

DESCRIPTION

REINFORCED CONCRETE STRUCTURE AND REINFORCEMENT METHOD FOR CONCRETE STRUCTURE

FIELD OF THE INVENTION

[0001]

The present invention relates to a reinforced concrete structure and a reinforcement method for a concrete structure. More particularly, the present invention relates to a reinforced concrete structure and a reinforcement method for a concrete structure such as road tunnels.

BACKGROUND OF THE INVENTION

[0002]

The reinforcement of concrete structures is generally carried out by removing deteriorated concrete, injecting crack reinforcing agents, and placing lining concrete. However, any simple method is required because these involve many heavy works at higher places.

[0003]

To address this problem, a reinforcement method has been proposed, which attaching fabrics, knitted fabrics or non-woven fabrics made of synthetic fibers to reinforcing portions, and applying a resin onto the fabrics to cure to form so-called fiber reinforced plastic (FRP). Conventionally, aramid fibers and carbon fibers have been used as synthetic fibers.

[0004]

Recently, there is an increased need for continuing the monitoring of the aging of concrete structures after reinforcing their surfaces. However, the surfaces of the concrete structures reinforced by the conventional method are covered with reinforcing layers such as opaque resins and sheet materials, and are difficult to visually observe conditions of the bases of the concrete structures from the outside.

[0005]

Therefore, when visually observing the conditions of the bases of the concrete structures covered with reinforcing layers using the conventional reinforcement method, they require removal of a part of the existing reinforcing layers on the surfaces to form an inspection window in order to expose the bases.

[0006]

However, the forming of the inspection window in order to observe the conditions of the bases of the concrete structures causes a concern that the strength of the region of the window would be decreased or the inspection window could be a starting point for deterioration of the reinforcing layers.

[0007]

Therefore, construction methods have been proposed to enable the base of the constructed concrete structure to be observed using adhesives and fiber sheets. For example, Patent Literature 1 proposes a repair method for a concrete structure, comprising applying a primer resin (an acryl resin) to a surface of the concrete structure, attaching fiber substrates (nylon fibers or vinylon fibers) to the applied surface, and then applying a top coat resin (an acryl resin) thereon. Further, Patent Literature 2 proposes a reinforced coating method for a concrete structure surface, comprising applying a transparent polyurethane resin solution to the surface of the concrete structure, attaching glass continuous fiber sheets to the surfaces, applying a transparent polyurethane resin solution thereon to impregnate the glass continuous fiber sheets with the solution, and then drying it to solidify and form a transparent or translucent coating layer.

CITATION LIST

Patent Literatures

[0008]

[Patent Literature 1] Japanese Patent Application Publication No. 2006-342538 A

[Patent Literature 2] Japanese Patent Application Publication No. 2010-1707 A

SUMMARY OF THE INVENTION

Problem to be Solved by the Invention

[0009]

However, a main purpose of each of the methods described in Patent Literature 1 and 2 is to suppress flaking of the concrete, so that the layers formed by these methods do not have any required strength as reinforcing layers. In other words, there are problems that the layers formed by these methods have lower tensile strength, and the reinforcing performance of the concrete structure is not sufficient, and the effect of suppressing generation of harmful gases is not sufficiently obtained.

Means for Solving the Problem

[0010]

The present invention has been made to solve the above problems. An object of the present invention is to provide a reinforced concrete structure and a reinforcement method for a concrete structure, which can visually observe the base of the concrete structure, and has improved reinforcing performance of the concrete structure, and an improved effect of suppressing generation of harmful gases.

[0011]

As a result of intensive studies, the present inventors have found that the above problems can be solved by providing the surface of the concrete structure

with a certain reinforcing layer and a certain protective layer in this order, and have completed the present invention.

[0012]

Thus, the present invention relates to a reinforced concrete structure, a surface of the concrete structure comprising at least a reinforcing layer and a protective layer in this order,

wherein the reinforcing layer has an integrated structure of at least one glass fiber sheet having a weight per area of from 500 to 1000 g/m² and at least one cured adhesive for concrete structures;

wherein the protective layer is a coated film of a protective coating containing at least one inorganic component; and

wherein a difference between refractive indices of the glass fiber sheet and the cured adhesive for concrete structures is less than 0.04.

[0013]

Further, the present invention relates to a method for reinforcing a concrete structure, comprising forming at least a reinforcing layer and a protective layer in this order, on a surface of the concrete structure,

wherein the reinforcing layer has an integrated structure of at least one glass fiber sheet having a weight per area of from 500 to 1000 g/m² and at least one cured adhesive for concrete structures;

wherein the protective layer is a coated film of a protective coating containing at least one inorganic component; and

wherein a difference between refractive indices of the glass fiber sheet and the cured adhesive for concrete structures is less than 0.04.

Effects of the Invention

[0014]

According to the present invention, it is possible to provide a reinforced concrete structure and a reinforcement method for a concrete structure, which can visually observe the base of the concrete structure, and has improved reinforcing performance of the concrete structure, and an improved effect of suppressing generation of harmful gases.

DETAILED DESCRIPTION OF THE INVENTION

[0015]

Hereinafter, embodiments of the present invention will be specifically described with reference to the drawings. It is to understand that the present invention is not limited to the following embodiments, and various changes, improvements and the like may be carried out based on knowledge of a person skilled in the art without departing from the spirit of the present invention. Components disclosed in embodiments may form various inventions by appropriate combinations. For example, some components may be removed from all the components shown in embodiments.

[0016]

A reinforced concrete structure according to an embodiment of the present invention is provided with at least a reinforcing layer and a protective layer in this order, on a surface of the concrete structure. A method for reinforcing a concrete structure according to an embodiment of the present invention (which may, hereinafter, be abbreviated as a "reinforcement method") is carried out by forming at least a reinforcing layer and a protective layer in this order, on a surface of the concrete structure. It is understood that the term "concrete" collectively refers to cement paste, mortar, and concrete, unless otherwise stated.

[0017]

The reinforcing layer, also referred to as an FRP layer, has an integrated structure of at least one glass fiber sheet and a cured adhesive for concrete structures.

The glass fiber sheet forming the reinforcing layer can be obtained by forming glass fiber called glass yarn or glass roving into a woven, non-woven, or braided fabric. Since the woven, non-woven, and braided fabric obtained using glass fiber are commercially available, the commercially available products may be used.

[0018]

When the glass fiber sheet is the woven or braided fabric, its axial structure may be any of various multiaxial structures such as biaxial or triaxial structures, although not particularly limited thereto. Especially, the glass fiber sheet is preferably a biaxial weave in which fibers in a warp direction are orthogonal to those in a weft direction. The use of the biaxial woven glass fiber sheet can improve tensile strengths of the glass fiber sheet and the reinforcing layer while improving the visibility of the base.

