STUDY ON MOLD ON THE SURFACE OF FRP FOR CONSTRUCTION STRUCTURAL USE

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ABSTRACT

Surface of FRP often shows various kinds of appearance changes through the exposure in the outdoor environment. In some cases, these appearance changes seem to be caused not only by deterioration but also by biological reasons such as mold. There are some previous reports that industrial materials are affected by mold; however, there are not so many studies of the present state of mold on the FRP use as a construction structural materials. The authors collected the examples of mold on FRP used in the outdoor environment, and the examples were categorized based on observation by the naked eye into four cases. Observations by digital and biological microscopes were also carried out for the each case. Observation results can explain that these cases were mainly caused by mold or microbe. Identification including the cultivation test is not finished for these cases, but it is planned in the future.

KEYWORDS
structural FRP, durability, deterioration, mold, moss, microbe

INTRODUCTION

Surface of FRP often shows various kinds of appearance changes through the exposure in aquatic environments or in the outdoor environment. It is important to study appearance changes on FRP since they may lead to deterioration. In some cases, appearance changes on FRP seem to be caused not only by physical or chemical reasons but also by biological reasons such as bacteria and mold. For the deterioration due to bacteria on FRP used in aquatic environments, the mechanism was extensively studied (Wagner et al. 1996; Sampath and Khanna 1997; Gu et al. 1997). For appearance changes due to mold, there are some previous reports that industrial materials exposed to the outdoor environment are affected by mold (Inoue 1986). However, there are limited studies of the present state of mold on the structural FRP exposed to the outdoor environment.

The purpose of this study is to clarify whether the appearance changes due to mold on the surface of structural FRP happen when exposed to the outdoor environment. The authors collected the examples of the appearance changes on the surface of FRP used in the outdoor environment, which seem to be a biological reason. The examples are categorized based on observation by the naked eye, and then the reasons of each case are discussed based on observations by digital and biological microscopes.

EXPERIMENTAL METHODS

Two real sized FRP test bridges and FRP specimens in the outdoor environment are investigated. The FRP bridges and FRP specimens have been placed in exposure sites in Tsukuba where about 60km from Tokyo or Rikubetsu where located in Hokkaido, Japan. Tsukuba and Rikubetsu are a mild region and a cold region in Japan, respectively. Figure 1 shows average temperatures in each month at the two exposure sites. The average temperature in Tsukuba remains above zero degrees Celsius throughout the year, while the average temperature in Rikubetsu reaches below zero degrees Celsius from November to March.

Table 1 shows the constitutions of FRP for the exposure tests. Examples of appearance changes on the surface of these FRP bridges or FRP specimens were collected through a naked eye observation, and then examples that seem to be a biological reason were categorized. To categorize the appearance changes accurately, cultivation tests are needed, but as a first step, the categorizations are carried out based on the allochroism on the surface of FRP and on the characteristic of appearance such as punctate, powdery, dust-like, patch-like and so forth. The appearance changes were also observed by using digital microscope (Figure 2, YDZ-3F, Yashima Optical Co.). A very small amount of sample was picked up using a knife at the part where changes of appearance seem to be biological. The sample was spread to a slide glass and then observed by using biological microscope.
Figure 1. Average temperatures in each month at Tsukuba and Rikubetsu exposure sites

