is proper. When the flow speed of the abrasive water jet AWJ is set to be constant, in a case that the quantity of the abrasives G mixed is large, the processing efficiency is improved, so that the processing time tends to take a short time, and in a case that the quantity of the abrasives G mixed is small, the processing time tends to take a long time.

For example, in a case that the pressure of the water jet WJ is set to be 300 MPa and the diameter D1 in the water nozzle 4 is set to be 0.1 mm. to 0.15 mm, it can be guessed that...
the processing efficiently becomes peak and the quantity of the abrasives G mixed becomes maximum under the condition that the ratio of D3/D1 is set to be about 13 as shown in FIG. 3.

[0094] In fact, various conditions like flow speed and pressure of the water jet WJ, and the diameter D1 in the water nozzle 4 should be considered. Therefore, it is preferable that the ratio of D3/D1 is properly set in the range of 5 to 25 or 5 to 20 sandwiching the peak ratio 13.

<Second Mixing Route>

[0095] On the other hand, the water jet AW jetted into the mixing chamber 3 out of the outlet port 53 of the mixing nozzle 5 also causes a negative pressure while it passes from the outlet port 53 of the mixing nozzle 5 in the mixing chamber 3 to the abrasive nozzle 6. Therefore, the abrasives G are mixed also in the water jet AW (refer to an arrow R2 in FIG. 2).

<Relation Between First and Second Mixing Routes>

[0096] The outlet port 53 of the mixing nozzle 5 is located at the front tip of the mixing nozzle 5, and is disposed at a predetermined height H1 above the abrasive nozzle 6.

[0097] The height H1 from the abrasive nozzle 6 to the outlet port 53 of the mixing nozzle 5 is set to be shorter than a length H2 of the through hole 51 of the mixing nozzle 5.

[0098] That is, this relation between the height H1 and the length H2 intends the following. The second mixing route R2 for mixing the abrasives G in the water jet AW jetted out of the outlet port 53 of the mixing nozzle 5 downward affects the abrasives G introduced into the mixing chamber 3 to be absorbed in an inlet port of the abrasive nozzle 6. Therefore, the abrasives G concentrate at the inlet port of the abrasive nozzle 6 in a high density unevenly, so that the inlet port of the abrasive nozzle 6 tends to be filled with the abrasives G. For this reason, it is preferable that the length or height H1 for the second mixing route R2 is shortened and the length or height H2 of the first mixing route R1 is lengthened by that much.

[0099] The abrasive nozzle 6 is located on a downstream side of the flow direction of the water jet AW against the mixing nozzle 5. The abrasive nozzle 6 is a member for introducing the water jet AW mixed with the abrasives G through the first mixing route R1 and the second mixing routes R2 hereunto and for jetting the abrasive water jet AW1 to a workpiece (not shown).

[0100] The hole diameter D2 of the abrasive nozzle 6 is generally set to be about 0.3 mm to 0.5 mm. It is preferable that the hole diameter D2 is set to be smaller than the hole diameter D3 of the mixing nozzle 5 and larger than the hole diameter D1 of the inlet port 41A of the inlet hole 41 of the nozzle part 43 of the water nozzle 4.

[0101] That is, by setting the hole diameter D2 of the abrasive nozzle 6 to be smaller than the hole diameter D3 of the mixing nozzle 5, the abrasive nozzle 6 can be set to have a small diameter. Therefore, the precision and efficiency of the cutting process can be improved. And by setting the hole diameter D2 of the abrasive nozzle 6 to be larger than the hole diameter D1 of the water nozzle 4, an effect of reducing the degree of filling the abrasive nozzle 6 with abrasives G can be expected.

