

METHOD FOR STRENGTHENING REINFORCED CONCRETE STRUCTURES

BACKGROUND OF THE INVENTION

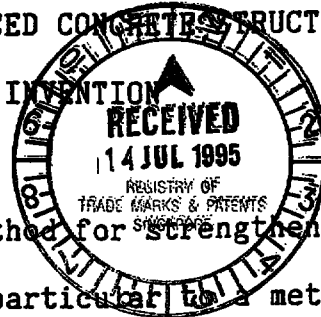
(Field of the Invention)

This invention relates to a method for strengthening reinforced concrete structures and in particular to a method for strengthening reinforced concrete structures using a fiber reinforced plastic plate.

(Prior Art)

Recently, it has been in serious question that concrete decks or girders of highway bridges or buildings deteriorate due to corrosion or fatigue of reinforcing steel, neutralization of concrete and the like. Strengthening of such defects is conventionally done by bonding a steel plate to concrete decks or girders, which is often conducted in a narrower space surrounded by decks. The steel plate is so heavy that a crane such as a crane truck is necessary to lift up and bond the plate to the decks, but it is sometimes impossible to use the crane because of a spatial condition. Further, a surface of concrete structures is not always smooth but usually rough. Thus, in order to bond the steel plate to the concrete structure completely, it is necessary to thicken a bond layer sufficiently to avoid an effect of surface roughness of the concrete structures, which would cause troubles.

On the other hand, an attention has been paid to a FRP strengthening method in which highway decks or girders are strengthened by a fiber reinforced plastic plate, thereby the strengthening work being conducted without holding up traffic. In such a strengthening method, after a resin is coated directly on a



surface of concrete structures, a unidirectional fiber reinforcement in a form of sheet such as, for example, those described in Japanese Patent Kokai No. 3-224,901, is impregnated with a resin followed by curing thereof to form a fiber reinforced plastic plate which is simultaneously bonded to the concrete structures. This is called as a Hand Lay-Up curing method, thereby the concrete structures being strengthened even if the surface is more or less rough. The Hand Lay-Up method is quite convenient because no heavier material as a steel plate is required, however, still there exists following problems caused by in-site curing of FRP.

(1) At first, an uncured resin is coated on the under surface of concrete structures such as decks and girders. If the resin has lower viscosity and poorer thixotropy, the uncured resin tends to run down from the surface of the concrete so that an sufficient amount of resin can not remain on the surface and that thus run down resin dirtily adheres to workers in the site.

(2) Under a condition of increased viscosity and thixotropy, running down of the resin stops but an impregnation rate of the resin into the fiber reinforcement extremely slows down and in fact the resin is little impregnated thereinto.

(3) After a deaeration rolling thereof, as the resin is gradually impregnated into the fiber reinforcement, air contained therein is moved upward and accumulated between the impregnated fiber reinforcement and the undersurface of the deck. Because of tightness of the concrete deck, thus accumulated air is not deaerated spontaneously to form a big void after the resin is cured. As a result, a layer of FRP is swollen up, which is typically observed

when the fiber reinforcement is applied at a higher position.

(4) Rainwater goes down on the surface of the deck or girder and gathers to the void through cracks of concrete. Under an outer condition below the freezing point, frozen rainwater therein is swollen to separate the FRP from the deck.

(5) During the resin impregnation and deaeration rolling, the fiber reinforcement in a form of sheet tends to slip from a portion to be strengthened to allow the reinforcing fibers to zigzag. This should decrease strength and other mechanical properties such as modulus in tension of the fiber reinforced plastic plate.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a method for strengthening reinforced concrete structures using a fiber reinforced plastic plate by coating a resin on a concrete surface of reinforced concrete decks or girders and then laminating a fiber reinforcement in a sheet form thereon followed by resin impregnation and cold cure wherein

(A) the resin is a cold curable epoxy resin having density of 40 to 200 poise and a thixotropy index of 3.0 to 8.0, and

(B) the fiber reinforcement is a unidirectional strengthening fabric in which a series of ancillary weft threads are allocated on both surface sides of a sheet of yarn strips comprising flat reinforcing fiber-multifilament yarns, which are arranged unidirectionally and in parallel to form a sheet and have no flex where stress is concentrated, and a series of ancillary warp threads parallel to the multifilament are woven with the ancillary weft threads to hold the yarn strips in one piece, interstices existing

between adjacent reinforcing fiber-multifilament yarns to solve the problems inherent in conventional strengthening of reinforced concrete structures as described above and to provide a more effective, simpler and more reliable method for strengthening such structures.

