PERFORMANCE OF EPOXY PUTTY-FRP FOR UNDERWATER STRUCTURAL CONCRETE

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ABSTRACT

The extraordinary properties of fiber reinforced polymer (FRP) composites of lightweight, high strength-to-weight ratio, corrosion resistance, potentially high overall durability, tailiorability and high specific attributes enable them to be used in areas where the conventional construction materials might be restricted. Despite of FRP has many advantages, this material has negative effect if immersed in water, the bond between FRP and surface concrete can be long term maintained. The strength between the FRP and surface of concrete and other material will be decrease when strength as long as debonding has been occurred.

This paper is to verify performance of these materials with epoxy putty, several tests such as flexural strength test, bond strength test, and chemical resistance test, etc were carried out. The results showed that the concrete attached the epoxy putty as adhesive maintaining the performance of structures, and also do not easily dissolve in immersed in seawater.

KEYWORDS: Concrete, FRP, Epoxy Putty, Flexure, Strength, Chemical Testing

INTRODUCTION

Fiber reinforced polymer (FRP) materials are being increasingly used for new construction or to retrofit bridges [1-9]. Examples of FRP applications in bridges include reinforcing steel or concrete beams for added strength or stiffness, wrapping concrete columns to restore/increase load capacity or to increase seismic resistance, or composite decks for increased loads and/or minimized repair time. Advantages of FRP construction/rehabilitation include light weight (increased live loads allowed), corrosion resistance, increased seismic tolerance, modular construction (greater quality assurance and less traffic disruption), and lower life costs. The lower life costs projections rely on the longer life of the structure in construction will increase by 525% globally and by 750% in North America from 2000 to 2010 [9].

The fiber reinforced polymers (FRP) systems are comprised of specialized fabrics and resins, which in unique combination, create tested and proven composites. Carbon, glass or aramid reinforcing fibers are combined with high quality resins to produce a multitude of high performance FRP strengthening systems, which gives design engineers a wide range of options to meet the individual needs of a project. FRP Systems have a successful performance record with over two decades of use. This includes extensive testing as well as performing as designed during seismic events on three continents.

The integrity of the bond between the FRP and the concrete or steel structure is crucial for success, especially for beam and slab configurations. Moisture and salt ingress into rehabilitated components has the potential to degrade the bond due to continued corrosion within the concrete or steel, delamination of the FRP during freeze/thaw cycles, or
thermodynamic weakening of interfacial chemical bonds. It is therefore important to develop a nondestructive evaluation method to monitor the integrity of the bond between FRP and concrete or steel in rehabilitated structures.

External bonding technique using fiber reinforced composites is the most widely used retrofitting method for improving structural performance. Numerous researchers [1-6] have studied performance improvement of retrofitted structures using FRP and verified its practical usage as a construction material. FRP far exceeds safety and durability of underwater requirements. Also, it is non-conductive and fatigue resistant. By surface bonding of FRPs on concrete structures, it increases strength and ductility of concrete members far greater than any other surface attaching materials and helps to prevent concrete members from corroding in wet conditions [2,4].

Despite these advantages, underwater epoxy adhesive used to attach FRPs to concrete surface is rather expensive and its workability and adhesive strengths are usually insufficient for repair and strengthening of underwater RC members [7]. For these reasons, the proper repair and strengthening of structural members underwater have been difficult to achieve. Also, unless a better underwater epoxy is developed, sufficient repair and strengthening of underwater structure can only be achieved by enforcing dry condition on damaged regions of the structural member. In order to enforce dry condition, miniature cofferdam around the damaged area of the member has to be temporarily constructed during repair and strengthening period, which is a great time and economical loss requiring laborious works and heavy equipments [8].

For these reasons, there have been great efforts to develop repair and strengthening methods suitable for underwater. To achieve this goal, two approaches have been taken. One approach is by improving construction method (e.g., repair and strengthening methodology) and the other is by developing better repair and strengthening material for underwater usage [9-11].