[0102] Furthermore, the present invention has been described separately about the first mixing route R1 and the second mixing route R2 so that the present invention can be easily understood in this embodiment by simplifying the matter. However, there exist abrasives G to be mixed in pieces of water jet scattered in the mixing chamber 3. For this reason, the above-mentioned separate description for the first mixing route R1 and the second mixing route R2 does not mean that the entire abrasives G supplied to the mixing chamber 3 are mixed in the water jet only via the first mixing route R1 and the second mixing route R2. In regard to the first mixing route R1, a swirl flow can be generated in some cases when the abrasives G are flung up in the upstream. Such a swirl flow affects the length or height H3 of the first mixing route R1 in some cases.

<Abrasive Supply Apparatus>

[0103] The abrasive supply apparatus 8 comprises a reservoir 81 for reserving the abrasives G therein; a flowing out hole 82 formed in the lower part of the reservoir 81; a conveyance rotor 83 disposed so as to define a predetermined gap G2 (refer to FIG. 4A) below the flowing out hole 82, and capable of rotating around an axis of a horizontal shaft 83a; a motor 84 to drive the conveyance rotor 83; a control unit (not shown) to control the motor 84; a receiver 85 disposed below the conveyance rotor 83; and an exhaust port 86 formed in the receiver 85, as shown in FIG. 1.

[0104] The conveyance rotor 83 comprises convex parts 83b forming a concavo-convex part on the outer surface of the conveyance rotor 83, and two walls 83a apart from each other in a direction along an axis of the conveyance rotor 83 and sandwiching the convex parts 83b between them as shown in FIGS. 1 and 4A to 4C. The convex parts 83b are formed linearly along the axis of the conveyance rotor 83 and are disposed over the circumference direction of the conveyance rotor. And the convex parts 83b are apart at equal distances from each other so that the convex parts 83b resemble vanes of a waterwheel. Each of the walls 83a is formed like a flange protruding in a radial direction from the corresponding edge of the outer surface of the conveyance rotor.

[0105] Hereby, the conveyance rotor 83 can keep abrasives G which flew out of the flowing out hole 82 staying there so not to be scattered, so that the necessary quantity of abrasives G can be conveyed to the receiver 85 in a proper timing.

[0106] The convex parts 83b are formed on the outer surface of the conveyance rotor 83 in the present embodiment. However, the present invention is not limited to this form. Any form or structure which can keep a predetermined quantity of abrasives G staying on the outer surface during a predetermined time is allowable. Therefore, recessed parts are allowable as concave parts in the aforementioned structure. And another structure having both of concave parts and convex parts is allowable. Furthermore, a structure having no such concave parts and convex parts is allowable.

[0107] The abrasive supply apparatus 8 is an apparatus which discharges a predetermined quantity of abrasives G downward through the flowing out hole 82 formed in the lower part of the reservoir 81, and conveys the abrasives G that flew out of the flowing out hole 82 to the receiver 85 via the conveyance rotor 83, and supplies the abrasives G to the supply port 31 opened to the mixing chamber 3 through the exhaust port 86 formed in the receiver 85, as shown in FIG. 1.

[0108] The predetermined gap G2 is provided between the flowing out hole 82 and the conveyance rotor 83 in the abrasive supply apparatus 8 as shown in FIG. 4A. Therefore, the abrasives G can be kept staying in the gap in a state of staying on the conveyance rotor 83 due to frictional resistance
between grains of the abrasives \( G \) while the conveyance rotor \( 83 \) is in a stopped condition as shown in FIG. 4A.  

[0109] On the other hand, when the conveyance rotor \( 83 \) rotates, the abrasives \( G \) stayed in the gap \( 52 \) are conveyed along the outer surface of the conveyance rotor \( 83 \), and further abrasives \( G \) are discharged into the gap through the flowing out hole \( 82 \) in the abrasive supply apparatus \( 8 \) as shown in FIG. 4C.  

[0110] Thus, in the abrasive supply apparatus \( 8 \), the abrasives \( G \) which flew into the gap \( 52 \) are conveyed along the outer surface of the conveyance rotor \( 83 \) by rotation of the conveyance rotor \( 83 \) in correspondence to the rotational speed as shown in FIG. 1. And the abrasives \( G \) are received by the receiver 85 disposed below the conveyance rotor 83. And then, the abrasives \( G \) are supplied to the supply port 31 opened to the mixing chamber 3 through the exhaust port 86 formed in the receiver 85.  