The interstices between the reinforcing fiber-multifilament yarns of the fiber reinforcement is preferably in a range of 0.2 mm. to 1.0 mm. The reinforcing fiber-multifilament yarns and ancillary weft threads are preferably bonded by a low-melting polymer on the fiber reinforcement.

According to the present invention, in a method for strengthening reinforced concrete structures using a fiber reinforced plastic plate by coating a resin on an undersurface of reinforced concrete decks and then laminating a fiber reinforcement in a sheet form thereon followed by resin impregnation and cold cure, the resin is a cold curable epoxy resin having viscosity of 40 to 200 poise and a thixotropy index of 3.0 to 8.0, the fiber reinforcement is an unidirectionally reinforced fabric of non-crimp structure having an interstice of 0.2 mm. to 1.0 mm. between flat multifilament yarns of reinforcing fiber. Accordingly, the following effects are obtainable.

(1) The resin does not drop down from the undersurface of the concrete structure so that a predetermined amount of the resin is kept thereon enough to impregnate to the fiber reinforcement.

(2) Because of easier deaeration through interstices between the reinforcing fiber-multifilament yarns, void formation and swelling of the CFRP plate can be prevented. This effect is typically significant when the fiber reinforcement is applied at a

higher portion.

(3) As the fiber reinforcement is not shifted unfavorably during the rolling process for impregnation and deaeration, outstanding mechanical properties as a fiber reinforced plastic plate such as increased strength and modulus in tension.

Further, when the fiber reinforcement is bonded by use of a low-melting polymer extending as a line or a dotted line, additional effects can be obtained as in the following.

(1) During cutting process and rolling for impregnation and deaeration at working sites, the reinforcing fiber-multifilament yarns and ancillary threads never be frayed, which improves workability thereof.

(2) Disorders of fiber arrangement is not occurred during the rolling for impregnation and deaeration under a condition of high pressure.

Accordingly, the most effective and simplest reinforcement of concrete structures can be achieved with remarkable reliability.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a partial perspective view of an undersurface side of a deck which shows an example of the present method for strengthening reinforced concrete structures.

Fig. 2 is a partial perspective view of an example of a fiber reinforcement used in the present invention.

Fig. 3 is a cross section of an another fiber reinforcement.

DETAILED DESCRIPTION AND THE PREFERRED EMBODIMENTS

Referring now to drawings, the present invention will be detailed in the following.

Fig. 1 shows a diagrammatic oblique view of a deck seen from an under surface thereof, which illustrates the present method for strengthening reinforced concrete structures. Fiber reinforced plastic plates 2, 2', 2" - - - are arranged parallel each other to a longitudinal direction of a concrete deck 1 at equal spaces and bonded on the under surface of the deck 1. In addition, similar fiber reinforced plastic plates 3, 3', 3" - - - are also arranged parallel each other to a crosswise direction of the deck 1 at equal spaces to cross over the longitudinal plates 2, 2', 2" - - -.

According to a typical working method for strengthening a deck by means of fiber reinforcement, the under surface of the deck is cleaned by organic solvent such as acetone or soap water to remove dirt or oil, etc. adhered thereto followed by filling mortar or a resin in cracks or concrete dents on the surface and grinding protruded concrete to smooth the bonding surface. If necessary, the surface to be strengthened may be roughed using, for example, a sander. In order to improve bonding properties between the plate and the concrete surface, an epoxy resin primer having lower viscosity is then applied on the surface and allowed to stand for a period of about a day to a week to cure the primer resin. Subsequently, a matrix resin of the fiber reinforcement is applied on the under surface of the deck by use of a coating roll to allocate fiber reinforcement in a form of sheet to a longitudinal or crosswise direction of the deck at equal spaces. In the fiber reinforcement, each fiber is arranged parallel to the longitudinal direction. The fiber reinforcement is further coated by the matrix resin and rolled to simultaneously perform resin impregnation and deaeration followed

