

HIGHLY CHEMICAL-RESISTANT CONCRETE STRUCTURE AND MANUFACTURING METHOD THEREOF

BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION

[0001] The present invention relates to a highly chemical-resistant concrete structure, applicable to a concrete structure such as a Hume pipe or manhole, having excellence in chemical resistance such as acid resistance and salt-damage resistance, and relates to a manufacturing method thereof.

DESCRIPTION OF THE BACKGROUND ART

[0002] There has been a rapid increase in number of the sewer pipes as a Japanese infrastructural support for sewage systems used past their standard service lives, 50 years or longer, after having been constructed. There has been a need, in the future, to carry out an appropriate stock management such as prolonging of their service lives.

In projects of restructuring the sewer pipes in such a background, deteriorated concrete pipes have been regenerated and replaced in a principal manner.

[0003] In general, there are various forms of damage generated in concrete pipes, *e.g.*, the sag caused by differential settlement, the contamination of foreign matter such as roots of trees, the cracks. In particular, the corrosion of concrete caused by the action of acids including hydrogen sulfide and sulfuric acid is a seriously problematic form of damage.

For this reason, when a large loss of the cross-sectional shape of a concrete pipe occurs due to the corrosion caused by the above acids, such a concrete pipe has needed to be replaced promptly with a new concrete pipe. Otherwise, the left concrete pipe has posed the risk of inducing the cave-in of a road triggered by external factors such as load and vibration.

[0004] For a concrete pipe for replacement, an acid-resistant pipe highly resistant to acid corrosion has been desired.

As such acid-resistant pipes, there have been known, *e.g.*, a resin lining pipe having its concrete-pipe surface covered with resin such as epoxy resin, urethane resin, acrylic resin, and a resin concrete pipe made of unsaturated polyester resin as cement substitutes (Patent Documents 1 to 3).

[0005] Further, as an inexpensive acid-resistant pipe, there has been proposed, *e.g.*, a concrete pipe obtained by replacing 70% or higher of cement content, in the mixed cement concrete, with ground granulated blast-furnace slag (Patent Document 4).

[0006] (Prior Art Documents)
(Patent Documents)

Patent Document 1: Japanese Patent Application Laid-Open Publication No. S52-132020

Patent Document 2: Japanese Patent Application Laid-Open Publication No. S63-264676

Patent Document 3: Japanese Patent Application Laid-Open Publication No. 2002-248637

Patent Document 4: Japanese Patent Publication No. 5878258

[0007] (Problems to be solved)

Conventional acid-resistant pipes and techniques of manufacturing such pipes had the following points to be improved.

[1] The resin lining pipe has been obtained on the basis of a concrete pipe manufactured by a centrifugal molding machine.

Such a concrete pipe formed through centrifugal molding had a sludge component discharged to its inner surface.

The sludge component is strongly alkaline and its cement component is small in amount. For this reason, the sludge component has been difficult to reuse as a concrete product, and has required much labor and cost for disposal. In this regard, an effective method for disposal of the sludge component has been a long-term issue in the industry.

[2] The manufacturing of a resin lining pipe has required a lot of operations, such as centrifugal molding of a concrete pipe, curing of the centrifugally-molded concrete pipe, demolding of the cured concrete pipe, and subsequently, primer treatment to the surface of the hardened concrete pipe, coating of the primer-treated surface with resin. In addition, it has required continuous rotation of the concrete pipe for many hours until the complete hardening of coating resin supplied onto the inner surface of the concrete pipe.

For this reason, the resin lining pipe has been significantly low in productivity, and correspondingly higher in manufacturing cost.

[3] In the resin lining pipe obtained by coating the inner surface of the concrete pipe with resin, it has been likely that a boundary is formed between the concrete pipe and the resin, and as a result, the coating resin is separated from the concrete pipe.

[4] Through the use of unsaturated polyester resin higher in price by at least 10 times than cement, the resin concrete pipe has been manufactured at a correspondingly higher cost. In addition to that, when being centrifugally molded, a formwork has needed to be continuously rotated until the polymerization of unsaturated polyester resin and subsequently the hardening of such polymerized unsaturated polyester resin, which has resulted in correspondingly lower in productivity of the resin concrete pipe.

For this reason, resin concrete pipes have rarely been adopted.

[5] As for the concrete pipe having 70% or higher of cement content replaced with ground granulated blast-furnace slag for acid-resistance improvement, it has been difficult to form such a pipe through centrifugal molding due to the increased viscosity of the concrete.

[6] As for the concrete pipe obtained by replacing cement with an increased amount of ground granulated blast-furnace slag or fly ash for acid-resistance improvement, there have been many developing regions and countries having difficulties in procuring a large amount of the blast-furnace slag and fly ash as by-products generated in the steelmaking and thermal-power generation, and as a result, the cost of such products manufactured in such regions and countries has been increased.

[7] In general, concrete made of a large amount of ground granulated blast-furnace slag is low in initially manifesting strength. For this reason, it has taken many hours up until the demolding of the made concrete, which has resulted in correspondingly lower in productivity.