However, the improvements in construction methodology have limited possibility for the repair and strengthening of underwater structural members due to the fact that the construction has to be performed underwater. Therefore, the best possible repair and strengthening of underwater members can be achieved through developing an underwater oriented repair and strengthening material for surface attaching method, the simplest underwater retrofitting method available currently. In order to maximize this method’s implementation, the development of epoxy adhesive for underwater usage is a critical issue. However, currently, there are only a limited number of studies on epoxy development for underwater usage [7,9].

High performance adhesive for underwater usage has to be able to maintain sufficient bond strength and good workability underwater. Also, when used for coating purpose, it should not dissolve in water and produce any residuals after solidification as well as being environmentally friendly. Therefore, in this study, highly efficient underwater hardening epoxy is developed, which is applicable for repair and strengthening of concrete structures located in wet conditions. Using various performance evaluating experiments, the developed epoxy putty material properties are proposed.

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FRPs, a recent marketing survey projected that use of FRPs. In this study is concerned the structural concrete performances of which are attached surface with epoxy putty

**Development of Epoxy Putty**

Interfacial properties between FRP composites and polymeric matrix play a very important role in deciding final capacity of a composite material. Particularly, interfacial shear strength of FRP is one of the most basic factors for evaluating mechanical and durability properties under special environmental condition.

If interfacial shear strength of bonding material is rather low, the overall failure behavior of the retrofitted member would be affected mainly by low interfacial adhesive strength. Therefore, high-performance fiber reinforced composite’s great tensile capacity due to the high strength of reinforcing fibers can not fully be utilized due to immature failure of interface [11]. To overcome this problem developed the Aqua-Advanced-FRP for Retrofitting of Underwater Concrete Structural Members have conducted by Na et al.,2010. In order to repair and strengthen concrete structural members located in water using FRP sheets (i.e., GFRP, CFRP, etc.), the development of high performance epoxy for underwater usage is a necessity [12-14].

**Components of Epoxy Putty**

The used for base resin of composite to increase bond strength between concrete and FRPs in the wet conditions. Also, epoxy silane coupling agent of silane system is added to increase bond strength. In order to maintain suitable viscosity for securing workability, disfunctional reactive diluent is added. To improve adhesive capacity underwater, a mixture of modified aliphatic amine and amido-amine for hardener is used. Polyamid-amine is added to increase hardening capacity underwater. In addition, workability is improved by adding nonylphenol dispersing agent to give flow ability. The final product of underwater hardening epoxy, which is manufactured by the mixture procedures explained above is shown in Figure 1. Figure 1 shows the single components of the mix of the developed underwater hardening epoxy.

Epoxy silane (glycidoxy-propyltrimethoxy silane), a main component of underwater hardening epoxy base resin, reacts with amine system hardener and forms a solid material. Also, methoxy functionality (–O–CH₃) contained in epoxy silane derives silane coupling hardening reaction and attaches to concrete matrix or fiber. Its hardening reaction progresses by itself so that it performs a role of increasing bond strength with concrete as well as increasing acid and chemical resistances. Figure 1a and 1b show the reaction mechanism of glass fiber, which is used for strengthening of underwater hardening epoxy and concrete structure.

Underwater hardening epoxy has a composition shown in Tables 1. By varying the amount of mixture contents of these components, epoxy putty with great adhesive strength between concrete surface and FRP are developed. Epoxy putty should have a good workability, not dissolve in water during construction, not create residual particles during hardening, and be environmentally friendly.