by cold cure. Similarly, the fiber reinforcement in a form of sheet is further allocated on the deck to a crosswise or a longitudinal direction thereof at equal spaces followed by resin coating, rolling, resin impregnation, deaeration and cold cure. In this way, a layer of fiber reinforced plastic is laminated on the under surface of the concrete deck to strengthen the deck. Depending on a required degree of strength, such a laminating process is repeated to increase the thickness of lamination, i.e., an amount of reinforcing fiber. This is a typical and conventional process for strengthening decks as concrete structure by fiber reinforced plastic, which is also employed in the present invention.

A cold curable epoxy resin is used in the present invention as a matrix resin to apply on the under surface of the deck or to impregnate into the fiber reinforcement. Because of outstanding resistance to alkalis, the epoxy resin is not corroded nor degraded with the laps of time under an alkaline condition of concrete. The epoxy resin has superior bonding properties to concrete structures and reinforcing fibers, which considerably contributes to effective strengthening of the decks by such fibers. Further, the epoxy resin as a matrix is conveniently cured at room temperature and curing thereof proceeds while allowing to stand for a certain period of time after the resin impregnation. Such outstanding bonding and curing properties of the epoxy resin make the strengthening work of decks easy. If thermosetting resins are used, appropriate heating means should be necessary in a strengthening site.

The epoxy resin used in the present invention has density of 40 to 200 poise and a thixotropic index of 3.0 to 8.0. When the

density is less than 40 or the thixotropic index is less than 3.0, the uncured resin on the fiber reinforcement tends to run down therefrom so that a sufficient amount of resin can not be remained on the surface, which decreases a bonding effect between the deck and the fiber reinforced plastic plate. Further, the resin is not enough filled in the fiber reinforcement to increase the strengthening effect. The run down resin adheres dirtily to workers under the deck or is cured during running down thereof to cause ugly unevenness on the outer surface of the reinforced plastic. Because of lower viscosity and poorer thixotropy of the resin, the fiber reinforcement in a form of sheet tends to slip from a portion to be strengthened, thereby zigzagging fibers and lowering the reinforcing effect of the sheet. Thus, strength and other mechanical properties such as modulus in tension of the fiber reinforced plastic plate is apparently decreased.

On the other hand, under a condition of resin viscosity more than 200 poise and a thixotropic index more than 8.0, the resin is little dispersed and insufficiently impregnated in the reinforcing fibers because of higher viscosity thereof, when the resin is applied on the fiber reinforcement followed by impregnation and deaeration rolling. Accordingly, even when fiber reinforcement of superior strength and modulus in tension is employed, a combined strengthening effect thereof with such a resin is not exhibited and expected strength or modulus in tension is not obtained.

When the resin has viscosity of 40 to 200 poise and a thixotropic index of 3.0 to 8.0, various problems caused by lower viscosity and poorer thixotropy such as running down of the resin,

difficulty in retaining thereof on the fiber reinforcement, insufficient bonding effect between the deck and the fiber reinforcing plastic plate, unevenness of the outer surface of the reinforcement, zigzagging of reinforcing fibers and the like. Although impregnation rate of the resin is rather late, the impregnation into the fiber reinforcement proceeds steadily. However, there still exists a problem of void even if a condition of resin viscosity is fallen in the range described above. In general, air contained in the fiber reinforcement is replaced by the resin after impregnation and deaeration rolling thereof, moved upward and collected between the impregnated fiber reinforcement and the under surface of the deck, which forms a void. Because of tightness of the concrete deck, thus collected air is not deaerated spontaneously but is left as a big void after the resin is cured, which allows a layer of FRP to swell up. Rainwater goes down on the surface of concrete and is pooled in the void, which freezes at a temperature below subzero. Cubical expansion of the frozen rainwater causes cracks between the concrete surface and the fiber reinforced plastic plate and would then separate these materials.