SUMMARY OF THE INVENTION

[0008] In view of the foregoing points, an objective of the present invention is to provide a highly chemical-resistant concrete structure and manufacturing method thereof, that

excels in productivity and is suppressed correspondingly lower in manufacturing cost.

[0009] (Means for Solving Problems)

One aspect of the present invention is provided by a highly chemical-resistant concrete structure manufactured through centrifugal molding, the highly chemical-resistant concrete structure comprising: a concrete layer containing a cement-based binder (A); and an inner protective layer so formed concurrently with the concrete layer as to be laminated on an inner surface of the concrete layer through centrifugal molding, wherein the inner protective layer contains at least a binder (B) having latent hydraulic property or pozzolanic reactivity to be hardened by a sludge component discharged to the inner surface of the concrete layer, and a fine aggregate (C).

In another aspect of the present invention, the binder (B) is a binder having latent hydraulic property or pozzolanic reactivity and is at least one type selected from a group consisting of, *e.g.*, ground granulated blast-furnace slag, fly ash, silica fume, volcanic ash, silicate clay, and diatomaceous earth.

In another aspect of the present invention, the fine aggregate (C) for the inner protective layer to be supplied to the inner surface of the concrete layer is at least one type selected from a group consisting of slag-based fine aggregate, silica sand, and natural fine aggregate.

In still another aspect of the present invention, the inner protective layer includes a buffer layer formed as a continuous structure at an inner surface side of the concrete layer, and a chemical-resistant layer formed as a continuous structure at an inner surface side of the buffer layer, and wherein an amount of sludge so discharged from the concrete layer as to be mixed into the chemical-resistant layer is smaller than an amount of sludge so discharged from the concrete layer as to be mixed into the buffer layer.

In yet another aspect of the present invention, the chemical-resistant layer contains a kneaded mixture of at least the binder (B), the fine aggregate (C), and sludge water.

One aspect of the present invention is provided by a manufacturing method of a highly chemical-resistant concrete structure by a centrifugal molding machine, the manufacturing method comprising: a concrete-layer formation step of supplying concrete into a formwork of the centrifugal molding machine so as to form a concrete layer through centrifugal molding, thereby to compact a formed concrete layer; and an inner-protective-layer formation step of supplying a mixed material containing at least a binder (B) having latent hydraulic property or pozzolanic reactivity to be hardened by a sludge component discharged to an inner surface of the concrete layer and a fine aggregate (C), to the inner surface of the concrete layer so as to form an inner protective layer concurrently with the concrete layer through centrifugal molding during compaction of the concrete layer, thereby to form integrally the inner protective layer and the concrete layer.

In another aspect of the present invention, to the inner surface of the concrete layer during being formed through centrifugal molding, the mixed material in a dry state containing the binder (B) and the fine aggregate (C), or, the mixed material in a paste containing the binder (B), the fine aggregate (C), and kneading water is supplied.

In still another aspect of the present invention, the binder (B) is a binder having latent hydraulic property or pozzolanic reactivity and is at least one type selected from a group consisting of, *e.g.*, ground granulated blast-furnace slag, fly ash, silica fume, volcanic ash, silicate clay, and diatomaceous earth.

In still another aspect of the present invention, the fine aggregate (C) for the inner protective layer to be supplied to the inner surface of the concrete layer is at least one type selected from a group consisting of slag-based fine aggregate, silica sand, and natural fine aggregate.

[0010] (Advantageous Effects of the Invention)

According to the above-described aspects of the present invention, at least one of the following effects could be achieved:

[1] The cement-based binder (A) is used as a binder of the concrete layer serving as a major part of a body of the concrete structure, thereby to facilitate the manufacture of the concrete layer, and in addition, the inner protective layer, for which the binder (B) of high chemical resistance is used, is formed concurrently with the concrete layer, thereby to enable the manufacture of a highly chemical-resistant concrete structure in a reduced period of time at a reduced cost.

Further, for manufacturing such a highly chemical-resistant concrete structure, a well-known centrifugal molding machine could suffice without any further need for additional particular equipment.

[2] In this embodiment, a formation step completed while forming the concrete layer and inner protective layer concurrently within a time range from several tens of minutes to approximately 2 hours could shift to a final curing step.

This enables a larger decrease in time and labor, and a larger improvement in productivity, for the manufacture of the highly chemical-resistant concrete structure, in comparison with conventional techniques. One of the conventional techniques is manufacturing a resin lining pipe in which at least two days have been required for the manufacture including steps of forming a concrete pipe, drying an inner surface of the concrete pipe through steam curing, and thereafter causing resin to adhere to a dried inner surface of the concrete pipe. Another of the conventional techniques is manufacturing a resin concrete pipe in which continuous rotation of a concrete pipe without any ceases has been required until materials undergo a polymerization reaction so as to be chemically hardened during being formed through centrifugal molding.

[3] The binder (B), excelling in chemical resistance, is applied only to the inner protective layer by which the concrete structure needs to be protected, thereby to enable the concrete structure to be effectively improved in chemical resistance through the use of a reduced amount of the binder (B).