**Table 1: Physical and Chemical Properties Epoxy Putty**

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity (H₂O = 1)</td>
<td>1.4 – 2.3</td>
</tr>
<tr>
<td>Vapor pressure (mm Hg)</td>
<td>NIL @ 78 F</td>
</tr>
<tr>
<td>Volatile by volume (%)</td>
<td>0</td>
</tr>
<tr>
<td>Vapor density (Air = 1)</td>
<td>&gt;1</td>
</tr>
<tr>
<td>Evaporation rate (Butyl acetate = 1)</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>Solubility in water</td>
<td>Negligible</td>
</tr>
<tr>
<td>pH (5% solution in water)</td>
<td>9.5</td>
</tr>
</tbody>
</table>
RESEARCH METHODOLOGY

In this study, the concrete mix proportion as shown in Table 2, and concrete compressive strength, it can be seen in Figure 2. The results indicate that the concrete age on 28 days achieved of 42 MPa. In order to determine the optimum the strength of concrete combine epoxy putty-PRP , four iterative steps are taken. For the first step, concrete mix design is determined, Second step, the casting of cube 100 mm x 100 mm x 100 mm, cylinder $\Theta$ 100 x 200 mm, and beam 100 mm x 100 mm x 500 mm, these samples cured as immersed in water at 27°C. The third step is for normal concrete tested for compression with 60 days and flexural testing for beam. The fourth step is the surface of beam samples attached by epoxy putty as bonded between concrete surface and FRP (see Figure 5a.), this epoxy putty expose to air with few minutes then resin and 3 layers grid fiber attached on these surfaces within hardly. Finally the concrete samples beam size of 100 mm x 100 mm x 500 mm under of sides attached epoxy putty for chemical testing, these samples immersed in solution of 10% sulfuric acid, 10% hydrochloric acid, 10% sodium hydroxide and 10% sodium chloride.

Table 2: The Concrete Mix Proportion

<table>
<thead>
<tr>
<th>Slump (cm)</th>
<th>W/C (%)</th>
<th>Density of Aggregate (t/m3)</th>
<th>Unit weight (kg/m3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0.4</td>
<td>2.43</td>
<td>S</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.54</td>
<td>G</td>
</tr>
<tr>
<td></td>
<td>173</td>
<td>367</td>
<td>W</td>
</tr>
<tr>
<td></td>
<td>765</td>
<td>1126</td>
<td>C</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>S</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>G</td>
</tr>
</tbody>
</table>

Fig. 2: Normal Concrete Compressive Strength
PERFORMANCE OF CONCRETE BONDED EPOXY PUTTY-FRP

Fiber Reinforced Polymer (FRP)

The flexural capacity of RC flexural members such as beams and slabs can be increased by bonding FRP to their tension face as described in section follows. Failure of an FRP strengthened beam may occur by the compressive crushing of concrete, the tensile rupture of the FRP or debonding in one several forms, the steel reinforced should have sufficient yielded at failure to ensure the formation of obvious cracks prior to failure by concrete crushing, FRP rupture or FRP debonding with the aim of ensuring some degree of ductility in these generally brittle modes of failure [15]. FRP samples size 300 m x 3 mm x 50 mm with 3 layers (see Figure 3a) between each bonded epoxy putty with thickness of 2 mm, total of this sample thickness of 9.6 mm. The sample support setup for testing flexure (see Figure 3.b). The result can be seen in Figure 3c, the figure indicate that the FRP as brittle material has liner stress and strain relationship.

Figure 3: a. FRP Plate 3 Layers, These Surface Attached by Epoxy Putty

Figure 3: b. Flexure Testing of FRP Plate 3 Layers, These Surface Bonded Epoxy Putty

Figure 3: c. FRP Plate Flexure Testing Result
FRP Tensile Testing

Adhesive strength between FRP and concrete using epoxy putty is examined using the test method of [16] as shown in Fig. 4a. The experiment was performed on normal strength concrete to find adhesive performance characteristics. After applying epoxy putty and attaching FRPs on concrete, the specimens are air cured. The adhesive strength test results are shown in Figure 4c.

From the results of pull-off test, 25.58 MPa tensile strengths was achieved by FRP, it is better than the products currently in the market. The Figure also indicated that FRP just has elasticity characteristic material. The use fiber as strengthened this material to need consideration accurately.