According to JIS(Japanese Industrial Standard)-K-6833, measurement of the resin viscosity is carried out as in the following. Using a single cylindrical rotator, 500 ml of sample is placed in a container. A rotor of viscometer is set in the center of the sample after a temperature thereof has reached to predetermined degree and then rotated at rotor velocity of 20 rpm for a minute. At this time, the graduation of the indicator is read. The viscosity is calculated by multiplying the read graduation of the viscometer by a specific

conversion factor.

The thixotropy index is measured similarly as the viscosity measurement as described above using the same rotor except the rotor velocity is different. That is, the thixotropy index is a ratio of viscosity measured at different velocity. Under rotor velocity conditions of 20 rpm and 2 rpm, the thixotropy index is calculated as in the following:

$$\text{thixotropy index} = \frac{\text{viscosity measured at 2 rpm}}{\text{viscosity measured at 20 rpm}}$$

As a result of the inventors' eager investigation, swelling of the fiber reinforced plastic plate can be avoided by use of fiber reinforcement 4 in a form of sheet as shown in Fig. 2 even if the resin viscosity is 40 to 200 poise and the thixotropy index is 3.0 to 8.0.

A plurality of reinforcing fiber-multifilament yarns are arranged in parallel and unidirectionally each other to leave interstices between adjacent multifilament yarns. Voids formed between the reinforcement and the concrete surface are removed by means of such interstices, i.e., these interstices are useful for preventing an undesirable formation of void. It is experimentally confirmed that the interstices are essential for removing voids and that preferable width thereof is 0.2 mm to 1.0 mm. An interstice of not more than 0.2 mm wide possibly allows to leave voids between the fiber reinforcement and the deck. While, an interstice of more than 0.1 mm wide causes a decrease in numbers of the reinforcing fiber-multifilament yarn, or weight of the yarn to be arranged on a unit area (e.g., weigh/square meter). It is necessary to repeat lamination

many times until a predetermined amount of yarn is laminated on the deck to be reinforced, which takes longer time. On the other hand, if increased weight of reinforcing fibers per unit area is used to keep proper interstices between yarns, width of each yarn is inevitably reduced so that rate of resin impregnation thereto is lowered.

When a resin is coated on fiber reinforcement having interstices of 1.0 mm. to 0.2 mm. between reinforcing fiber-multifilament yarns followed by deaeration using a fluted roll to a crossing direction of the yarns, air bubbles are easily removed through the interstices.

Fiber reinforcement 4 in a form of sheet comprises a series of yarn strips (a) of reinforcing fiber-multifilament yarns 5 in which flat multifilament yarns 5 having no flex where stress is concentrated are arranged in parallel and unidirectionally to form a sheet, a series of ancillary warp threads 6 and (b) put between and arranged parallel to the multifilament yarns 5 and a series of ancillary weft threads 7 and (c) allocated on both sides of a sheet surface, the series of ancillary warp threads (b) and the series of ancillary weft threads (c) being woven to hold the yarn strips (a) in one piece. As the reinforcing fiber-multifilament yarns 5 are arranged straight without flexing to form so-called non-crimp structure, resin-hardened multifilament yarns 5 exhibit, without exhibiting any stress concentration, increased tensile strength and tensile modulus of a plastic plate thus fiber reinforced. Further, because of a flat cross section of the yarn strips 5, thickness thereof is thin enough to impregnate with the resin

irrespective of its higher viscosity. When the yarn strips 5 have an elliptic cross section, the resin impregnation proceeds favorably at both thinner sides of the strips but unfavorably around the center thereof. The thicker an access to a core portion of the strips is, the more difficult to impregnate with the resin, which results in an unimpregnated portion around the core.

In order to increase in the weight of fiber, flat multifilament yarns 5 of reinforcing fiber are laminated and woven. A lamination of two layers of yarns 5 is shown in Fig. 3 and , if necessary, that of multilayers may be used. As the multifilament yarns are flat, predetermined interstices can be kept between the yarns even under a condition of increased weight of fiber as described above.

Flatness of the multifilament yarns 5, i.e., width of strip/thickness of strip, is preferably about 30 to 100. At a flatness less than 30, the resin impregnation is decreased when the weight of fiber is increased, while at 100 or more, it is difficult to keep a desired interstice between yarns.