[0019]

The glass fiber sheet has a weight per area of from 500 to 1000 g/m², and preferably from 600 to 800 g/m². The weight per area of the glass fiber sheet of 500 g/m² or more provides a tensile strength of the reinforcing layer of 150 kN/m or more, which enables desired reinforcing performance to be obtained. Further, the weight per area of 1000 g/m² or less can allow flexibility and workability of the reinforcing layer to be ensured.

[0020]

The glass fiber sheet preferably has a mesh opening of from 1 to 25 mm, and more preferably from 2 to 10 mm, although not particularly limited thereto. The mesh opening in the above range can provide improved adhesion of the reinforcing

layer to the concrete structure and an enhanced effect of suppressing fire spread in case of fire or the like

[0021]

The glass fiber forming the glass fiber sheet may preferably contain 12% by mass or more of ZrO_2 and 10% by mass or more of R_2O in which R is at least one selected from Li, Na, and K. The controlling of the contents of ZrO_2 and R_2O in the above ranges will make the glass fiber sheet difficult to be degraded by alkali components derived from the concrete structure, so that a decrease in strength of the reinforcing layer can be suppressed.

[0022]

The glass fiber sheet may contain components other than glass fiber. The components other than glass fiber include, but not limited to, fibers made of components other than glass, thermoplastic resins, thermosetting resins, inorganic compounds, and metals. These can be used alone or in combination of two or more types.

[0023]

The glass fiber sheet may preferably contain thermally fusible fibers in at least one direction. As used herein, the thermally fusible fibers refer to fibers that can be melted by heat. The use of the thermally fusible fibers can allow the glass fibers to be bonded and prevent the glass fiber sheet from unraveling. Examples of thermally fusible fibers include nylon fibers and polyester fibers. These can be used alone or in combination of two or more types.

[0024]

The glass fiber sheet may preferably have a content of components other than the glass fiber of 50 g/m^2 or less, and more preferably less than 50 g/m^2 . The controlling of the content of components other than the glass fiber to 50 g/m^2 or less can allow the visibility of the base to be improved.

[0025]

The adhesive for concrete structures used for the reinforcing layer is cured to be integrated with the glass fiber sheet.

The adhesive for concrete structures is preferably, but not particularly limited to, a composition containing at least one resin selected from the group consisting of (meth)acryl resins, vinyl ester resins, unsaturated polyester resins, urethane resins, urea resins, epoxy resins and silicone resins; more preferably a composition containing at least one resin selected from the group consisting of (meth)acryl resins, vinyl ester resins, unsaturated polyester resins, urethane resins, urea resins, epoxy resins and silicone resins as a main component; most preferably a composition containing at least one resin selected from the group consisting of (meth)acryl resins and epoxy resins as a main component. By containing these resins, the tensile strength of the reinforcing layer can be improved.

As used herein, the "main component" means that a percentage of the component based on the entire composition is 50% by mass or more, and preferably 60% by mass or more, and more preferably 70% by mass or more, and even more preferably 80% by mass or more.

[0026]

The composition containing the (meth)acryl resin may preferably contain a (meth)acrylate, a radical polymerization initiator and a decomposition accelerator in terms of curing at room temperature. As used herein, the (meth)acryl includes at least one selected from the group consisting of acryl groups and methacryl groups. The (meth)acrylate includes at least one selected from the group consisting of acrylates and methacrylates.

The (meth)acrylate include, preferably, at least one selected from the group consisting of (meth)acrylates having aromatic groups and alkyl (meth)acrylates in terms of higher effect of the present invention. The (meth)acrylates having aromatic groups include, preferably, benzyl (meth)acrylate. The alkyl (meth)acrylates include, preferably, cyclohexyl (meth)acrylate.

[0027]

The radical polymerization initiator includes, preferably, organic peroxides. The organic peroxides include, preferably, cumene hydroperoxide because of its higher effect of the present invention.

An amount of the radical polymerization initiator to be used is from 0.5 to 10 parts by mass per 100 parts by mass of the (meth)acrylate, and more preferably from 1 to 7 parts by mass.

The decomposition accelerator preferably reacts with the radical polymerization initiator at room temperature to generate radicals. A preferable decomposition accelerator is a metal salt. The metal salt includes, preferably, cobalt octylate because of its higher effect of the present invention.

An amount of the decomposition accelerator to be used is preferably from 0.05 to 10 parts by mass per 100 parts by mass of the (meth)acrylate, and more preferably from 0.1 to 4 parts by mass.

[0028]

For the composition containing the epoxy resin, at least a main agent and a curing agent are separately stored in an agent A and an agent B, respectively, in terms of curability. In this case, both agents can be used by simultaneously or separately applying them to an adherend, contacting and curing it.

The epoxy resin includes, preferably, aromatic epoxy resins. The aromatic epoxy resins include, preferably, compounds having a bisphenol structure. The compounds having the bisphenol structure include, preferably, bisphenol A type diglycidyl ether.

The curing agent is a component that can cure the epoxy resin. The curing agent includes, preferably, amine compounds.

An amount of the curing agent to be used is preferably such that an active hydrogen equivalent of the curing agent is from 0.5 to 1.5 equivalents per an equivalent of epoxy groups of the epoxy resin, and more preferably from 0.8 to 1.3.

An amount of the curing agent to be used is preferably from 30 to 100 parts by mass parts per 100 parts by mass of the epoxy resin, and more preferably from 50 to 70 parts by mass.

[0029]

The adhesive (composition) for concrete structures may further contain an inorganic component as needed. Preferred as the inorganic component are oxides of metal elements (typical elements, transition elements). The oxides of the metal elements (typical elements, transition elements) include, preferably, titanium dioxide.

An amount of the inorganic component to be used is from 0.5 to 10 parts by mass per 100 mass parts of the resin, and more preferably from 1 to 7 parts by mass.

[0030]

The adhesive for concrete structures may further contain known components such as oils, rubbers, viscosity modifiers, pigments, dyes, plasticizers, sensitizers, catalysts, polymerization inhibitors, waxes, tackifiers, silane coupling agents, antioxidants, flame retardants, and organic solvents in a range where its performance is not degraded.

[0031]

A method for curing the adhesive for concrete structures is not particularly limited, and various known curing methods may be used. Examples of the curing methods that can be used herein include a method for curing the adhesive by volatilizing volatile components, a method for curing the adhesive for concrete structures by allowing components to react with moisture in the air, a method for curing the adhesive by mixing two (or more) agents (the main agent and the curing agent) and curing them by a chemical reaction, and a method for curing the adhesive by applying external energy such as heat or light, and the like. Among these, the method for curing the adhesive by mixing two agents and curing them by

the chemical reaction is more preferable, in view of the strength of the reinforcing layer and the workability of the concrete structure.

[0032]

Two or more types of adhesives for concrete structures may be used in combination. When two or more adhesives for concrete structures are used in combination, the two or more adhesives for concrete structures may be mixed in advance, or a second or subsequent adhesive for concrete structures may be used after a first adhesive for concrete structures has been applied.