![Figure 4: a. FRP Model for Strength Testing](image1)

![Figure 4: b. Tensile Testing of FRP Setup](image2)

![Figure 4: c. Relationship Between Stress and Strain of FRP](image3)
Flexure Beams Testing

The beam strengthened with an FRP plate without without prestressing or mechanical anchorage (Figure 4). This method of strengthening RC beams was first researched in the mid-1980s at the Swiss Federal Laboratory for Material Testing and Research (EMPA) [1], but most of the research on FRP plate bonding for flexural strengthening has been carry out over the past 18 years. Detailed review of the extensive research conducted so far can be found in the open literature [17-22]. As a result of extensive research to date, a reasonably detailed understanding has been obtained and comprehensive design theory developed.

A number of distinct failure modes of beam bonded with an FRPs plate have been observed in numerous experimental studies [18,20]. A schematic representation of these failure modes are shown in Figure 4. Failure of an FRP plate beam may be by the flexural failure of the critical section or by debonding of the FRP plate from the beams. In the former type of failure, the composite action between the bonded plate and the RC beam is maintained up to the failure of the critical section.

Debonding failures generally occur in the concrete beam, which is also assumed in the design theory presented in this paper. This is because, with the strong adhesive epoxy putty currently available and with appropriate surface preparation for the concrete substrate, debonding failures along the physical interfaces between the adhesive epoxy putty and the concrete and between the adhesive epoxy putty and the FRP plate are generally not critical.

The samples tested consists of 3-4 samples for 4 types specimens as shown Figure 5a, these are normal concrete beam specimen NC-CH, one bottom side of specimens BS-CH, 2 side left and right of beam specimen 2S-CH, and 3 side (right-left-and bottom) of beam specimen 3S-CH were tested. The two simple were implemented (see Figure 5b) with 2 point load were attached. The failure of beam tested are caused by over load it can be seen Figure 5c. The result indicated there is significant strength for beam bonded FRP at bottom side and 3 side FRP in comparison with the normal concrete beam NC-CH. The crack was occurred in left and right side due to failure in in moment loading.

Figure 5: a. Kind of the Concrete Beam Bonded by Epoxy Putty-FRP

Figure 5: b Flexure Testing of Fibers Attached Under Beam
Figure 5: c. The Failure Flexure Testing of Fibers Attached Under Beam

Tensile–Shear Bond Test

Tensile–shear bond test is performed to evaluate shear strength on adhesiveness of the developed epoxy bond. Figure 6a and 6b shows dimensions and size of tensile–shear bond test specimen of epoxy putty-FRP. After bonding two FRP strip using epoxy putty, the specimen was fixed in the center of tester grips. After aligning it vertically, one end of the specimen is pulled whereas the other end is fixed in stationary position. The maximum load was recorded until the specimen reached the failure. The calculated tensile–shear bond strength of epoxy putty from the measured experimental maximum load data. It can be seen in Figure 6a and 6b.

The test results show that the developed epoxy’s average tensile–shear bond strength was 16.6 MPa. It is safe to conclude that Epoxy Putty-FRP can be used in underwater, because the bond strength value is nearly same as the generally-required adhesive shear strength of above ground epoxy.

A good understanding of the bond behavior between the FRP plate and the substrate concrete is of great importance for understanding and predicting the debonding behavior of FRP plated RC Beams. Bond behavior between FRP and concrete has been widely studied experimentally using simpleull-off tests or using theoretical/finite element models [23-26]. Figure 6a and 6c show the schematic and a typical implementation of this research.
Figure 6: b. FRP Bond Strength of Concrete Beam Testing Setup

The ultimate tensile force that can be resisted by the FRP plate in a simple pull-off test before the FRP plate debonds from the concrete prism is referred to as the ultimate load or the bond strength. The bond strength is defined herein using the tensile force (or the tensile stress) in the pale instead of the average interfacial shear stress because the latter can be conceptually misleading [16,23, 25-26] investigated that the ultimate load of a pull-off test initially increases as the bond length increases but, when the bond length reaches a threshold value, any further increase in the bond length does not lead to a further increase in the ultimate load.