Table 1 Constituions of FRP

<table>
<thead>
<tr>
<th>Code</th>
<th>Type of material</th>
<th>Fiber</th>
<th>Matrix</th>
<th>Surface coating</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hand lay-up GFRP</td>
<td>E-glass</td>
<td>Unsaturated polyester resin</td>
<td>Gel coat</td>
</tr>
<tr>
<td>7A, 7B</td>
<td>Pultruded GFRP</td>
<td>E-glass</td>
<td>Vinylester resin</td>
<td>Acrylic urethane resin</td>
</tr>
<tr>
<td>8, 4</td>
<td>Pultruded GFRP</td>
<td>E-glass</td>
<td>Vinylester resin</td>
<td>None</td>
</tr>
<tr>
<td>2</td>
<td>Pultruded GFRP</td>
<td>E-glass</td>
<td>Vinylester resin</td>
<td>None</td>
</tr>
<tr>
<td>3A, 3B, 3C</td>
<td>Pultruded GFRP</td>
<td>E-glass</td>
<td>Vinylester resin</td>
<td>None</td>
</tr>
<tr>
<td>6a</td>
<td>Pultruded GFRP</td>
<td>E-glass</td>
<td>Vinylester resin</td>
<td>Fluorine resin</td>
</tr>
</tbody>
</table>

a: No. 6 consists of the same material as that of No. 2, but its surface is coated by fluorine resin top coat.

APPEARANCE CHANGES OBSERVED BY THE NAKED EYE

Table 2 shows the appearance changes on FRP test bridges and FRP specimens probably due to microbe, which were observed by the naked eye at Tsukuba and Rikubetsu exposure sites. The results can be categorized into four configurations: 1) Black punctate allochroism, 2) Black dust-like allochroism, 3) Ginger powdery allochroism, and 4) Bistered punctate allochroism.

1) Black punctate allochroism, which seems that bread molds arise, appeared on No.1, No.7A and No.8 placed at Tsukuba, Rikubetu and Rikubetu, respectively. It is confirmed that if 1) Black punctate allochroism is scrubbed from the surface, it will be peeled off in powder form. 2) Black dust-like allochroism, which means that the surface of specimens is wholly covered with black dust-like substances, appeared on No.2 and No.3A placed at Tsukuba. It was especially observed at the part where blooming of fibers on the surface of No.2 and No.3A was observed. 3) Ginger powdery allochroism, which means that paste-like substances colored with ginger are adhered on the surface of a specimen, appeared on specimen No.6. It was observed on the wall of the main tower of FRP cable-stayed bridge. Finally, 4) Bistered powdery allochroism, which means that powdery substances colored with bister are adhered on the surface of a specimen, appeared on No.3B that was placed at the opposite side of No.3A. The surface where 4) Bistered powdery allochroism is observed has the following conditions: the amounts of sun light and of detaching of resins on the surface of No.3B are lower than the ones found at No.3A. Meanwhile, since No.3C was not observed by the naked eye, it is not categorized into the four configurations. However, No.3C is observed at the same portion of No.3A, and it seems that No.3C is white spherical fouling which is partially observed at No.3A by digital microscope. Also, it is thought that No.4 and No.7B are kinds of moss, and therefore they are not categorized into the four configurations.