[4] The concrete layer serves as a major part of a pipe thickness, and as a result, a period of time taken for the made concrete to manifest strength is so shortened that a required period of time until the demolding of the made concrete could be saved.

[5] Due to the fact that the mixed material for the inner protective layer does not contain the cement-based binder (A), and that the calcium hydroxide contained in the inner protective layer is consumed by the binder (B) such as blast-furnace slag and fly ash when the inner protective layer is hardened through the use of sludge water, a calcium component in the inner protective layer thus finished could be largely reduced.

As a consequence, the inner protective layer could be far largely improved in chemical resistance in comparison with prior art.

[6] By forming the concrete layer and inner protective layer concurrently with each other, the concrete layer and inner protective layer could be integrated so as to have a continuous structure without any clear boundaries in a radial direction of any imaginary cross-sections of the concrete structure along its axial direction.

It is, therefore, difficult for the inner protective layer to be separated from the concrete layer even upon receipt of a shock, and the concrete structure could be maintained satisfactorily, in chemical resistance, for a long period of time.

[7] In case the chemical-resistant layer of the inner protective layer is damaged in part, the buffer layer continues to serve as the protective layer of the concrete layer, and therefore, the inner protective layer could be guaranteed, in chemical resistance, for a significantly long period of time.

[8] Even under the circumstances where the mixed material for the inner protective layer is supplied in a dry state, the inner protective layer could be hardened through the use of sludge or sludge water discharged from the concrete layer. A final recovery and disposal amount of the sludge or sludge water, having been discarded as wastes inevitably up until now, could therefore be reduced.

[9] Highly chemical-resistant concrete structures of correspondingly high quality to the above could be economically manufactured even in developing regions and countries having difficulties in procuring the binder (B) such as ground granulated blast-furnace slag and fly ash.

This is because, even for regions and countries having difficulties in procuring the mixed materials for the inner protective layer, it is easy to have pre-mixed materials prepared within a pack for transportation in other regions or countries where such materials could be procured with ease.

[10] Blast-furnace slag and fly ash are generated as by-products in iron manufacturing and thermal-power generation, and as a result, the amount of CO₂ generated in obtaining the binder (B) of high chemical resistance could be zero, which contributes to the reduction of environmental loads.

BRIEF DESCRIPTIONS OF THE DRAWINGS

[0011] For more thorough understanding of the present invention and advantages thereof, the following descriptions should be read in conjunction with the accompanying drawings in which:

FIG. 1 depicts an enlarged longitudinally cross-sectional view of a surface portion of a concrete pipe along an axial direction serving as a highly chemical-resistant concrete structure;

FIG. 2 depicts a perspective view of a model of a centrifugal molding machine;

FIG. 3 depicts a laterally cross-sectional view, with a partial omission, of a concrete pipe along a radial direction when a concrete layer is formed through molding;

FIG. 4 depicts a laterally cross-sectional view, with a partial omission, of a concrete pipe along a radial direction when an inner protective layer is formed through molding;

FIG. 5 depicts a photograph taken of a part of laterally cross-sectional surface of a hardened concrete pipe along a radial direction; and

FIG. 6 depicts an explanatory view showing changes in pipe thickness of test pieces of EXAMPLE 1 and REFERENCE 1, respectively, in an acid-resistance test.

DESCRIPTIONS OF EMBODIMENTS OF THE INVENTION

[0012] Hereinafter, embodiments according to the present invention will be described with reference to the drawings. It is noted that the term “chemical resistance” used in embodiments according to the present invention means resistance such as acid resistance, salt-damage resistance, corrosion resistance, chemical-attack resistance.

[0013] [1] HIGHLY CHEMICAL-RESISTANT CONCRETE STRUCTURE

An explanation will be provided regarding an embodiment, *e.g.*, a concrete pipe 10 such as a Hume pipe or manhole manufactured through centrifugal molding, as a highly chemical-resistant concrete structure.

[0014] FIG. 1 depicts an enlarged longitudinally cross-sectional view of an inner surface side of the concrete pipe 10 along an axial direction.

The concrete pipe 10 includes a concrete layer 11, which is made of concrete, formed into a cylindrical shape, and an inner protective layer 12 formed into a cylindrical shape concentrically on an inner surface of the concrete layer 11.

[0015] [2] CONCRETE LAYER

The concrete layer 11 constitutes a cylindrical pipe made of concrete obtained by kneading, with water, a cement-based binder (A), admixture such as expansive additive, fine aggregate, coarse aggregate, wherein such a cylindrical pipe is formed through centrifugal molding.

The cement-based binder (A) is not necessarily limited to any specific material, but may be a sort of cement to which, *e.g.*, normal portland cement, high-early-strength portland cement, ultra-high-early-strength portland cement, moderate-heat portland cement, low-heat portland cement, sulfate-resistant portland cement are applicable.

The composition itself of the concrete layer 11 has been well-known, and therefore is not a special one.

[0016] [3] INNER PROTECTIVE LAYER

The inner protective layer 12 is a hard layer configured to prevent sulfuric acid or the like from infiltrating up to the concrete layer 11.