[0033]

The cured adhesive for concrete structures preferably has a Gardner color scale of 8 or less. The controlling of the Gardner color scale of 8 or less can allow the visibility of the base to be improved. The Gardner color scale can be measured in accordance with JIS K 0071-2:1998.

[0034]

The glass fiber sheet and the cured adhesive for concrete structures, which make up the reinforcing layer, have a difference between their refractive indices of less than 0.04, and preferably less than or equal to 0.025, and more preferably less than 0.025. The controlling of the difference between the refractive indices in such a range can allow the visibility of the base to be ensured.

As used herein, the term "refractive index" refers to a refractive index measured in accordance with JIS K7142: 2014.

[0035]

The tensile strength per unit length of a type B specimen prepared in accordance with JIS A1191: 2004 using the glass fiber sheet and the adhesive for concrete structures used for the reinforcing layer is preferably 150 kN/m or more, and more preferably 175 kN/m or more. As used herein, the Type B specimen refers to a glass fiber sheet impregnated with an adhesive for concrete structures. The tensile strength in such a range can achieve reinforcing performance

comparable to that of the conventional method for reinforcing a concrete structure using a carbon fiber sheet or an aramid fiber sheet.

[0036]

The reinforcing layer is formed by using the glass fiber sheet and the adhesive for concrete structures as described above. Specifically, the reinforcing layer is formed by impregnating the glass fiber sheet with the adhesive for concrete structures and then curing the adhesive for concrete structures.

When forming the reinforcing layer on the surface of the concrete structure, the adhesive for concrete structures may be applied onto the surface of the concrete structure, the glass fiber sheet may be arranged on the applied surface, and the glass fiber sheet may be then impregnated with the adhesive for concrete structures to cure them.

[0037]

The method for applying the adhesive for concrete structures may employ a known method in the art, such as coating with a roller, trowel, or spatula, and spray painting.

The adhesive for concrete structures may be applied at once or in two or more parts. However, it is preferable to apply the adhesive in two or more parts. By applying the adhesive for concrete structures in two or more parts, an amount required for integration with the glass fiber sheet can be applied while preventing dripping. When the adhesive for concrete structures is applied in two or more parts, the glass fiber sheet can be arranged and the adhesive for concrete structures can be then applied thereupon.

[0038]

An amount of the adhesive for concrete structures applied is preferably from 0.2 to 2.0 kg/m², and more preferably from 0.5 to 1.4 kg/m² with respect to one glass fiber sheet. The controlling of the amount of the adhesive for concrete structures applied of 0.2 kg/m² or more can allow the glass fiber sheets to be fixed. The

controlling of the amount of the adhesive for concrete structures applied of 2.0 kg/m^2 or less can allow the visibility of the base to be improved.

[0039]

The method of impregnating the glass fiber sheet with the adhesive for concrete structures may preferably be carried out using a bubble removing roller, although not particularly limited thereto. The use of the bubble removing roller can allow air bubbles in the adhesive for concrete structures and the glass fiber sheet to be removed, leading to easy impregnation of the glass fiber sheet with the adhesive for concrete structures.

[0040]

The reinforcing layer may preferably include two or more glass fiber sheets, especially two glass fiber sheets. The use of two or more glass fiber sheets can provide reinforcing performance comparable to that of the existing reinforcement method using carbon fiber sheets or aramid fiber sheets.

When using the two or more glass fiber sheets, two or more glass fiber sheets may be arranged at once onto the surface to which the adhesive for concrete structures is applied, or they may be arranged one by one in two or more separate parts; preferably, they are arranged one by one in two or more separate parts. By arranging the glass fiber sheets one by one in two or more separate parts, the glass fiber sheets can be prevented from falling out due to their own weights. When arranging the glass fiber sheets one by one in two or more separate parts, it is sufficient to repeat the process of arranging the glass fiber sheet on the surface coated with the adhesive for concrete structures, applying the adhesive for concrete structures thereon, and then arranging the glass fiber sheet on the coated surface.

[0041]

The reinforcing layer may optionally be provided with a means for preventing the glass fiber sheet from falling out by using a known technique such as anchor pins and anchor bolts. Although the number of anchor pins and anchor bolts used

is not particularly limited, an area of the reinforcing layer covered by the anchor pins and anchor bolts is preferably less than or equal to 20% of the entire reinforcing layer, and more preferably less than 20%, and even more preferably less than or equal to 10%, and most preferably less than 10%. The controlling of the area of the reinforcing layer covered by those means to the above range can allow the visibility of the base to be ensured.

[0042]

Before forming the reinforcing layer on the surface of the concrete structure, the base of the concrete structure may be optionally treated. The treatment of the base of the concrete structure can allow the adhesion of the reinforcing layer to the concrete structure to be maintained for a long period of time.

The treatment of the base is carried out to remove laitance, surface fouling, and/or deteriorated bases, and can use known techniques such as water jetting, sand blasting, sander scraping, and wire brushing.

[0043]

Before forming the reinforcing layer on the surface of the concrete structure, a cross-sectional repairing of the concrete structure may be optionally carried out. The cross-sectional repairing can improve the adhesion of the reinforcing layer to the concrete structure.

As a cross-sectional repairing material, a known material such as concrete, mortar, cement pastes, grout materials, polymer cement mortar, and resin mortar may be used. These materials can be used alone or in combination of two or more types.

[0044]

Further, before forming the reinforcing layer on the surface of the concrete structure, a primer may be optionally applied to the surface of the concrete structure. The application of the primer can improve the adhesion of the concrete structure to the reinforcing layer, as well as can impregnate a cracked or otherwise deteriorated

concrete structure with the primer to achieve a robust concrete structure. The primer also has a function of maintaining performance of the reinforcing layer over a long period of time by preventing moisture, alkali metals, and gases from exuding from the concrete structure.

[0045]

Example of the primer that can be used herein include known materials such as (meth)acryl resin primers, epoxy resin primers, vinyl ester resin primers, silicone resin primers, and inorganic primers. These materials can be used alone or in combination of two or more types.

The cured primer preferably has a Gardner color scale of 8 or less. The controlling of the Gardner color scale to 8 or less can allow the visibility of the base to be improved.

An amount of the primer applied may generally be from 0.05 to 1.0 kg/m², although it may vary depending on the condition of the concrete structure.

The application method of the primer may employ a known method such as rollers, brushes, trowels, spatula, or the like, and by spray painting, although not particularly limited thereto.

[0046]

Furthermore, before forming the reinforcing layer on the surface of the concrete structure, an unevenness adjustment of the structure may optionally be carried out in advance. The unevenness adjustment can form a uniform reinforcing layer on the surface of the concrete structure, so that the reinforcing performance can be stably produced over a larger area.

The unevenness adjustment can be carried out using an unevenness adjustment material. The unevenness adjustment material includes a known material such as resin mortar or polymer cement mortar, which is a combination of a resin and an aggregate. These materials can be used alone or in combination with two or more types.