APPEARANCE CHANGE OBSERVED BY MICROSCOPES

Observation by Digital Microscope

Figure 3 shows the results of observation by digital microscope on No.1, No.7A and No.8 which indicate 1) Black punctate allochroism. As a result, No.1 and No.7A seem to have networks consisting of fungal filaments, while No.8 does not. It is thought that No.1, No.7A and No.8 have different kinds of mold although they have a similar characteristic on observation by the naked eye. Figure 4 shows the results of observation by digital microscope on No.2 and No.3A which indicate 2) Black dust-like allochroism. The black part tangling to exposed glass fibers seems to be adhered on the surface of FRP. No.2 and No.3 have a laver-like and a particle-like appearances, respectively, which look like due to dust. Figure 5 shows the results of observation by digital microscope on 3) Ginger powdery allochroism, and it is confirmed that soil-like particle substances colored with ginger are adhered on its surface.
<table>
<thead>
<tr>
<th>Code</th>
<th>Name</th>
<th>Exposure site</th>
<th>Exposed duration</th>
<th>Visual Characteristic</th>
<th>Assumed reason</th>
<th>Whole picture</th>
<th>Close-up picture</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hand lay-up</td>
<td>Tsukuba</td>
<td>Six years</td>
<td>Black punctate allochroism</td>
<td>Bread mold</td>
<td><img src="image1" alt="Hand lay-up" /></td>
<td><img src="image2" alt="Close-up" /></td>
</tr>
<tr>
<td>7A</td>
<td>Pultruded FRP</td>
<td>Rikubetsu</td>
<td>11 years</td>
<td>Black punctate allochroism</td>
<td>Bread mold</td>
<td><img src="image3" alt="Pultruded FRP" /></td>
<td><img src="image4" alt="Close-up" /></td>
</tr>
<tr>
<td>8</td>
<td>FRP-plate girder bridge</td>
<td>Tsukuba</td>
<td>Five years</td>
<td>Black punctate allochroism</td>
<td>Bread mold</td>
<td><img src="image5" alt="FRP-plate girder bridge" /></td>
<td><img src="image6" alt="Close-up" /></td>
</tr>
<tr>
<td>2</td>
<td>Cable stayed FRP bridge</td>
<td>Tsukuba</td>
<td>16 years</td>
<td>Black dust-like allochroism</td>
<td>Blot</td>
<td><img src="image7" alt="Cable stayed FRP bridge" /></td>
<td><img src="image8" alt="Close-up" /></td>
</tr>
<tr>
<td>3A</td>
<td>Pultruded rectangular pipe</td>
<td>Tsukuba</td>
<td>17 years</td>
<td>Black dust-like allochroism</td>
<td>Blot</td>
<td><img src="image9" alt="Pultruded rectangular pipe" /></td>
<td><img src="image10" alt="Close-up" /></td>
</tr>
<tr>
<td>6</td>
<td>Cable stayed FRP bridge</td>
<td>Tsukuba</td>
<td>16 years</td>
<td>Ginger powdery allochroism</td>
<td>Unsure</td>
<td><img src="image11" alt="Cable stayed FRP bridge" /></td>
<td><img src="image12" alt="Close-up" /></td>
</tr>
<tr>
<td>3B</td>
<td>Pultruded rectangular pipe</td>
<td>Tsukuba</td>
<td>17 years</td>
<td>Bistered punctate allochroism</td>
<td>Material deterio-ration</td>
<td><img src="image13" alt="Pultruded rectangular pipe" /></td>
<td><img src="image14" alt="Close-up" /></td>
</tr>
<tr>
<td>3C</td>
<td>Pultruded rectangular pipe</td>
<td>Tsukuba</td>
<td>17 years</td>
<td>Black punctate allochroism (found by microscope)</td>
<td>Unsure (mold)</td>
<td><img src="image15" alt="Pultruded rectangular pipe" /></td>
<td><img src="image16" alt="Close-up" /></td>
</tr>
<tr>
<td>4</td>
<td>Pultruded I-shaped beam</td>
<td>Tsukuba</td>
<td>Five years</td>
<td>White patch-like allochroism</td>
<td>A kind of moss</td>
<td><img src="image17" alt="Pultruded I-shaped beam" /></td>
<td><img src="image18" alt="Close-up" /></td>
</tr>
<tr>
<td>7B</td>
<td>FRP pultruded specimen</td>
<td>Rikubetsu</td>
<td>11 years</td>
<td>White fouling</td>
<td>A kind of moss</td>
<td><img src="image19" alt="FRP pultruded specimen" /></td>
<td><img src="image20" alt="Close-up" /></td>
</tr>
</tbody>
</table>
Figure 6 shows the results of observation by digital camera and by digital microscope on 4) Bistered punctate allochroism. In the part where 4) Bistered punctate allochroism appears, falling of resins is not dominant, and exposure of fibers cannot be found. A random patch pattern of bistered points is observed by digital camera and by digital microscope, which does not show a special structure. It is thought that resin shown in 4) Bistered punctate allochroism was deteriorated since part of resin has a crack (the arrow in Figure 5), namely these appearance changes cannot be due to mold.

