Comparative study on the surface treatment for marine structure rehabilitation with glass Fiber-Reinforced high strength Self-Compacting mortar

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Abstract: Rehabilitation method plays an important role in maintenance process of the structure in general and the marine structure in particular. This paper aims to present a comparative study on the surface treatment for marine structure rehabilitation with glass fiber-reinforced high strength self-compacting mortar or SCM. Three types of rehabilitation methods in terms of surface treatment are as-cast surface, surface prepared with steel brush and surface with hole-connector. The experimental results showed that flexural strength of rehabilitated beam with as-cast surface, surface prepared with steel brush, and surface with hole-connector has improved 22%, 31% and 4% respectively higher than that of non-rehabilitated one. The precracked rehabilitated beams had load-carry capacity, for the case of as-cast surface, surface prepared with steel brush, and surface with hole-connector, their flexural strength were 41%, 37% and 31% respectively that of the corresponding non-precracked beams. Visual observation of the non-rehabilitated and rehabilitated beam cross-section after the third-point bending test revealed that their failure mode was similar. Besides, regarding the rehabilitated beams, there is no crack between conventional concrete and SCM.
Keywords: Rehabilitation, surface treatment, marine structure, high strength self-compacting mortar.

1. Introduction

Nowadays, with the great progress of science and engineering in general, material science and technology are also gaining important achievements. These achievements are making important developments to create many types of materials with superiority applied in all areas of life. One of these important materials that must be mentioned is concrete (Aitcin, 1998). In the construction engineering industry, concrete plays an important role and is used with large amount in construction works, especially marine structures (Bentur & Mindess, 1990). Since the 1990s, Mehta has stated that "The 21st century will be known as the century of concrete in marine environments" (Mehta, 1990). This judgment has attracted the attention of many research experts in the field of materials as well as countries bordering the sea including Vietnam (Cao, 1999).

Due to working in the marine environment, which has strong corrosive agents and is affected by a combination of many factors, marine constructions are often much lower in durability and actual life than those in the river. The lifetime and quality of these buildings depend on the durability of the concrete structures or the quality of the concrete used. With the application of scientific and technical advances into the concrete fabrication technology, it allows us to produce high quality, reinforced concrete and fiber reinforced concrete structures with long lifetime (Hoang, 2011; Nguyen, 2016).

When the concrete structure exposed to the marine environment, steel fiber inclusion might be suffered from corrosion. Thus, glass fiber seems to be an effective option (Ngo, 2020). With the aim to attempt to rehabilitate marine

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structure, this paper intends to present in detail the rehabilitation work of structural element by using glass fiber-reinforced high strength self-compacting mortar (SCM). Several rehabilitation methods in terms of surface treatment such as as-cast surface, surface prepared with steel brush and surface with hole-connector will be presented in details. The outcome would serve for further investigation on the application of this SCM not only for the rehabilitation of marine structure, but also for producing other innovative structure for coastal protection in Vietnam.

2. Specimen preparation and experimental program

2.1. Material used

Materials used in this study are following: Ordinary Portland cement OPC40, silica fume, natural sand from Lo River- Phu Tho Province, and manufactured sand and crushed stone from Kien Khe - Ha Nam Province.

Besides, alkali resistant glass fiber conforming to ASTM C1666 was used for SCM mix. Superplasticizer was a high-range water reducer admixture, which is a third generation polycarboxylate superplasticizer with a commercial brand VMAT-PC01. Lastly, water used for the proportion mix was tap water at Hanoi area.

Details of the material used in this study in term of physical and mechanical characteristic of cement and silica fume, sieve analysis and characteristic of coarse and fine aggregates, as well as characteristic of glass fiber, superplasticizer, and water can be found in the previous publication (Nguyen, 2020).

2.2. Mix proportion of conventional concrete and SCM

In this study, two types of concrete mix proportion were designed. The first one was conventional concrete of strength class 30 MPa. This type of concrete was used for preparation of the reference structure or in practice existing structure that needs to be rehabilitated. While, the second is SCM mix of strength class 60 MPa used for rehabilitating the marine structure. Some "trial-and-error" were involved to adjust the dosage of water and superplasticizer content. Eventually, the mix proportion and properties of conventional concrete and SCM used in this study were obtained and they can be found in details in Refs (Ngo, 2000; Nguyen, 2020).

2.3. Rehabilitation method

Three rehabilitation methods in terms of surface treatment including as-cast surface, surface prepared with steel brush and surface with hole-connector are involved in this study. The as-cast surface, as shown in Figure 1, implies that the surface is left untreated as original upon casting SCM for rehabilitation procedure.