The cured unevenness adjustment material preferably has a Gardner color scale of 8 or less. The controlling of the Gardner color scale to 8 or less can allow the visibility of the base to be improved.

In general, the amount of the unevenness adjustment material applied may preferably be less than or equal to 1.8 kg/m^2 , and more preferably less than 1.8 kg/m^2 , although it may vary depending on the unevenness of the surface.

The application method of the unevenness adjustment material may employ a known method such as coating with a trowel or spatula and spray painting.

[0047]

The protective layer is a coated film of a protective coating, which is formed on the surface of the reinforcing layer. As used herein, the "coated film" means a cured product of the protective coating.

The protective coating forming the protective layer contains an inorganic component(s) having a melting point of 1000°C or lower. By containing such an inorganic component in the protective coating, the inorganic component can melt to form a glassy coated film in the event of fire, thereby inhibiting the fire spread and the generation of harmful gases. The lower limit of the melting point of the inorganic component is generally 400°C , although not limited thereto.

As used herein, the "melting point" refers to a melting point measured by differential scanning calorimeter (DSC).

[0048]

The inorganic component having a melting point of 1000°C include SiO_2 -containing components such as silicon dioxide, silicic acid, silicates, and silica; metallic elements (typical elements and transition elements), nonmetallic elements, as well as hydrogen compounds, oxides, oxoates, hydroxides, halides, sulfates, nitrates, carbonates, and acetates thereof; metal complexes (coordination compounds), and the like. These can be used alone or in combination of two or more types. Examples of the silicates include aluminosilicate, ultramarine,

Egyptian blue, magnesiorowlandite-(Y), aluminum silicate, potassium silicate, calcium silicate, sodium silicate, hafnium(IV) silicate, magnesium silicate, hydroxyllestadite, tobelite, sodium hexafluorosilicate, bentonite, and the like.

[0049]

The protective coating may further contain an organic binder. By containing the organic binder in the protective coating, a binding force of the inorganic component can be increased and a stable coated film can be formed.

Examples of the organic binder include waxes, polyvinyl alcohol, paraffin, polyvinyl butyral, (meth)acryl resins, urethane resins, glyoxal resins, phenol resins, butadiene resins, polycarboxylic acids, fatty acids, fatty acid amides, and polyester. These can be used alone or in combination of two or more types.

[0050]

A mass ratio of solid contents of the inorganic component having a melting point of 1000 °C or less to the organic binder is preferably from 30:70 to 70:30. The controlling of the mass ratio of the solid contents in such a range can stably achieve both of the coated film formability and the effect of the protective layer (the effect of inhibiting the fire spread and the generation of toxic gases).

[0051]

The inorganic component preferably has a SiO₂ content of 30% by mass or more in the inorganic component. The controlling of the SiO₂ content in such a range can stably improve the above effect produced by the protective layer.

[0052]

The protective coating may contain a known component(s) such as inorganic fillers, oils, rubbers, viscosity modifiers, pigments, dyes, plasticizers, polymerization initiators, sensitizers, catalysts, polymerization inhibitors, waxes, tackifiers, silane coupling agents, antioxidants, flame retardants, and organic solvents to the extent that the performance is not degraded.

[0053]

The protective layer (coated film) is formed by applying the protective coating to the surface of the reinforcing layer and then curing it.

A curing method of the protective coating is not particularly limited, and various known methods may be used. For example, the curing method includes a method of curing the protective coating by volatilizing volatile components in the protective coating, a method of allowing the components in the protective coating to react with moisture in the air, a method of curing the protective coating by mixing two (or more) agents (a main agent and a curing agent) and curing them by a chemical reaction, and a method of curing the protective coating by applying external energy such as heat or light. Among these methods, the method of curing the protective coating by volatilizing the volatile components (moisture) of the protective coating is preferable, in view of the compatibility with inorganic components and workability.

[0054]

The protective coating can be applied by a known method such as coating with rollers, brushes, trowels, or spatula, and spray coating.

An amount of the protective coating applied is preferably from 0.01 to 1.0 kg/m², and more preferably from 0.02 to 0.2 kg/m², as converted into a solid content.

[0055]

The protective layer (coated film) preferably has a Gardner color scale of 8 or less. The controlling of the Gardner color scale to 8 or less can allow the visibility of the base to be improved.

[0056]

The reinforced concrete structure and reinforcement method for a concrete structure may optionally be provided with coated films, adhesive layers, fiber sheets, films, resin moldings, and the like, known in the art, alone or in combination, between the reinforcing layer and the protective layer or on the surface of the protective layer.

[0057]

When the reinforced concrete structure according to the embodiment of the present invention is subjected to a gas toxicity test (using a plurality of mice) as defined in Fire Preventive and Fireproof Performance Test and Evaluation Procedure Manual under the Building Standards Law of Japan, an average time from the start of the test to the mice stopping their behavior is preferably 6.8 minutes or more. Such an average time will reduce the possibility of evacuees being caught in harmful combustion gases and endangering their lives when a tunnel fire is assumed. Therefore, it is possible to use the reinforced concrete structure according to the embodiment of the present invention in the tunnel.

[0058]

In the fire spread test in NEXCO Test Method 738, the reinforced concrete structure according the embodiment of the present invention preferably has a flame-out time of 30 seconds or less, and the lead of the fire caused by combustion is preferably less than 600 mm from the ignition point. Such a flame-out time or the like can reduce the possibility of evacuees being caught in harmful combustion gases and endangering their lives when the tunnel fire is assumed. Therefore, it will be possible to use the reinforced concrete structure according to the embodiment of the present invention in the tunnel.

As used herein, the "fire spread test in NEXCO Test Method 738" refers to NEXCO Test Method 738-2011, "Fire Spread Test Method for Tunnel Repair Materials".

EXAMPLES

[0059]

Hereinafter, the present invention will be described in more detail with reference to Examples, but the present invention is not limited to these Examples.

[0060]

<Preparation of Glass Fiber Sheet>

Raw materials having the compositions as shown in Table 1 were melted and spun into yarns to obtain glass fibers (glass yarns).

[0061]

[Table 1]

No.	Glass Fiber (% by mass)					
	SiO ₂	ZrO ₂	Li ₂ O	Na ₂ O	K ₂ O	Al ₂ O ₃
1-1	78	12	10	0	0	0
1-2	78	12	0	10	0	0
1-3	78	12	0	0	10	0
1-4	76	12	4	4	4	0
1-5	56	16	16	0	0	12
1-6	52	16	12	0	0	20
1-7	56	10	10	0	0	24
1-8	56	10	0	10	0	24
1-9	56	10	0	0	10	24
1-10	56	12	8	0	0	24
1-11	56	12	0	8	0	24
1-12	56	12	0	0	8	24
1-13	44	10	8	0	0	38

[0062]

Next, a predetermined number of glass yarns and thermally fused yarns formed from nylon fibers (thermally fused fibers) were bundled with a sizing agent to obtain beams (fiber bundles). As the sizing agent, an emulsion containing a silane coupling agent was used. The obtained beams were used to produce glass fiber sheets with each axis structure. The details of the prepared glass fiber sheets are shown in Table 2. In the beam structure, the "Other" refers to the sizing agent.