[0111] An adequate quantity of abrasives \( G \) can be smoothly and evenly supplied to the mixing chamber 3 in a proper timing by adequately controlling the rotational speed of the conveyance rotor \( 83 \) by using the control unit not shown in the abrasive supply apparatus \( 8 \).  

[0112] An abrasive water jet machine 100 including the abrasive water jet nozzle 1 according to the present embodiment constructed as above serves the following effects.  

[0113] In the abrasive water jet nozzle 1, the abrasives \( G \) introduced into the mixing chamber 3 can be mixed in the water jet via two mixing routes \( R1 \) and \( R2 \). One of the two mixing routes \( R1 \) and \( R2 \) is the first mixing route \( R1 \) (refer to the height \( H1 \) in FIG. 2) on which the abrasives \( G \) introduced into the mixing chamber 3 are absorbed through the outlet port \( 53 \) of the mixing nozzle 5 to be mixed in the water jet \( WJ \) in the upstream. The other is the second mixing route \( R2 \) (refer to the height \( H1 \) in FIG. 2) on which the abrasives \( G \) introduced into the mixing chamber 3 are absorbed to be mixed in the water jet \( AW \) jetted out of the outlet port \( 53 \) of the mixing nozzle 5 in the downstream. Hence, the abrasives \( G \) are mixed separately via the two mixing routes \( R1 \) and \( R2 \).  

[0114] Hereby, in the abrasive water jet nozzle 1, the abrasives \( G \) in the mixing chamber 3 are not intensively absorbed in the inlet port of the abrasive nozzle 6, so that the abrasives \( G \) are mixed uniformly in the water jet \( WJ \) without unevenness to effectively reduce the degree of filling of the interior of the abrasive nozzle 6 with the abrasives \( G \).  

[0115] The abrasive water jet machine 100 can smoothly supply the adequate quantity of abrasives \( G \) to the mixing chamber 3 without unevenness by using the abrasive supply apparatus 8. Therefore, the abrasives \( G \) are uniformly mixed in the water jet \( WJ \), and the degree of filling the interior of the abrasive nozzle 6 with the abrasives \( G \) is effectively reduced, so that precision and efficiency of the cutting process can be improved.  

[0116] The present embodiment according to the present invention has been described in the above. However, the present invention is not limited to that embodiment, and may include embodiments properly modified.  

[0117] For example, the abrasive supply apparatus 8 which supplies the abrasives \( G \) through the conveyance rotor \( 83 \) is used in the present embodiment, but the present invention is not limited to this type. For example, the quantity of the abrasives \( G \) can also be controlled by adjusting the diameter of the flowing out hole \( 82 \) by using movable needle valve.  

[0118] Furthermore, in the present embodiment, only one supply port 31 is opened to the mixing chamber 3, but the present invention is not limited to this type. For example, the supply port 31 may be formed more than one, and in this case, the abrasive supply apparatus 8 may be disposed more than one correspondingly to the supply ports 31.  