The inner protective layer 12 contains at least a binder (B) having latent hydraulic property or pozzolanic reactivity and a fine aggregate (C).

The above mixed material in a dry state free from water or in a paste state containing kneading water is supplied to the inner surface of the concrete layer 11, and the inner protective layer 12 is formed concurrently with the formation of the concrete layer 11.

The inner protective layer 12 is constituted by: a buffer layer 14 formed as a continuous structure to be continuous to the concrete layer 11 at an inner surface side of said concrete layer 11; and a chemical-resistant layer 15 formed as a continuous structure to be continuous to the buffer layer 14 at an inner surface side of said buffer layer 14.

[0017] [3.1] Reason for Formation of Inner Protective Layer

The inner surface of the concrete layer 11 is covered with the inner protective layer 12 in order to, *e.g.*, suppress the progress of corrosion caused by the generation and peeling-off of gypsum dihydrate, which is coarse and fragile, as a result of violent reaction occurring between sulfuric acid and calcium hydroxide contained in a large amount in the concrete layer 11 upon its exposure to sulfuric acid

[0018] [3.2] Layer Thickness of Inner Protective Layer

The inner protective layer 12 is a layer thick appropriately enough to prevent sulfuric acid from infiltrating therethrough up to the concrete layer 11.

Such a layer thickness of the inner protective layer 12 is determined depending upon a pipe diameter. More specifically, when the layer thickness is approximately 3 to 50 mm, a required time for sulfuric acid to infiltrate therethrough up to the concrete layer 11 increases, and as a result, the chemical-resistant function of the concrete pipe 10 and the function of preventing the gypsum-dihydrate layer from peeling off the concrete pipe 10 could be guaranteed for a long period of time.

It is preferred that the minimum layer thickness of the inner protective layer 12 be selected in consideration of sufficiency of the thickness for the suppression of pop-out phenomenon.

[0019] [3.3] Binder (B)

As a binder for the inner protective layer 12, the binder (B) having property of hardening after chemical combination with the sludge component (cement mortar component) of the concrete layer 11 is used. The mixed material prior to being supplied for the inner protective layer 12 does not contain any cement-based binder.

The sludge component is a component of a slurry material containing the cement-based binder (A), fine aggregate, and water, and such a sludge component means sludge having a large amount of solid component, or sludge water having a large amount of water component with an extremely small amount of solid component.

The binder (B) means a binder having latent hydraulic property in which the binder is not hardened merely by mixture with water but is hardened by alkaline stimulation, or a binder having pozzolanic reactivity in which the binder contains silica or alumina.

[0020] As the binder (B) having latent hydraulic property, *e.g.*, at least one of ground granulated blast-furnace slag, granulated blast-furnace slag, air-cooled blast-furnace slag, and steelmaking slag, may be used.

Through the use of the ground granulated blast-furnace slag standardized by the JIS A 6206 "Ground granulated blast-furnace slag for concrete" in particular, the structure of the inner protective layer 12 is densified due to the binder's latent hydraulic property so that the sulfuric-acid resistance and salt-damage resistance could be improved.

[0021] As the binder (B) having pozzolanic reactivity, *e.g.*, at least one of fly ash, silica fume, and the like, may be used. Soluble silicon dioxide (SiO_2) is chemically combined with the calcium hydroxide (Ca(OH)_2) generated at the time of the hydration of cement, and is converted into insoluble hydrate.

As an alternative binder (B), volcanic ash, silicate clay, may be used.

[0022] [3.4] Fine Aggregate (C)

As the fine aggregate (C) for the inner protective layer, *e.g.*, slag fine aggregate, silica sand, natural fine aggregate, may be used.

The inner protective layer 12 contains a smaller fraction of calcium in comparison with the concrete layer 11 thereby to be improved in chemical resistance. Through the use of slag fine aggregate as the fine aggregate (C), the inner protective layer 12 could be further improved in chemical resistance.

[0023] [3.5] Mix Proportion of Binder (B) and Fine Aggregate (C)

The mix proportion of the binder (B) and the fine aggregate (C) is approximately

1:2 as a guide.

The mix proportion of the binder (B) and the fine aggregate (C) is not necessarily limited to the above proportion range, but may be selected appropriately in consideration of purpose of use and use environment with respect to the concrete pipe 10.

[0024] [3.6] Reason for Non-Homogenously Structured Inner Protective Layer

The inner protective layer 12, having mainly the binder (B) hardened by chemical combination with the sludge component and the fine aggregate (C), does not have a homogeneous structure.

The reason for non-homogeneous structure of the inner protective layer 12 is that the sludge component of the concrete layer 11 is mixed into the inner protective layer 12 by the influence of rotational centrifugal force, and thus the inner protective layer 12 has various amounts of the mixed sludge distributed differently among positions in said inner protective layer 12.

As a result, in the inner protective layer 12, the mixed sludge is distributed increasingly in amount at a position closer to the inner surface of the concrete layer 11, while the mixed sludge is distributed decreasingly in amount at a position further from the inner surface of the concrete layer 11.