[0063]

[Table 2]

No.	Glass Fiber Sheet						
	Weight/Unit Area (g/m ²)	Beam Structure (g/m ²)			How to Weave	Opening (mm)	Refractive Index
		Glass fiber	Thermally Fused Fiber	Other			
2-1	700	680	15	5	Biaxial	2	1.57
2-2	500	480	15	5	Biaxial	2	1.57
2-3	1000	980	15	5	Biaxial	2	1.57
2-4	400	380	15	5	Biaxial	2	1.57
2-5	1100	1080	15	5	Biaxial	2	1.57
2-6	700	600	15	85	Biaxial	2	1.57
2-7	700	600	85	15	Biaxial	2	1.57
2-8	700	680	15	5	Uniaxial	2	1.57
2-9	700	680	15	5	Triaxial	2	1.57
2-10	700	680	15	5	Biaxial	0.5	1.57
2-11	700	680	15	5	Biaxial	30	1.57

[0064]

<Adhesive for Concrete Structures>

Adhesives for concrete structures were prepared by mixing the components as shown in Table 3. The cured products of the prepared adhesives for concrete structures were measured for a Gardner color scale and refractive index. The results are also shown in Table 3. The Gardner color scale and refractive index were measured according to the method as described above.

[0065]

[Table 3]

	Adhesive for Concrete Structures (% by mass)							
	3-1	3-2	3-3	3-4	3-5	3-6	3-7	3-8
Acryl Resin Composition A	98	--	--	--	96	--	48	48
Acryl Resin Composition B	--	--	--	--	--	98	--	--
Epoxy Resin Composition	--	98	--	--	--	--	50	--
Vinyl Acetate Resin Composition	--	--	98	--	--	--	--	50
Water Glass	--	--	--	98	--	--	--	--
Titanium Oxide	2	2	2	2	4	2	2	2
Gardner Color Scale	6	6	6	6	10	6	6	6
Refractive Index	1.55	1.56	1.48	1.51	1.56	1.51	1.56	1.53

[0066]

The components as shown in Table 3 are as follows:

(Acryl Resin Composition A)

An acryl resin composition cured by redox polymerization, which contains Viscoat #160 (trade name; benzyl acrylate from OSAKA ORGANIC CHEMICAL INDUSTRY LTD), PERCUMYL H (trade name; cumene hydroperoxide from NOF CORPORATION), and cobalt octylate (from OSAKI INDUSTRY Co., Ltd.) in a mass ratio of 100:2:2;

(Acryl Resin Composition B)

An acryl resin composition cured by redox polymerization, which contains Viscoat #155 (trade name: cyclohexyl acrylate from OSAKA ORGANIC CHEMICAL INDUSTRY LTD), PERCUMYL H (trade name: cumene hydroperoxide from NOF CORPORATION), and cobalt octylate (from OSAKI INDUSTRY Co., Ltd.) in a mass ratio of 100:2:2.

(Epoxy Resin Composition)

An epoxy resin composition cured by a polyaddition reaction of glycidyl groups with amino groups, which contains jER828 (trade name; bisphenol A diglycidyl ether from Mitsubishi Chemical Corporation) and ST11 (trade name; modified amine from Mitsubishi Chemical Corporation) in a mass ratio of 100:60.

[0067]

(Vinyl acetate resin composition)

One-component curable adhesive CH18 (trade name; vinyl acetate resin emulsion type adhesive from Konishi Co., Ltd.) cured by volatilization of water.

(Water Glass)

No. 3 water glass (from FUJI CHEMICAL CO., LTD.) defined in JIS K 1408, which is cured by volatilization of water.

(Titanium Oxide)

R 820 (trade name; sulfuric acid method titanium oxide from ISHIHARA SANGYO KAISHA Ltd.). Titanium oxide was used to adjust the color scale of the adhesive for concrete structures.

[0068]

<Protective Coating>

The protective coatings having the compositions as shown in Table 4 were prepared using Snowtex 40 (trade name; colloidal silica from Nissan Chemical Corporation) as the SiO₂-containing component, TTO-W-5 (trade name; neutral titania sol from ISHIHARA SANGYO KAISHA Ltd.) as the other inorganic component, and R 967 (trade name; an aqueous polyurethane resin from Kusumoto Chemicals, Ltd.) as the organic binder. The Gardner color scale was measured for the coated film of each prepared protective coating according to the method as described above. Further, the melting points of the inorganic components were measured using a differential scanning calorimeter (Brucker DSC 3100 SA). The results are also shown in Table 4.

[0069]

[Table 4]

No.	Composition of Protective Coating (% by mass)			Physical Properties	
	SiO ₂	Other Inorganic Components	Organic Binder	Melting Point of Inorganic Component (°C)	Gardner Color Scale
4-1	25	25	50	900	6
4-2	50	0	50	900	6
4-3	0	0	100	--	6
4-4	10	40	50	920	6
4-5	30	70	0	930	6
4-6	70	30	0	790	6
4-7	25	25	50	1060	6
4-8	25	25	50	900	10

[0070]

The following evaluations were conducted using the glass fiber sheets, adhesives for concrete structures, and protective coatings obtained above. The combination of materials used in each of Examples and Comparative Examples is shown in Table 5. In Table 5, the difference between refractive indices means the difference between the refractive indices of the glass fiber sheet and the cured adhesive for concrete structures.

[0071]

[Table 5]