DESCRIPTION OF REFERENCE NUMERALS  

[0119] 1 Abrasive water jet nozzle  
[0120] 2 Nozzle main body  
[0121] 3 Mixing chamber  
[0122] 4 Water nozzle  
[0123] 5 Mixing nozzle  
[0124] 6 Abrasive nozzle  
[0125] 8 Abrasive supply apparatus  
[0126] 31 Supply port  
[0127] 41 Inlet hole  
[0128] 41A Inlet port  
[0129] 43 Nozzle part  
[0130] 51 Through hole  
[0131] 52 Tapered part  
[0132] 53 Outlet port  
[0133] 81 Reservoir  
[0134] 82 Flowing out hole  
[0135] 83 Conveyance rotor  
[0136] 83a Horizontal shaft  
[0137] 83b Convex part  
[0138] 83c Wall  
[0139] 84 Motor  
[0140] 85 Receiver  
[0141] 86 Exhaust port  
[0142] 100 Abrasive water jet machine  
[0143] 101 Water jet supply apparatus  
[0144] AW Water jet mixed with abrasives  
[0145] AWJ Abrasive water jet  
[0146] D1 Diameter of inlet port of nozzle part of water nozzle  
[0147] D2 Diameter of through hole of abrasive nozzle  
[0148] D3 Diameter of through hole of mixing nozzle  
[0149] G Abrasive  
[0150] Q Water jet  
[0151] R1 First mixing route  
[0152] R2 Second mixing route  
[0153] WJ Water jet  

What is claimed is:  

1. An abrasive water jet nozzle for jetting an abrasive water jet to a workpiece to process the workpiece, the abrasive water jet being a water jet supplied to an inlet hole and mixed with abrasives, comprising:  
a mixing chamber for absorbing the abrasives therein together with air through a supply port, the mixing chamber being composed as an air chamber;  
a water nozzle having the inlet hole and jetting the water jet;  
a mixing nozzle disposed on a downstream side against the water nozzle, to mix the abrasives in the water jet jetted out of the water nozzle, and to jet the water jet mixed with the abrasives into the mixing chamber out of a through hole of the mixing nozzle; and  
an abrasive nozzle disposed on a downstream side against the mixing nozzle, to introduce the water jet mixed with the abrasives thereto, and to jet the abrasive water jet to the workpiece,  
wherein a diameter of the through hole of the mixing nozzle is larger than a diameter of an inlet port of the inlet hole of a nozzle part of the water nozzle so that the abrasives stayed in the nozzle part of the water nozzle are absorbed
together with air in a clearance formed between an inner surface defining the through hole and the water jet passing through the through hole to mix the abrasives in the water jet in the through hole.

2. The abrasive water jet nozzle according to claim 1, wherein the diameter of the through hole of the mixing nozzle is 5 to 25 times as large as the diameter of the inlet port of the inlet hole of the nozzle part of the water nozzle.

3. The abrasive water jet nozzle according to claim 1, wherein a length of the through hole of the mixing nozzle is longer than a distance from an outlet port positioned at a front end of the through hole to the abrasive nozzle.

4. The abrasive water jet nozzle according to claim 2, wherein a length of the through hole of the mixing nozzle is longer than a distance from an outlet port positioned at a front end of the through hole to the abrasive nozzle.

5. The abrasive water jet nozzle according to claim 1, wherein a diameter of a through hole of the abrasive nozzle is smaller than the diameter of the through hole of the mixing nozzle, and is larger than the diameter of the inlet port of the inlet hole of the nozzle part of the water nozzle.

6. The abrasive water jet nozzle according to claim 2, wherein a diameter of a through hole of the abrasive nozzle is smaller than the diameter of the through hole of the mixing nozzle, and is larger than the diameter of the inlet port of the inlet hole of the nozzle part of the water nozzle.

7. The abrasive water jet nozzle according to claim 3, wherein a diameter of a through hole of the abrasive nozzle is smaller than the diameter of the through hole of the mixing nozzle, and is larger than the diameter of the inlet port of the inlet hole of the nozzle part of the water nozzle.

8. The abrasive water jet nozzle according to claim 1, wherein the mixing nozzle has an approximately cylindrical shape and has a tapered part formed on an outer surface thereof, the tapered part being configured to decrease a diameter toward the abrasive nozzle, and the tapered part being formed from a position facing the supply port to a front tip of the mixing nozzle.

9. The abrasive water jet nozzle according to claim 2, wherein the mixing nozzle has an approximately cylindrical shape and has a tapered part formed on an outer surface thereof, the tapered part being configured to decrease a diameter toward the abrasive nozzle, and the tapered part being formed from a position facing the supply port to a front tip of the mixing nozzle.