[0025] [3.7] Buffer Layer

As shown in FIG. 1, the buffer layer 14 laminated on the inner surface of the concrete layer 11 includes mainly the mixed material of: the binder (B) hardened by chemical combination with the sludge component; and the fine aggregate (C), and serves as an intermediate protective layer formed between the concrete layer 11 and the chemical-resistant layer 15.

A part of the sludge component of the concrete layer 11 is mixed into and chemically combined with the buffer layer 14 during the formation of the inner protective layer 12 through molding. The mixed sludge is distributed in a gradually decreasing manner from the outer surface to the inner surface of the buffer layer 14.

The buffer layer 14 serves a function of supporting chemical resistance when the chemical-resistant layer 15 is damaged.

[0026] [3.8] Chemical-Resistant Layer

The chemical-resistant layer 15 laminated on the inner surface of the buffer layer 14, which serves as a protective layer, includes mainly the mixed material of: the binder (B); and the fine aggregate (C). The chemical-resistant layer 15 is chemically combined with the sludge water during the formation of the inner protective layer 12 through molding.

The chemical-resistant layer 15 contains a smaller fraction of the mixed sludge in comparison with the buffer layer 14.

The sludge is hardly caused to be mixed into the chemical-resistant layer 15 even by the formation through centrifugal molding, and as a result, the chemical-resistant layer 15 includes substantially as 100% the mixed material of: the binder (B); and the fine aggregate (C).

[0027] [MANUFACTURING METHOD]

Next, an explanation will be provided regarding a manufacturing method of the above-described concrete pipe 10.

[0028] [1] FORMATION OF CONCRETE LAYER

A concrete-layer formation step of forming the concrete layer 11 will be described with reference to FIGS. 2 to 5.

[0029] [1.1] Set-Up of Reinforcing Cage

As shown in FIG. 2, a formwork 20 is so assembled as to incorporate the reinforcing cage formed in a cylindrical shape inside the formwork 20. The formwork 20 includes an outer formwork 21 and a donut-shaped gable-end formwork 22, without any inner formwork.

[0030] [1.2] Supply of Concrete

Subsequently, the formwork 20 is rotated on a centrifugal molding machine while the concrete containing the cement-based binder (A) kneaded by a mixer is supplied through a supply device 23 such as a conveyor into the assembled formwork 20. The mix proportion of the concrete has been well-known.

[0031] [1.3] Rotation of Formwork

The concrete layer 11 is formed in a cylindrical shape in such a manner that: the formwork 20 is rotated at a low speed (2 to 3 G) so that the concrete is diffused all over in the initial stage of the formation; the formwork 20 is rotated at an increased (medium) speed (10 to 15 G) so that the concrete is compacted to a predetermined extent; and finally, the formwork 20 is rotated at a high speed (approximately 30 G) so that the concrete is compacted densely, and thereby, a cylindrically-shaped concrete layer 11 is formed.

[0032] [1.4] Layer Thickness of Concrete Layer

FIG. 3 shows a cross-sectional view of the formwork 20 and the concrete layer 11 at the time of the formation through centrifugal molding.

In the step of forming the concrete layer 11, the concrete is inserted in a smaller amount than the required amount for a predetermined pipe thickness, where the pipe thickness of the concrete layer 11 is determined to be thinner in consideration of the expected layer thickness of the inner protective layer 12 to be formed in the next step.

The expected thickness of the inner protective layer 12 may be set to be approximately 3 to 50 mm depending upon the diameter of the concrete pipe 10, and is selected appropriately in consideration of purpose of use and use environment with respect to the concrete pipe 10.

In order that the concrete layer 11 is integrated with the inner protective layer 12, it is preferred that the inner surface of the concrete layer 11 be allowed to be in a rough state without completely smooth finish.

[0033] [2] Formation of Inner Protective Layer

The inner-protective-layer formation step of forming the inner protective layer 12 will be described with reference to FIG. 4.

[0034] [2.1] Examples of Mixed Material for Inner Protective Layer

As the mixed material for the inner protective layer 12, *e.g.*, a combination of the following materials may be used:

- Binder (B) such as ground granulated blast-furnace slag;
- Fine slag aggregate (C);
- Fly ash;
- Silica fume; and
- Lime-gypsum composite (expansive additive) containing 1 to 15% aluminum oxide, by mass, as a chemical component.

[0035] [2.2] State of Supply of Mixed Material

The mixed material in a dry state free from water may be supplied to the inner surface of the concrete layer 11. Alternatively, the mixed material in a paste state, obtained as a result of being kneaded in advance with kneading water, may be supplied.

[0036] [2.2.1] Case of supply in dry state

During the formation of the concrete layer 11 through centrifugal molding, the sludge component containing water, cement component, and aggregate particles is discharged, through centrifugal separation, to the inner surface of the concrete layer 11.

When the mixed material for the inner protective layer 12 in a dry state is supplied to the inner surface of the concrete layer 11, the sludge component is so mixed with the mixed material as to be in a paste state during a period of time when the sludge component is allowed by rotational centrifugal force to pass through the mixed material.

In the case of such supply in a dry state, the consumed sludge component increases in amount during a period of time when the inner protective layer 12 is rendered in a paste state, and thus the finally-recovered amount of the sludge component is further reduced.