Many theoretical model have been developed to predict the bond strength of FRP-to-concrete bonded joints. Among the existing bond strength models, the model developed by [23] have been found to provide the prediction of test results [23], bond strength model predict that the strength in the bonded plate in MPa, the cause debonding failure in a simple pull-off test is given by:

$$
\sigma_p = \alpha \beta_{\text{eff}} \sqrt{\frac{E_{\text{Frp}}}{t_{\text{Frp}}}} \frac{f_{\text{c}}}{b_{\text{c}}}
$$

Where the width ratio factor

$$
\beta_{\text{w}} = \sqrt{\frac{2 - b_{\text{Frp}}/b_{\text{c}}}{1 + b_{\text{Frp}}/b_{\text{c}}}}
$$

The bond length factor

$$
\beta_{\text{L}} = \begin{cases} 
1 & \text{if } L \leq L_c \\
\sinh \left( \frac{L - L_c}{2L_c} \right) & \text{if } L > L_c
\end{cases}
$$

And the effective bond length (mm)

$$
L_{\text{eff}} = \sqrt{\frac{E_{\text{Frp}} t_{\text{Frp}}}{\sigma_p^2}}
$$

In which $E_{\text{Frp}}$, $t_{\text{Frp}}$, and $b_{\text{Frp}}$ are the elastic modulus (MPa), thickness(mm) and width (mm) of the FRP plate, respectively, $f_{\text{c}}$ and $b_{\text{c}}$ are the concrete cylinder compressive strength (MPa) and width (mm) of the concrete block, respectively, and L is the bond length mm). A value of 0.427 for $\alpha$ was found by [23] to provide a best fit of the test data gathered by them, while a value of 0.315 provides a 95 percentile lower bound which is suitable for use in ultimate limit
state design. These equations can be used for the concrete bounded by FRP plate alone without adhesive such as epoxy putty, the use of $b_c$ on these equations also does not effect on bonding strength for axial force, However $b_c$ is needed by flexural strength of beams. The use of $t_{np}$ should be calculated based on the type of FRP. The thickness of PRF Plate is not fully represented of their strength.

The result achieved that all of bond strength testing failures were occurred on FRP. Its indicated that epoxy putty as adhesive between the concrete surface and FRP are more stronger. Generally, shear bond strength of adhesive is required to have the strength over 15 MPa to epoxy used in dry condition, which is based on [27]. On the other hand, it has required shear bond strength of over 10 MPa for an epoxy used in wet condition.

**Chemical Resistance Test**

Each of 5 beams of 100mm x 100 mm x 500 mm was immersed in solution of 10% sulfuric acid, 10% hydrochloric acid, 10% sodium hydroxide and 10% sodium chloride. The changing rate of each specimen’s weight is measured for 3 months. The conductivity results and the flexure testing results of performance epoxy-putty are shown in Figs. 7a and 7b, respectively. The conductivity results does not indicate the epoxy-putty durability, but normal beam specimen are more soluble As the results, the changing of weight is caused by different chemical reactions taking place different chemical solutions the specimen is placed in. Not only the weight of the specimens exposed to 10% sulfuric acid and 10% hydrochloric acid changes but also the color and shape changes. Therefore, these epoxies are easily affected by acidic chemicals and using them in industrial complexes has to be considered carefully. From the results of experimental study, the specimens material attached epoxy putty are able to withstand the chemical attaching and other severe environmental.

![Figure 7: a. Chemical Percentage Contents](image)

![Figure 7: b. Flexure Beam Testing Immersed in Chemical Solution](image)
CONCLUSIONS

In this study, Concrete bonded Epoxy putty-FRP is developed. It can be used for repair and strengthening of structural members immerse in water. To develop high performance epoxy putty, the optimum mix proportion was determined. From various material tests performed on the optimum mix proportion of the epoxy putty to evaluate their performance capacity, epoxy putty can be used for repair and strengthening of underwater structure using FRPs. In particular, the developed epoxy putty does not easily dissolve in water and has the same performance as the epoxies used in above ground construction. The testing of concrete using epoxy putty for fatigue testing is need because these structures are always located in dynamic condition such as sea port construction, break water, etc.

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