Yarns of reinforcing fiber used in the present invention comprises those of multifilaments in which a plurality of filaments are bound. Such fibers include those of higher strength and modulus such as carbon fiber, polyaramide fiber and glass fiber. Among others carbon fiber is resistant to alkalis and preferably used in the present invention.

Ancillary threads are used to hold yarn strips in one piece but not to substantially improve mechanical properties of the fiber reinforced plastic, preferable fineness being 50 denier to 700 denier.

Particularly when the fineness of ancillary warp threads are more than 700 denier, interstices between the strips are occupied by such ancillary threads to cause difficulties in the deaeration of resin. Fibers used as the ancillary threads include those of glass, polyester, polyaramide, nylon, ABS, polyethylene, polypropylene, vinylon and the like but are not restricted by these fibers. Among others glass fiber, polyaramide fiber and vinylon fiber have lower heat-shrinkable properties and accordingly outstanding dimensional stability, thereby changes in density of the yarn strips of reinforcing fiber caused by shrinkage of ancillary weft threads being prevented. Further, because of little shrinkage of the reinforcing fiber-multifilament yarns such as those of carbon, polyaramide and vinylon, a conventional problem of zigzagging of the reinforcing fiber-multifilament yarns can be solved. Such a problem has been often occurred due to shrinkage of the ancillary warp threads.

As the resin used in the present invention has viscosity and a thixotropy index higher than those of used in the conventional Hand Lay-Up method, relatively forced impregnation and deaeration rolling are required to successfully impregnate with the resin to the fiber reinforcement. Deviations of weave pattern and disorders of arrangement of multifilament yarns in the fiber reinforcement might be occurred due to such a forced rolling manner or pressure used thereby. Accordingly, it is preferable that the reinforcing fiber-multifilament yarns and/or the ancillary warp threads are bonded with the ancillary weft threads by means of a low-melting polymer extending as a line or a dotted line in the fiber reinforcement. While the low-melting polymer is extended as a line or a dotted line

to simply bond the ancillary weft threads to the multifilament yarns and/or those of warp, impregnation of the matrix resin never be inhibited. The low-melting polymer used herein includes thermoplastic polymers such as nylon, copolymerized nylon, polyester, ABS, polyethylene, polypropylene and the like. A yarn strip comprising these polymers is arranged with the reinforcing fiber-multifilament yarns and the ancillary threads to weave all together, which is then heated to a temperature above the melting point of the low-melting polymer followed by cooling to bond each yarn and thread.

Substantially, the low-melting polymer is not a reinforcing material for the fiber reinforced plastic and is preferably added only in a small amount because an addition thereof in excess should inhibit impregnation of the matrix resin. It is preferred to add the low-melting polymer in an amount of about 0.6 to 20 g./m².

A preferred embodiment of a method for strengthening reinforced concrete structures of the present invention will be described in the following.

Example 1

Carbon fiber yarns having a fineness of 7,200 denier were used as the warp multifilament yarns of reinforcing fiber, two strips of which were laminated while keeping yarn flatness of 6.5 mm wide to arrange thereof unidirectionally and in parallel each other in a sheet form. In addition, glass fiber yarns having fineness of 405 denier as the ancillary warp threads, those having fineness of 202.5 denier and nylon yarns having fineness of 50 denier as the low-melting polymer were arranged and inserted between or applied on the carbon fiber yarns to weave all together. The low-melting nylon yarns were

then melted by means of a heater on a weaving machine to bond the carbon fiber yarns and the glass fiber yarns as the ancillary weft threads to form a fabric A shown in Fig. 3.

As a model experiment for reinforcing decks, a polyester film was adhered to an undersurface of a veneer plywood by means of a double-adhesive tape. After the veneer plywood was secured, a room temperature curing epoxy resin having viscosity of 100 poise and a thixotropy index of 4.0 was homogeneously coated on the film by a spreading roller followed by application of the fabric A thereon, further coating of the same resin in a similar manner as described above and subsequent resin impregnation and deaeration using a fluted roller. As a result, it was observed that air was easily removed through interstices between the carbon fiber yarns. An additional fabric A was applied on the first fabric so as to arrange the carbon fiber yarns of both fabrics unidirectionally each other. Homogeneous coating of the epoxy resin by the spreading roller, and the resin impregnation and deaeration using the the fluted roller were repeated similarly as described above. Air was again removed smoothly through the interstices. No disorder of the fiber arrangement due to rollers was observed.