[0037] [2.2.2] Case of supply in paste state

The mixed material for the inner protective layer 12 may be supplied in a paste state, where such a mixed material is obtained as a result of being kneaded in advance with an appropriate amount of kneading water.

In the case of such supply in a paste state, cement particles and fine aggregate particles are hardly allowed to pass through the inner protective layer 12 due to the screening in comparison with the case in a dry state, and thus a smaller amount of the sludge is contained in the inner protective layer 12. In consideration of the recovered amount of the sludge component, however, there is preferably used the minimum amount of kneading water, having the fluidity for the mixed material to be supplied, could be guaranteed.

[0038] [2.3] Rotation of Formwork

The inner protective layer 12 having a dense structure is formed on the inner surface of the concrete layer 11 through centrifugal molding in such a manner that the formwork 20 is rotated, as in the case of the formation of the concrete layer 11, at a speed increasing gradually from low, via medium, to high level so that the inner protective layer 12 could be compacted by rotational centrifugal force.

Even in the step of forming the inner protective layer 12, the permeating sludge water without any cement component to the inner surface of the inner protective layer 12 is discharged by high-speed rotation.

After the inner surface is provided with smooth finish by the removal of excessive sludge water through the use of bar and spatula, the rotation of the formwork 20 is

stopped.

[0039] [2.4] Structure of Inner Protective Layer

The inner protective layer 12 is not formed as an entirely homogeneous structure, but formed as being the buffer layer 14 having the mixed sludge distributed increasingly in amount at a position further adjacent to the inner surface of the concrete layer 11 and as being the chemical-resistant layer 15 having the mixed sludge distributed decreasingly at a position further separated from the inner surface of the concrete layer 11 (FIG. 1).

[0040] [3] HARDENING REACTION

The concrete pipe 10 increases gradually in strength, by the compaction of the concrete pipe 10, and by the hardening reaction caused in parallel with the compaction to occur in the concrete layer 11 and the inner protective layer 12.

[0041] The hardening in the concrete layer 11 is allowed to progress through the reaction between the cement-based binder (A) and kneading water.

The hardening in the inner protective layer 12 is allowed to progress through the chemical combination with: the binder (B) having latent hydraulic property or pozzolanic reactivity; and the sludge or sludge water 13.

[0042] [4] CURING AND DEMOLDING

The formwork 20 is removed from the centrifugal molding machine, and is moved to a predetermined location for curing while the concrete pipe 10 is maintained inside the formwork 20.

As curing means, *e.g.*, steam curing may be used. The steam curing could expedite the process of demolding.

The temperature for the steam curing of the concrete pipe 10 is selected appropriately in such a manner that the physical properties of the concrete pipe 10 are not adversely affected.

It is to be noted that the curing means is not necessarily limited to the above steam curing but may be natural curing.

[0043] When the concrete pipe 10 reaches a predetermined level of strength required for demolding, the concrete pipe 10 is taken out from the formwork 20, and thereby a series of operation is completed.

[0044] [5] PROPERTIES OF CONCRETE PIPE

The principal properties of the concrete pipe 10 will be described with reference to FIG. 5.

[0045] [5.1] Integration of Concrete Layer and Inner Protective Layer

The concrete pipe 10 as an embodiment according to the present invention is not manufactured by a method of joining the inner protective layer 12 with the previously hardened concrete layer 11, and thus has no cold joint generated.

[0046] In the concrete pipe 10 as an embodiment according to the present invention, due to the fact that the concrete layer 11 and the inner protective layer 12 are formed concurrently before being hardened, the inner surface of the concrete layer 11 and the

inner protective layer 12 fit together well. As a result, the boundaries between the concrete layer 11 and the inner protective layer 12, and between the buffer layer 14 and the chemical-resistant layer 15 included in the inner protective layer 12 have a continuous structure formed to be integral as a whole.

In other words, no clear boundary surface is formed in a cross-section of the concrete pipe 10, unlike in the cross-section of the resin lining pipe in prior art.

The inner protective layer 12 in particular, is laminated on the inner surface of the concrete layer 11, which inner surface is allowed to be in a coarse state with fine irregularities but without being provided with smooth finish, thereby improving adhesion (integration) significantly between the concrete layer 11 and the inner protective layer 12.

[0047] As described above, the concrete pipe 10 has integrated continuous structures in any cross-sections, it is therefore difficult for the inner protective layer 12 to cause any phenomena of being separated from the inner surface of the concrete pipe 10 even upon receipt of a shock on said inner surface.

[0048] [5.2] Chemical Resistance of Inner Protective Layer

The inner protective layer 12 contains mainly the binder (B) having latent hydraulic property or pozzolanic reactivity with a significantly reduced amount of calcium hydroxide ($\text{Ca}(\text{OH})_2$) as the weakest component to acid among all the cement hydrates.

For an example, when the binder (B) is a binder having latent hydraulic property, typically ground granulated blast-furnace slag, it is necessary for such a binder (B) to be hardened through the alkaline stimulation by the sludge or sludge water 13. The calcium hydroxide contained in the sludge component is, therefore, further consumed when the inner protective layer 12 is hardened, and the calcium component in the inner protective layer 12 further decreases in amount, and thereby its chemical resistance is improved.