10. The abrasive water jet nozzle according to claim 3, wherein the mixing nozzle has an approximately cylindrical shape and has a tapered part formed on an outer surface thereof, the tapered part being configured to decrease a diameter toward the abrasive nozzle, and the tapered part being formed from a position facing the supply port to a front tip of the mixing nozzle.

11. The abrasive water jet nozzle according to claim 4, wherein the mixing nozzle has an approximately cylindrical shape and has a tapered part formed on an outer surface thereof, the tapered part being configured to decrease a diameter toward the abrasive nozzle, and the tapered part being formed from a position facing the supply port to a front tip of the mixing nozzle.

12. An abrasive water jet machine including the abrasive water jet nozzle according to claim 1 and an abrasive supply apparatus for supplying a predetermined quantity of abrasives to the mixing chamber, wherein the abrasive supply apparatus comprises:

   a reservoir for reserving the abrasives therein;

   a flowing out hole formed in a lower part of the reservoir;

   a conveyance rotor disposed so as to define a predetermined gap below the flowing out hole, and capable of rotating around a horizontal axis;

   a receiver disposed below the conveyance rotor; and

   an exhaust port formed in the receiver.

13. An abrasive water jet machine including the abrasive water jet nozzle according to claim 2 and an abrasive supply apparatus for supplying a predetermined quantity of abrasives to the mixing chamber, wherein the abrasive supply apparatus comprises:

   a reservoir for reserving the abrasives therein;

   a flowing out hole formed in a lower part of the reservoir;

   a conveyance rotor disposed so as to define a predetermined gap below the flowing out hole, and capable of rotating around a horizontal axis;

   a receiver disposed below the conveyance rotor; and

   an exhaust port formed in the receiver.

14. An abrasive water jet machine including the abrasive water jet nozzle according to claim 3 and an abrasive supply apparatus for supplying a predetermined quantity of abrasives to the mixing chamber, wherein the abrasive supply apparatus comprises:

   a reservoir for reserving the abrasives therein;

   a flowing out hole formed in a lower part of the reservoir;

   a conveyance rotor disposed so as to define a predetermined gap below the flowing out hole, and capable of rotating around a horizontal axis;

   a receiver disposed below the conveyance rotor; and

   an exhaust port formed in the receiver.

15. An abrasive water jet machine including the abrasive water jet nozzle according to claim 5 and an abrasive supply apparatus for supplying a predetermined quantity of abrasives to the mixing chamber, wherein the abrasive supply apparatus comprises:

   a reservoir for reserving the abrasives therein;

   a flowing out hole formed in a lower part of the reservoir;

   a conveyance rotor disposed so as to define a predetermined gap below the flowing out hole, and capable of rotating around a horizontal axis;

   a receiver disposed below the conveyance rotor; and

   an exhaust port formed in the receiver.

16. An abrasive water jet machine including the abrasive water jet nozzle according to claim 8 and an abrasive supply apparatus for supplying a predetermined quantity of abrasives to the mixing chamber, wherein the abrasive supply apparatus comprises:

   a reservoir for reserving the abrasives therein;

   a flowing out hole formed in a lower part of the reservoir;

   a conveyance rotor disposed so as to define a predetermined gap below the flowing out hole, and capable of rotating around a horizontal axis;

   a receiver disposed below the conveyance rotor; and

   an exhaust port formed in the receiver.

17. The abrasive water jet machine according to claim 12, wherein the conveyance rotor has a concavo-convex part formed on an outer surface thereof.

18. The abrasive water jet machine according to claim 13, wherein the conveyance rotor has a concavo-convex part formed on an outer surface thereof.
19. The abrasive water jet machine according to claim 14, wherein the conveyance rotor has a concavo-convex part formed on an outer surface thereof.

20. An abrasive water jet machine including the abrasive water jet nozzle according to claim 1.