	Glass Fiber	Glass Fiber Sheet	Number of Laminated Glass Fiber Sheets	Adhesive for Concrete Structures	Protective Coating	Difference Between Refractive Indices
Example 1	1-1	2-1	2	3-1	4-1	0.02
Example 2	1-1	2-1	1	3-1	4-1	0.02
Example 3	1-2	2-1	2	3-1	4-1	0.02
Example 4	1-3	2-1	2	3-1	4-1	0.02
Example 5	1-4	2-1	2	3-1	4-1	0.02
Example 6	1-5	2-1	2	3-1	4-1	0.02
Example 7	1-6	2-1	2	3-1	4-1	0.02
Example 8	1-7	2-1	2	3-1	4-1	0.02
Example 9	1-8	2-1	2	3-1	4-1	0.02
Example 10	1-9	2-1	2	3-1	4-1	0.02
Example 11	1-10	2-1	2	3-1	4-1	0.02
Example 12	1-11	2-1	2	3-1	4-1	0.02
Example 13	1-12	2-1	2	3-1	4-1	0.02
Example 14	1-13	2-1	2	3-1	4-1	0.02
Example 15	1-1	2-2	2	3-1	4-1	0.02
Example 16	1-1	2-3	2	3-1	4-1	0.02
Example 17	1-1	2-6	2	3-1	4-1	0.02
Example 18	1-1	2-7	2	3-1	4-1	0.02
Example 19	1-1	2-8	2	3-1	4-1	0.02
Example 20	1-1	2-9	2	3-1	4-1	0.02
Example 21	1-1	2-10	2	3-1	4-1	0.02
Example 22	1-1	2-11	2	3-1	4-1	0.02
Example 23	1-1	2-1	2	3-2	4-1	0.01
Example 24	1-1	2-1	2	3-5	4-1	0.01
Example 25	1-1	2-1	2	3-7	4-1	0.01
Example 26	1-1	2-1	2	3-1	4-2	0.02
Example 27	1-1	2-1	2	3-1	4-4	0.02
Example 28	1-1	2-1	2	3-1	4-5	0.02
Example 29	1-1	2-1	2	3-1	4-6	0.02
Example 30	1-1	2-1	2	3-1	4-7	0.02
Example 31	1-1	2-1	2	3-1	4-8	0.02
Comparative Example 1	1-1	<u>2-4</u>	2	3-1	4-1	0.02
Comparative Example 2	1-1	<u>2-5</u>	2	3-1	4-1	0.02
Comparative Example 3	1-1	2-1	2	3-8	4-1	<u>0.04</u>
Comparative Example 4	1-1	2-1	2	3-3	4-1	<u>0.09</u>
Comparative Example 5	1-1	2-1	2	3-4	4-1	<u>0.06</u>
Comparative Example 6	1-1	2-1	2	3-6	4-1	<u>0.06</u>
Comparative Example 7	1-1	2-1	2	3-1	<u>4-3</u>	0.02
Comparative Example 8	1-1	2-1	2	3-1	<u>Absent</u>	0.02
Comparative Example 9	<u>Absent</u>	<u>Absent</u>	<u>0</u>	3-1	4-1	0.02
Comparative Example 10	1-1	2-1	2	<u>Absent</u>	4-1	<u>--</u>
The underlines indicate that they are out of the scope of the present invention.						

[0072]

(1) Visibility

A construction surface (a surface having 150 mm x 70 mm) of a mortar piece having a 150 mm x 70 mm x 10 mm prepared in accordance with JIS R 5201: 2015 was scraped with a #150 paper sander to remove latitance, and dusts were removed by air blow. Two crack patterns having a width of 0.2 mm and a width of 0.5 mm were written with a black HB pencil in the longitudinal direction of the construction surface to obtain a specimen (hereinafter referred to as "mortar piece for visibility evaluation").

The construction surface of the mortar piece for visibility evaluation was then coated with an acrylic crack injection repair material (DENKA DK 550-003R) from DENKA as a primer using a roller. An amount of the primer applied was 0.15 kg/m².

After the primer was coated and left for 15 minutes, the reinforcing layer was formed on the primer. The reinforcing layer was formed as follows: as primer coating, an adhesive for concrete structures was applied with a rubber spatula or a metal trowel (an applied amount: 0.6 kg/m²). A predetermined number of glass fiber sheets were placed on the coated surface immediately after the application, and the glass fiber sheets were impregnated with a primer coating resin using a bubble removal roller. As the primer coating resin, the adhesive for concrete structures was used. The adhesive for concrete structures was then applied as the top coating using a rubber spatula or a metal trowel (an applied amount: 0.6 kg/m²), and then cured at 20 °C for 24 hours to harden the adhesive for concrete structures to form the reinforcing layer.

[0073]

Next, a protective layer was formed on the surface of the reinforcing layer. The protective layer was formed by applying a protective coating to the surface of

the reinforcing layer with a roller (an applied amount: 0.15 kg/m²) and then curing it at 20 °C for 7 days to dry and harden the protective coating.

The visibility was evaluated by visually observing the crack patterns after the formation of the reinforcing layer, using the following criteria:

○: Crack patterns having a width of 0.2 mm and a width of 0.5 mm can be visually observed over the entire region;

△: Crack patterns having a width of 0.5 mm can be visually observed over the entire region, but some or all of the crack patterns having a width of 0.2 mm cannot be visually observed; and

×: Some or all of the crack patterns having both widths of 0.2 mm and 0.5 mm cannot be visually observed.

[0074]

(2) Alkali Resistance

A construction surface (150 mm x 70 mm) of a mortar piece having 150 mm x 70 mm x 10 mm prepared in accordance with JIS R 5201: 2015 was scraped with a #150 paper sander to remove latitance, and the dusts were removed by air blow to obtain a specimen (hereinafter referred to as "mortar piece for alkali resistance evaluation").

The construction surface of the mortar piece for alkali resistance evaluation was coated with a primer under the same conditions as those of the visibility evaluation, and a reinforcing layer was formed thereon using an adhesive for concrete structures and glass fiber sheets, and a protective layer was formed using a protective coating. The reinforcing layer and protective layer were formed in this order.

The alkali resistance was measured as follows: after the protective layer was formed, each mortar piece for alkali resistance evaluation was submerged in a saturated calcium hydroxide solution for 28 days. After submerging, the mortar piece for alkali resistance evaluation was pulled out of the solution. The condition

of the surface was immediately observed visually and evaluated according to the following criteria:

○: No discoloration, breakage, peeling, swelling, cracking, or leakage was observed on the surface; and

△: Any of discoloration, breakage, peeling, swelling, cracking, and leakage was observed on the surface.

[0075]

(3) Workability

A construction surface (a surface having 300 mm x 300 mm) of a concrete common flat plate having 300 mm x 300 mm x 60 mm (common name: N 300) prepared in accordance with JIS A 5371:2016 was scraped with a #150 paper sander to remove latitance, and dusts were removed by air blow to obtain a specimen (hereinafter referred to as "concrete plate").

Subsequently, the 300 mm x 60 mm surface of the concrete plate was placed in contact with the ground so that the construction surface was perpendicular to the ground. The primer was then applied under the same conditions as those of the visibility evaluation, and a reinforcing layer was formed thereon using an adhesive for concrete structures and glass fiber sheets.

In the step of forming the reinforcing layer, the condition of the adhesive for concrete structures was visually observed until the curing of the adhesive was completed, and evaluated according to the following criteria:

○: No peeling, slipping-off, or falling of the glass fiber sheets, and no dripping of the adhesive for concrete structures were observed;

△: Slight slipping-off of the glass fiber sheet and slight dripping of the adhesive for concrete structures were observed;

×: Peeling, slipping-off or significant falling of the glass fiber sheets, and dripping of the adhesive for concrete structures were observed.