Figure 1. As-cast surface

The second method is to make the surface smoother by using a steel brush, as shown in Figure 2. The steel brush seems to remove 1-2 mm depth of mortar on the surface of the structure that needs to be rehabilitated.

a) Grinding with steel brush

b) After surface treatment

Figure 2. Surface prepared with steel brush

On the other hand, the surface with hole-connector, as a name, presents a series of holes, which are obtained by using a drill, as shown in Figure 3. The hole has 5 mm diameter and 5 mm depth. The distance from one to another is 50 mm and to the edge is 25 mm. The holes make the SCM seems to penetrate into the structure needs to be rehabilitated, which in turn results in a good connection one to another.

a) Making a series of holes by using a drill

b) After surface treatment

Figure 3. Surface with hole-connector

2.4. Rehabilitation procedure

In this study, the author takes a beam element as a simple example of rehabilitation for marine structure. The beam that needs to be rehabilitated has a dimension of 400 mm length, 100 mm width and 70 mm height. Apart from the uncracked beams, several beams have been precracked, as shown in Figure 4, to simulate the case that the structure had been damaged before, which in turn it needs to be rehabilitated for the improvement of life service.

Once there are available the beams that need to be rehabilitated and they are all settled into the moulds, the rehabilitation procedure starts with SCM preparation, as shown in Figure 5. SCM is then poured on the top surface of the beam that needs to be rehabilitated (400x100x70 mm^3) to make a new one with a dimension of 400x100x100 mm^3, as can be observed in Figure 6. Besides, for the comparative study, the reference beam made of conventional concrete still has a dimension of 400 mm length, 100 mm width and 100 mm height.

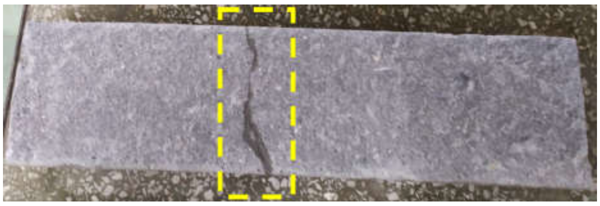

Figure 4. Precracked beam

When the rehabilitation procedure finished, all of the beams that have been rehabilitated were kept in the laboratory for 24 hours, then they were removed from the molds and cured under the standard condition (T=20±2°C; W>95%) in the curing chamber up to the testing date. While the reference beam was kept in the laboratory up to the testing date at the same age as the rehabilitated one.

Figure 5. SCM preparation

2.5. Experimental program

After the rehabilitation procedure 28 days, the reference and rehabilitated beams were subjected to bending test to define flexural strength, as illustrated in Figure 7. The third-point bending test is used with a span length of 300 mm and the distance between load application points is 100 mm.

Figure 6. SCM casting for rehabilitation

In fact, in the practical rehabilitation, SCM can be applied on the top or at the bottom, wherever it is needed, of the beam in operation. However, when the beam is on the bending test, there is a sagging and hogging moment in the beam, the bottom layer is under tension and the top layer is under compression. Since SCM works well on tension much better than conventional concrete due to the addition of fiber, thus the rehabilitated beam was placed to bending test so that the SCM layer was at the bottom to improve the efficient use of costly SCM.

3. Results and discussion

3.1. Performance of rehabilitated beams

Table 1 provides a detailed result of non-rehabilitated and rehabilitated beams of the same size (100x100x400 mm^3) under third-point bending test. The non-rehabilitated beam consists of entirely conventional concrete. While, the rehabilitated beams with three different surface treatments (as-cast surface, surface prepared with steel brush, and surface with hole-connector) contain a 30 mm SCM layer at the bottom apart from conventional concrete on the top.

Figure 7. Third-point bending test

Table 1. Performance of non-rehabilitated and rehabilitated beams under third-point bending

Beam	Flexural strength at 28 days
	MPa
Non-rehabilitated	3.15
	2.93
	3.06
Rehabilitated by the as-cast surface	3.75
	3.77
	3.63
	1.49*
	1.53*
Rehabilitated by the surface prepared with steel brush	3.96
	4.05
	4.01
	1.57*
	1.42*
Rehabilitated by the surface with hole-connector	3.23
	3.11
	3.17
	0.93*
	1.01*

(*) Precracked beam before rehabilitation

Figure 8 shows an average result of flexural strength of the non-rehabilitated and rehabilitated beams under third-point bending test. It is observed that flexural strength of rehabilitated beam with as-cast surface, surface prepared with steel brush, and surface with hole-connector has improved 22%, 31% and 4% respectively higher than that of non-rehabilitated one.

Among the rehabilitated beams, it can be seen that the one of surface prepared with steel brush has yielded the highest result, which is 8% and 26% higher than that of as-cast surface and surface with hole-connector respectively.