Figure 7 shows results of observation by digital microscope on white spherical allochroism which was found during observing No.3A. The white part tangling to exposed glass fibers seems to be adhered on the surface of FRP. White spherical allochroism seems to be a mold spore, but it also seems that dust is adhered on its surface.

**Observation by Biological Microscope**

Figure 8 shows the pictures by biological microscope on 1) Black punctate allochroism of No.1, No.7A and No.8. Especially in No.1, continuous black spherical spores are observed. According to a reference (Takashima 2002), the kind of mold in No.1 seems to be aspergillus niger, but in order to understand the identity accurately, a cultivation test is needed. Although No.7A and No.8 show a similar characteristic to that in No.1, they have green spherical spores that are not observed in No.1. The green spherical spores are also observed in No.6 that is shown in the previous section, but since No.1 and No.6 have clearly different appearances by digital microscope, further investigations concerning observation problems such as contamination are required.

Figure 9 shows pictures by biological microscope on 2) Black dust-like allochroism of No.2 and No.3. Although observation by digital microscope exhibited that No.2 and No3 seem not to be biological, observation by biological microscope can explain that spherical substances are adhered to fibers and that No.2 and No.3 seem to be biological such as a kind of mold or alga. In addition, the part colored with green can be partially confirmed in No.2 and No.3.

Figure 10 shows a picture by biological microscope on 2) Black dust-like allochroism of No.6. As a result, continuous spherical spores are observed, and they can be identified to a kind of mold, but a cultivation test is required and planned to understand the identity accurately. Meanwhile, in 4) Bistered punctate allochroism of No3B, sample for biological observation was not taken because it was far more difficult to obtain the sample from the surface than the other cases.
Figure 5. Pictures of 3) Ginger powdery allochroism

Figure 6. Pictures of 4) Bistered punctate allochroism.

Figure 7. Pictures of White spherical allochroism by digital microscope

Figure 8. Pictures of 1) Black punctate allochroism by biological microscope

Figure 9. Pictures of 2) Black dust-like allochroism by biological microscope

Figure 10. Picture of 3) Ginger powdery allochroism in No.6 by biological microscope
Appearance Changes Except for Due to Mold

No.4 and No.7B can be identified to a kind of moss, and Figure 11 shows the examples of moss which was well observed not only on FRP but also on concrete placed at the exposure sites.

Discussions and Future Plans

The observation results showed that appearance changes due to mold could happen on the surface of structural FRP; however, since the conditions of forming molds depend highly on the outdoor environment such as temperature, humidity, height from the ground and the orientation of setup, further study on the influence of the outdoor environment is necessary.

Cultivation tests including genetic test are planned to accurately categorize the appearance changes observed at the exposure tests. In terms of safety for structural use, it is also important to examine the influence of mold on the mechanical properties of FRP such as elastic modulus and strengths.

CONCLUSIONS

This study clarified that the appearance changes on the surface of structural FRP, which seem to be caused by mold, could happen when exposed to the outdoor environment for a long term. In the exposure tests, the appearance changes can be categorized into four configurations: 1) Black punctate allochroism, 2) Black dust-like allochroism, 3) Ginger powdery allochroism, 4) Bistered punctate allochroism.

In observation by digital microscope, it is thought that 1) Black punctate allochroism is due to mold and that 4) Bistered punctate allochroism is not due to mold, while 2) Black dust-like allochroism and 3) Ginger powdery allochroism cannot be identified in observation by digital microscope. In addition, observation by digital microscope showed that 2) Black dust-like allochroism has white spherical substances which were not found in observation by the naked eye.

In the case of observation by biological microscope, it is concluded that 2) Black dust-like allochroism and 3) Ginger powdery allochroism seemed to appear due to mold.

Further discussions on the influence of the outdoor environment to the appearance changes are necessary to understand the mechanism of forming molds on the surface of FRP. Also, cultivation tests including genetic test are needed and planned to fully categorize the appearance changes observed at the exposure tests.

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REFERENCES