[0076]

(4) Concrete Adhesion

Using the concrete plate having the reinforcing layer formed for the workability evaluation, a protective layer was formed on the surface of the reinforcing layer under the same conditions as those of the visibility evaluation. Subsequently, a 40 mm x 40 mm steel jig was attached to the surface of the protective layer with Denka's acryl resin mortar (Denka Dina N), and cutting was made along the jig until it reached the concrete plate. The jig was then pulled perpendicularly to the attached surface using a Ministry of Construction/Building Research Institute-type tensile adhesion tester to measure an adhesion strength (N/mm²). The measurement results were evaluated based on the following criteria:

- : 2.0 N/mm² or more (criterion conforming to Surface Protection Method of Repair Guideline in Hanshin Expressway Company Limited (medium corrosion prevention class C);
- △: 1.5 N/mm² or more (criterion conforming to NEXCO bridge structure separation prevention method); and
- ×: less than 1.5 N/mm².

[0077]

(5) FRP Tensile Strength

Using the glass fiber sheets and the adhesive for concrete structures used for preparing the reinforcing layer, a Type B specimen (FRP) was prepared in accordance with JIS A 1191:2004, and its maximum tensile load (kN) was calculated. An FRP tensile strength per unit length was then calculated according to the following equation [1]:

$$f_A = F / A \times B \quad \cdot \cdot \cdot \quad [1]$$

in which:

f_A is a tensile strength of a specimen per unit length (kN/m);

F is a maximum tensile load of the specimen (kN);

A is the number of fiber bundles in the specimen; and

B is the number of fiber bundles aligned in the tensile direction per 1 m width of glass fiber sheet (bundle/m).

[0078]

(6) Tensile Strength of Reinforcing Layer

Using the FRP tensile strength per unit length (kN/m) obtained above, the tensile strength of the reinforcing layer was calculated according to the following equation [2]:

$$f_B = f_A \times C \quad \cdot \cdot \cdot [2],$$

in which:

f_B is a tensile strength of the reinforcing layer (kN/m);

f_A is a tensile strength of the specimen per unit length (kN/m); and

C is the number of glass fiber sheets.

The tensile strength of the reinforcing layer was evaluated according to the following criteria:

○: 350 kN/m or more;

△: 300 kN/m or more and less than 350 kN/m; and

×: less than 300 kN/m.

[0079]

(7) Gas Toxicity

A test specimen was obtained by removing dusts from a surface of a construction surface (a surface having 220 mm x 220 mm) of a calcium silicate plate having 220 mm x 220 mm x 10 mm made in accordance with JIS A 5430:2013 by air blow.

The construction surface of the specimen was then coated with a primer under the same conditions as those of the visibility evaluation. A reinforcing layer was then formed thereon using an adhesive for concrete structures and glass fiber sheets, and a protective layer was formed using a protective coating. The reinforcing layer and the protective layer were formed in this order.

For the gas toxicity test, an average behavior stopping time (Xs) of mice was calculated and evaluated according to the following criteria in the gas toxicity test using mice defined in the Fire Preventive and Fireproof Performance Test and Evaluation Procedure Manual based on the Building Standards Law of Japan. The above Fire Preventive and Fireproof Performance Test and Evaluation Procedure Manual is, for example, published by the Center for Better Living.

○: Xs is 7.2 minutes or more;

△: Xs is 6.8 minutes or more and less than 7.2 minutes; and

×: Xs is less than 6.8 minutes.

[0080]

(8) Fire Spread

A test specimen was obtained by removing dusts from a surface of a construction surface (a surface of 900mm x 600mm) of a calcium silicate plate having 900mm x 600mm x 12mm made in accordance with JIS A 5430:2013 by air blow.

The construction surface of the specimen was then coated with a primer under the same conditions as those of the visibility evaluation, and a reinforcing layer was then formed thereon using an adhesive for concrete structures and glass fiber sheets, and a protective layer was formed using a protective coating. The reinforcing layer and the protective layer were formed in this order.

The fire spread was evaluated by measuring a flame-out time and an ignition point at the lead of the fire caused by combustion in the fire spread test defined in NEXCO Test Method 738, using the following criteria:

○: The flame-out time was 10 seconds or less, and the lead of the fire caused by combustion was less than 500mm from the ignition point;

△: The flame-out time was 30 seconds or less, and the lead of the fire caused by combustion was less than 600mm from the ignition point; and

×: The flame-out time was more than 30 seconds, or the lead of the fire caused by combustion was more than 600mm from the ignition point.

The results of each of the above evaluations are shown in Table 6.

[0081]

[Table 6]

	Visibility	Alkali Resistance	Workability	Concrete Adhesion		FRP Tensile Strength		Tensile Strength of Reinforcing Layer		Gas Toxicity		Fire Spread
				N/mm ²	Evaluation	kN/m	Evaluation	kN/m	Evaluation	Min.	Evaluation	
Example 1	○	○	○	4.6	○	191	○	382	○	7.6	○	○
Example 2	○	○	○	3.8	○	191	○	191	△	7.3	○	○
Example 3	○	○	○	4.2	○	197	○	394	○	7.8	○	○
Example 4	○	○	○	3.4	○	188	○	376	○	7.9	○	○
Example 5	○	○	○	4.9	○	181	○	362	○	7.9	○	○
Example 6	○	○	○	3.6	○	191	○	382	○	7.7	○	○
Example 7	○	○	○	3.4	○	192	○	384	○	7.6	○	○
Example 8	○	△	○	3.9	○	192	○	384	○	7.6	○	○
Example 9	○	△	○	3.6	○	195	○	390	○	7.6	○	○
Example 10	○	△	○	3.5	○	192	○	384	○	7.7	○	○
Example 11	○	△	○	3.7	○	184	○	368	○	8.0	○	○
Example 12	○	△	○	4.0	○	188	○	376	○	7.5	○	○
Example 13	○	△	○	4.2	○	189	○	378	○	7.5	○	○
Example 14	○	△	○	3.8	○	192	○	384	○	7.7	○	○
Example 15	○	○	○	5.1	○	176	○	352	○	7.7	○	○
Example 16	○	○	○	3.7	○	211	○	422	○	7.8	○	○
Example 17	△	○	○	3.5	○	190	○	380	○	7.9	○	○
Example 18	△	○	○	3.1	○	184	○	368	○	8.0	○	○
Example 19	○	○	△	4.3	○	160	△	320	△	6.9	△	○
Example 20	△	○	○	3.0	○	153	△	306	△	8.8	○	○
Example 21	○	○	○	1.8	△	200	○	400	○	9.8	○	○
Example 22	○	○	○	5.2	○	194	○	388	○	7.1	△	△
Example 23	○	○	○	4.1	○	187	○	374	○	8.1	○	○
Example 24	△	○	○	3.8	○	178	○	356	○	7.3	○	○
Example 25	○	○	○	2.8	○	178	○	356	○	9.2	○	○
Example 26	○	○	○	4.1	○	190	○	380	○	7.9	○	○
Example 27	○	○	○	3.9	○	183	○	366	○	7.1	△	○
Example 28	○	○	○	4.1	○	190	○	380	○	6.9	△	○
Example 29	○	○	○	3.7	○	190	○	380	○	7.3	○	△
Example 30	○	○	○	3.7	○	192	○	384	○	7.1	△	△
Example 31	△	○	○	3.6	○	185	○	370	○	7.8	○	○
Comparative Example 1	○	○	○	4.4	○	134	×	268	×	7.2	○	○
Comparative Example 2	○	○	×	2.7	○	192	○	384	○	10.1	○	○
Comparative Example 3	×	○	○	5.4	○	157	△	318	△	7.2	○	○
Comparative Example 4	×	○	○	1.9	△	162	△	324	△	7.9	○	○
Comparative Example 5	×	○	○	3.6	○	174	△	348	△	7.4	○	○
Comparative Example 6	×	○	○	5.4	○	197	○	394	○	7.3	○	○
Comparative Example 7	○	○	○	4.2	○	180	○	360	○	6.4	×	×
Comparative Example 8	○	○	○	3.8	○	188	○	376	○	5.9	×	×
Comparative Example 9	○	○	○	5.4	○	*1	×	*1	×	6.1	×	×
Comparative Example 10	--	--	×(*2)	--	--	--	--	--	--	--	--	--
* 1) FRP could not be formed.												
* 2) The reinforcing layer could not be formed.												