Regarding the precracked rehabilitated beams, if there was no rehabilitation process, the precracked beams would not rather carry more load due to mainly the brittleness of concrete material (Neville, 2002). Looking into Figure 8, these beams sustained more load, for the case of as-cast surface, surface prepared with steel brush, and surface with hole-connector, their flexural strength were 41%, 37% and 31% respectively that of the corresponding uncracked beam. This remarkable outcome indicates the significant role of SCM in the rehabilitation. Among the precracked rehabilitated beams, flexural strength of the one of as-cast surface and surface prepared with steel brush was similar and they were 50% higher than that of the one of surface with hole-connector.

3.2. Failure mode

Visual observation on the non-rehabilitated and rehabilitated beam cross-section after the third-point bending test, as shown in Figure 9, depicts the next two points. Firstly, the failure mode of the non-rehabilitated and rehabilitated beam was similar, as it is seen that the main crack was developed up to failure in the middle third of the beam, where it receives the maximum bending moment. Secondly, regarding the rehabilitated beams, there is no crack between conventional concrete and SCM, even though there was a cold-joint, as SCM was cast onto the conventional concrete when it had hardened before. In case of precracked beam before rehabilitation, the rehabilitated beam failed at the same crack that has been appeared previously.

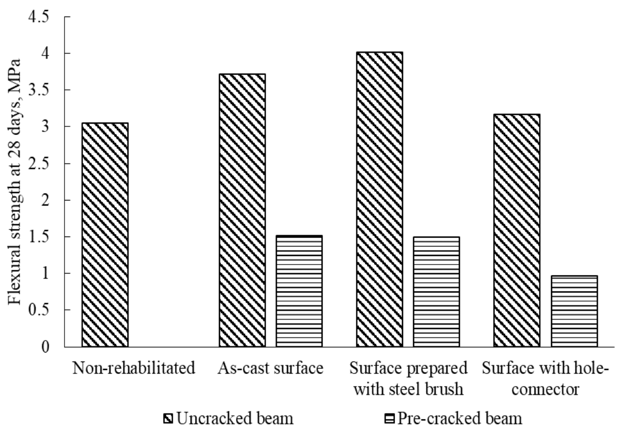

Figure 8. Average result of flexural strength of non-rehabilitated and rehabilitated beams under third-point bending

It is remarkable to note that in case of the rehabilitated beams of surface with hole-connector, there was a slight delamination between conventional concrete and SCM at the location amid adjacent holes, as it can be seen in Figure 9d. The main reason might be due to the distance between the holes was too short and the drilling process has caused microcrack at the bottom of the hole. Besides, the hole diameter of 5mm seemed to be small, SCM could barely have penetrated into the substrate conventional concrete. This is an explanation for why the outcome of this rehabilitation method yielded the worst result in comparison with the other two methods.

a) Non-rehabilitated beam

b) Beam rehabilitated by the as-cast surface

c) Beam rehabilitated by the surface prepared with steel brush

d) Beam rehabilitated by the surface with hole-connector

Figure 9. Failure modes after the third-point bending test

4. Conclusion

A comparative study on the surface treatment for marine structure rehabilitation with glass fiber-reinforced high strength self-compacting mortar was carried out in this paper. Three types of rehabilitation methods in terms of surface treatment are as-cast surface, surface prepared with steel brush and surface with hole-connector. The beam that needs to be rehabilitated was cast with conventional concrete of 30MPa, while glass fiber-reinforced high strength self-compacting mortar (SCM) was with 60MPa. The third-point bending test has been used for the evaluation of rehabilitating effectiveness.

The experimental results showed that flexural strength of rehabilitated beam with as-cast surface, surface prepared with steel brush, and surface with hole-connector has improved 22%, 31% and 4% respectively higher than that of non-rehabilitated one. Among the rehabilatated beams, it can be seen that the one of surface prepared with steel brush has yielded the highest result, which is 8% and 26% higher than that of as-cast surface and surface with hole-connector respectively.

The precracked rehabilitated beams had load-carrying capacity, for the case of as-cast surface, surface prepared with steel brush, and surface with hole-connector, their flexural strength were 41%, 37% and 31% respectively that of the corresponding non-precracked beams. Thank to

SCM, the precracked beams still sustained a certain sagging and hogging moment after rehabilitation.

Visual observation on the non-rehabilitated and rehabilitated beam cross-section after the third-point bending test revealed that their failure mode was similar, as it is seen that the main crack was developed up to failure in the middle third of the beam, where it receives the maximum bending moment. Besides, regarding the rehabilitated beams, there is no crack between conventional concrete and SCM, even though there was a cold-joint, as SCM was cast onto the conventional concrete when it had hardened before. In case of precracked beam before rehabilitation, the rehabilitated beam failed at the same crack that has been appeared previously.

Last but not least, the outcomes of this study are fruitful for further study on the application of SCM for other structures for coastal protection in Vietnam.

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