For another example, when the binder (B) is a binder having pozzolanic reactivity, in order that such a binder (B) is hardened, the calcium hydroxide contained in the sludge component is consumed by being chemically combined with silicon dioxide. The calcium component in the inner protective layer 12 decreases in amount, and thereby its chemical resistance is improved.

[0049] When sulfuric acid is brought into contact with the inner protective layer 12, the sulfuric acid infiltrates through the inner protective layer 12 in accordance with capillary phenomenon. Substantially in the absence of calcium hydroxide, violent reaction does not occur, while reaction occurs between the sulfuric acid and the calcium component of C-S-H and C-A-H contained in the inner protective layer 12 so that a gypsum-dihydrate layer is laminated over time in the vicinity of a surface of the inner protective layer 12.

The gypsum dihydrate has a dense structure with acid resistance, and therefore, even when the inner surface of the concrete pipe 10 is exposed continuously to sulfuric acid, the inner protective layer 12 having the laminated dense gypsum-dihydrate layer could suppress the sulfuric acid from infiltrating through the layer 12, thereby capable of effectively preventing the sulfuric acid from reaching the concrete layer 11.

[0050] Even assuming that sulfuric acid would infiltrate through the chemical-resistant layer 15 to reach the buffer layer 14 positioned at a deep-layer side of the chemical-resistant layer 15 due to several decades of aging, corrosion does not progress in a short period of time due to a significantly smaller amount of calcium component

contained in the buffer layer 14 in comparison with the concrete layer 11, and also, corrosion caused by sulfuric acid could be suppressed at a continuous manner whose level increases with increasing the gypsum-dihydrate layer.

As described above, the buffer layer 14 serves not only as a quasi-chemical-resistant-layer against capillary phenomenon but also a failsafe function of preventing corrosion in the concrete layer 11 even on the assumption of the occurrence of any defects in the chemical-resistant layer 15 due to the external impact.

The gypsum-dihydrate layer could be formed over an entire cross-section of the inner protective layer 12, and for this reason, it takes a significantly long period of many years for sulfuric acid to infiltrate through the inner protective layer 12 to reach the concrete layer 11. Chemical resistance could be ensured for a significantly longer period of time in comparison with the case of ordinary concrete in prior art.

[0051] The gypsum-dihydrate layer is assumed to be formed automatically in the case of contacting with acid in a shared environment. In a factory with a well-ordered manufacturing environment, however, the concrete pipe 10 may be so subjected to sulfuric acid treatment in advance prior to shipment as to form the gypsum-dihydrate layer on the inner surface of the concrete pipe 10.

[0052] [EXAMPLES]

Examples according to the present invention will be described in detail below.

[0053] [1] MATERIALS FOR USE

The following materials were used for the concrete layer 11. (Numerical values shown below express densities)

Binder (A)	Normal portland cement (Tokuyama Corporation) 3.16
Fine Aggregate	Natural sand 2.62
Coarse Aggregate	Crushed stone (20 mm to 5 mm) 2.70
High-Range Water-Reducing Admixture	Super 300 (manufactured by GCP Applied Technologies Inc) 1.02
Lime-Gypsum Composite	Expansive additive CSA#20 (manufactured by Denka Company Limited) 2.93

[0054] The following materials were used for the inner protective layer 12. (Values shown below express densities)

Binder (B)	Blast-furnace slag powder Esment specific surface 4000 cm ² /g (manufactured by Nippon Steel Esment Kanto Co., Ltd) 2.89
Fine Aggregate (C)	Blast-furnace slag fine aggregate (manufactured by Nippon Steel Esment Kanto Co., Ltd) 2.70

[0055] [2] TEST PIECES

Test pieces of the concrete pipe 10 were produced through the use of materials described above in accordance with the mix proportion indicated in TABLE 1 (EXAMPLE 1, REFERENCE 1).

[0056] TABLE 1 Example of mix proportion of concrete

		W/P	S/a	Air content	Quantity of material per unit [kg/m ³]							
					Water	Cement	Blast furnace Esment	CSA	Fine aggregate	Slag fine aggregate	Coarse aggregate	Water-reducing admixture
EXAMPLE 1	Concrete layer	38.9	48.0	2	170	396	0	41.4	844	0	941	2.62
	Inner protective layer	(shown separately)										
REFERENCE 1		38.9	48.0	2	170	396	0	41.4	844	0	941	2.62

[0057] In the mixed material for the inner protective layer in EXAMPLE 1, ground granulated blast-furnace slag and blast-furnace slag fine aggregate in 1:2 by weight ratio were kneaded with water in water-cement ratio 40%.

[0058] [3] ACID-RESISTANCE TEST

A pipe body was so produced as to have an inner diameter of 300 mm, a pipe thickness of 30 mm, and a pipe length of 300 mm, in accordance with the concrete mix proportion for each of EXAMPLE 1 and REFERENCE 1. The test pieces were produced by cutting out a slice of approximately 100 mm x 150 mm from the pipe body, and coating the surfaces other than the inner surface of the slice with epoxy resin.