[0082]

As shown in Table 6, in the reinforcement methods according to Examples 1-31 where the particular reinforcing layers and the particular protective layers were formed, all the evaluations were good.

In contrast, in the reinforcement method according to Comparative Example 1, the tensile strength of the reinforcing layer was not sufficient because the weight per unit area of glass fiber sheets used for forming the reinforcing layer was too low.

In the reinforcement method according to Comparative Example 2, the workability of the reinforcing layer was not sufficient because the weight per unit area of glass fiber sheets used for forming the reinforcing layer was too high.

In the reinforcement methods according to Comparative Examples 3 to 6, the visibility was not sufficient because the difference between the refractive indices of the glass fiber sheet and the cured adhesive for concrete structures was too large.

In the reinforcement method according to Comparative Example 7, the gas toxicity and fire spread were not sufficient because the protective coating did not contain any inorganic component.

In the reinforcement method according to Comparative Example 8, the gas toxicity and fire spread were not sufficient because no protective layer was formed.

In the reinforcement method according to Comparative Example 9, the tensile strength of the reinforcing layer, the gas toxicity, and the fire spread were not sufficient because no glass fiber sheet was used.

In the reinforcement method according to Comparative Example 10, each evaluation could not be performed because no adhesive for concrete structures was used, and the reinforcing layer (FRP) itself could not be formed.

[0083]

As can be seen from the above results, the present invention can provide a reinforced concrete structure and a reinforcement method for a concrete structure, which can visually observe the base of the concrete structure, and have improved

reinforcing performance of the concrete structure and an improved effect of suppressing the fire spread and the generation of harmful gases in case of fire.

CLAIMS

1. A reinforced concrete structure, a surface of the concrete structure comprising at least a reinforcing layer and a protective layer in this order,
wherein the reinforcing layer has an integrated structure of at least one glass fiber sheet having a weight per area of from 500 to 1000 g/m² and at least one cured adhesive for concrete structures;
wherein the protective layer is a coated film of a protective coating containing at least one inorganic component; and
wherein a difference between refractive indices of the glass fiber sheet and the cured adhesive for concrete structures is less than 0.04.
2. The reinforced concrete structure according to claim 1, wherein glass fiber forming the glass fiber sheet comprises 12% by mass or more of ZrO₂ and 10% by mass or more of R₂O in which R is at least one selected from Li, Na, and K.
3. The reinforced concrete structure according to claim 1 or 2, wherein the glass fiber sheet is a biaxial woven fabric in which fibers in a warp direction and fibers in a weft direction are orthogonal to each other.
4. The reinforced concrete structure according to any one of claims 1 to 3, wherein the glass fiber sheet has a mesh opening of from 1 to 25 mm.
5. The reinforced concrete structure according to any one of claims 1 to 4, wherein the glass fiber sheet comprises fibers, the fibers in at least one direction being thermally fused fibers.

6. The reinforced concrete structure according to any one of claims 1 to 5, wherein the glass fiber sheet has a content of at least one component other than glass fiber of less than 50 g/m².
7. The reinforced concrete structure according to any one of claims 1 to 6, wherein the adhesive for concrete structures is a composition comprising at least one resin selected from the group consisting of (meth)acryl resins, vinyl ester resins, unsaturated polyester resins, urethane resins, urea resins, epoxy resins and silicone resins.
8. The reinforced concrete structure according to any one of claims 1 to 7, wherein the cured adhesive for concrete structures has a Gardner color scale of 8 or less.
9. The reinforced concrete structure according to any one of claims 1 to 8, wherein the reinforcing layer comprises two or more of the glass fiber sheets.
10. The reinforced concrete structure according to any one of claims 1 to 9, wherein the protective coating contains at least one inorganic component having a melting point of 1000 °C or lower and an organic binder in a solid content mass ratio of from 30:70 to 70:30, and wherein a content of SiO₂ in the inorganic component is 30% by mass or more.
11. The reinforced concrete structure according to any one of claims 1 to 10, wherein the protective layer has a Gardner color scale of 8 or less.
12. The reinforced concrete structure according to any one of claims 1 to 11, wherein a tensile strength per unit length of a type B specimen prepared in

accordance with JIS A 1191: 2004 using the glass fiber sheet and the adhesive for concrete structures is 150 kN/m or more.

13. The reinforced concrete structure according to any one of claims 1 to 12, wherein, in a gas toxicity test as defined in Fire Preventive and Fireproof Performance Test and Evaluation Procedure Manual under the Building Standards Law of Japan, an average time from the start of the test to mice stopping their behavior is 6.8 minutes or more.

14. The reinforced concrete structure according to any one of claims 1 to 13, wherein, in a fire spread test in NEXCO Test Method 738, a flame-out time is 30 seconds or less, and the lead of fire caused by combustion is less than 600 mm from an ignition point.

15. A method for reinforcing a concrete structure, comprising forming at least a reinforcing layer and a protective layer in this order, on a surface of the concrete structure,

wherein the reinforcing layer has an integrated structure of at least one glass fiber sheet having a weight per area of from 500 to 1000 g/m² and at least one cured adhesive for concrete structures;

wherein the protective layer is a coated film of a protective coating containing at least one inorganic component; and

wherein a difference between refractive indices of the glass fiber sheet and the cured adhesive for concrete structures is less than 0.04.

16. The method for reinforcing a concrete structure according to claim 15, wherein the reinforcing layer is formed by applying the adhesive for concrete structures to a surface of the concrete structure, arranging the glass fiber sheet onto

the applied surface, and then impregnating the glass fiber sheet with the adhesive for concrete structures to cure it.