The resin began to cure when 40 minutes or so was passed after the treatment of cold impregnation. Neither of dropping down of the resin nor partial swelling of the carbon fiber reinforced plastic (CFRP plate) were observed. When the film was separated from the veneer plywood after the resin was cured completely, there was no void between the film and the CFRP plate.

Comparative Example 1

Using a cold curing epoxy resin having viscosity of 20 poise and a thixotropy index of 1.0 and the fabric A used in Example 1, the model experiment of Example 1 was repeated as in the following. First of all, however, when one or two minutes passed after the resin was homogeneously coated on the film by the spreading roller, the resin was partially collected to form an unevenly coated surface and began to drop down from sag portions of the surface. The fabric A was applied on the surface followed by homogeneous coating of the epoxy resin by the spreading roller and subsequent resin impregnation and deaeration by the fluted roller. Air was removed through interstices between the carbon fiber yarns similarly as in Example 1.

An additional fabric A was applied on the first fabric so as to arrange the carbon fiber yarns of both fabrics unidirectionally each other. Homogeneous coating of the epoxy resin by the spreading roller, and the resin impregnation and deaeration using the the fluted roller were repeated similarly as described above. Air was again removed smoothly through the interstices. During the first 40 minutes of the resin curing process, the resin was partially collected to form the unevenly coated surface and began to drop down from sag portions of the surface. Although the surface of the CFRP plate was uneven after the resin was cured, partial swelling on the surface caused by bending of the carbon fibers was not observed. The film was separated from the veneer plywood to observe an existence of any void between the film and the CFRP plate. As a result, layers of air were partially found as sunken portions of the CFRP plate. It is believed that lack of fill-out due to dropping down of the resin would result in such portions.

Comparative Example 2

Using glass fiber yarns of lower tension as the ancillary warp threads, a fabric B having an interstice of 0.1 mm. between the carbon fiber yarns was prepared in a similar manner described in Example 1. The model experiment of Example 1 was carried out by use of the fabric B and a resin having viscosity of 100 poise and a thixotropy index of 4.0. When coating of the resin by the spreading roller and subsequent impregnation thereof and deaeration by the fluted roller were completed, air was hardly removed through the first or the second layer of the carbon fiber yarns. The resin did not drop down after the resin is coated or during the curing process, but partial swelling of the CFRP plate was observed. It was found that the carbon fiber yarns were bent around such partially swollen portions where voids were formed between the film and the CFRP plate.



What is Claimed is:

1. In a method for strengthening reinforced concrete structures using a fiber reinforced plastic plate by coating a resin on a concrete surface of reinforced concrete decks or girders and then laminating a fiber reinforcement in a sheet form thereon followed by resin impregnation and cold cure, the improvement wherein

(A) the resin is a cold curable epoxy resin having density of 40 to 200 poise and a thixotropy index of 3.0 to 8.0, and

(B) the fiber reinforcement is a unidirectional strengthening fabric in which a series of ancillary weft threads are allocated on both sides of a sheet surface of yarn strips comprising flat reinforcing fiber-multifilament yarns, which are arranged unidirectionally and in parallel to form a sheet and have no flex where stress is concentrated, and a series of ancillary warp threads parallel to the multifilament yarns are woven with the ancillary weft threads to hold the yarn strips in one piece, interstices existing between adjacent reinforcing fiber-multifilament yarns.

2. A method claimed in Claim 1, wherein the interstices between the reinforcing fiber-multifilament yarns of said fiber reinforcement is 0.2 mm. to 1.0 mm.

3. A method claimed in Claim 1 or 2, wherein the reinforcing fiber-multifilament yarns and the ancillary weft threads are bonded by a low-melting polymer on said fiber reinforcement.