Each test piece in EXAMPLE 1 and REFERENCE 1 was immersed in 5% sulfate acid solution, and the pipe thickness was measured with respect to increase or decrease thereof. TABLE 2 indicates the test results, and FIG. 6 shows the actual test pieces.

[0059] TABLE 2

	Increase and decrease in pipe thickness (mm)						
	0th day of immersion	7th day of immersion	14th day of immersion	28th day of immersion	56th day of immersion	84th day of immersion	112th day of immersion
EXAMPLE 1	0.0	0.1	1.1	1.8	2.5	2.0	3.8
REFERENCE 1	0.0	-0.5	-1.4	-3.3	-8.3	-10.2	-14.1

[0060] The test pieces in EXAMPLE 1 according to the present invention increased in pipe thickness (mass) due to the deposition of gypsum dihydrate, but were not dissolved in sulfuric acid.

In contrast, the test pieces in REFERENCE 1 were dissolved in sulfuric acid from the surfaces, and were significantly reduced in pipe thickness (mass).

[0061] (Reference Numerals)

- 10 Concrete pipe (Highly chemical-resistant concrete structure)
- 11 Concrete layer
- 12 Inner protective layer
- 13 Sludge or sludge water (Sludge component)
- 14 Buffer layer
- 15 Chemical-resistant layer

20	Formwork
21	Outer formwork
22	Gable-end formwork
23	Supply device

WHAT IS CLAIMED IS:

1. A highly chemical-resistant concrete structure manufactured through centrifugal molding, the highly chemical-resistant concrete structure comprising:
 - a concrete layer containing a cement-based binder (A); and
 - an inner protective layer so formed concurrently with the concrete layer as to be laminated on an inner surface of the concrete layer through centrifugal molding, wherein the inner protective layer contains at least
 - a binder (B) having latent hydraulic property or pozzolanic reactivity to be hardened by a sludge component discharged to the inner surface of the concrete layer, and
 - a fine aggregate (C).
2. The highly chemical-resistant concrete structure as claimed in claim 1, wherein the binder (B) is at least one type selected from a group consisting of ground granulated blast-furnace slag, fly ash, silica fume, volcanic ash, silicate clay, and diatomaceous earth.
3. The highly chemical-resistant concrete structure as claimed in claim 1, wherein the fine aggregate (C) for the inner protective layer to be supplied to the inner surface of the concrete layer is at least one type selected from a group consisting of slag-based fine aggregate, silica sand, and natural fine aggregate.
4. The highly chemical-resistant concrete structure as claimed in any one of claims 1 to 3, wherein
 - the inner protective layer includes
 - a buffer layer formed as a continuous structure at an inner surface side of the concrete layer, and
 - a chemical-resistant layer formed as a continuous structure at an inner surface side of the buffer layer, and wherein
 - an amount of sludge so discharged from the concrete layer as to be mixed into the chemical-resistant layer is smaller than an amount of sludge so discharged from the concrete layer as to be mixed into the buffer layer.
5. The highly chemical-resistant concrete structure according to claim 4, wherein the chemical-resistant layer contains a kneaded mixture of at least the binder (B), the fine aggregate (C), and sludge water.
6. A manufacturing method of a highly chemical-resistant concrete structure by a centrifugal molding machine, the manufacturing method comprising:
 - a concrete-layer formation step of supplying concrete into a formwork of the centrifugal molding machine so as to form a concrete layer through centrifugal molding, thereby to compact a formed concrete layer; and
 - an inner-protective-layer formation step of supplying a mixed material containing at least a binder (B) having latent hydraulic property or pozzolanic reactivity to be hardened by a sludge component discharged to an inner surface of the concrete layer and a fine aggregate (C), to the inner surface of the concrete layer so as to form an inner

protective layer concurrently with the concrete layer through centrifugal molding during compaction of the concrete layer, thereby to form integrally the inner protective layer and the concrete layer.

7. The manufacturing method of the highly chemical-resistant concrete structure as claimed in claim 6, wherein

the mixed material in a dry state containing the binder (B) and the fine aggregate (C) is supplied to the inner surface of the concrete layer during being formed through centrifugal molding.

8. The manufacturing method of the highly chemical-resistant concrete structure as claimed in claim 6, wherein

the mixed material in a paste containing the binder (B), the fine aggregate (C), and kneading water is supplied to the inner surface of the concrete layer during being formed through centrifugal molding.

9. The manufacturing method of the highly chemical-resistant concrete structure as claimed in any one of claims 6 to 8, wherein

the binder (B) is at least one type selected from a group consisting of ground granulated blast-furnace slag, fly ash, silica fume, volcanic ash, silicate clay, and diatomaceous earth.

10. The manufacturing method of the highly chemical-resistant concrete structure as claimed in any one of claims 6 to 8, wherein

the fine aggregate (C) for the inner protective layer to be supplied to the inner surface of the concrete layer is at least one type selected from a group consisting of slag-based fine aggregate, silica sand, and natural fine aggregate.