APPLICATION OF GLASS FIBRE-REINFORCED HIGH STRENGTH SELF-COMPACTING MORTAR FOR REHABILITATING MARINE STRUCTURES

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Abstract: *Maintenance and rehabilitation of marine structure is currently indispensable in Vietnam to prolong the service life instead of re-building with a very high cost that cannot be done in the short term. This paper focuses on the rehabilitation work of a beam structure by using glass fiber-reinforced high strength self-compacting mortar or SCM. The process was carried out by simply pouring the fresh SCM onto the surface of the beam that needs to be rehabilitated. The third-point bending test has been used for the evaluation of rehabilitating effectiveness. The experimental results showed that the flexural strength of the rehabilitated beam with SCM application has improved 22% higher than that of the non-rehabilitated ones. In case of the rehabilitated beams that have cracked before, they still sustained a certain sagging and hogging moment after rehabilitation. Visual observation on the cross-section of the rehabilitated beam after the third-point bending test indicated that there was no delamination or crack between layers of SCM and existing structure.*

Keywords: Rehabilitation**,** marine structure**,** alkali-resistant glass fiber, high strength self-compacting mortar

1. INTRODUCTION

Vietnam is located on the eastern margin of the Indochinese peninsula and occupies about 331,211.6 square kilometers. With a coastline of more than 3,400 km, Vietnam is the 32nd largest country in the world out of 156 coastal countries. On the one hand, the sea brings to Vietnam many positive spiritual, as well as economic values, on the other hand, it has also devastated immensely thousands of construction works and houses close by the sea and left immeasurable consequences. Therefore, the demand on building breakwater structures and coastal protection works is very necessary and has increased over the years. These construction works can help the country to counteract negative impacts from the sea, prevent floods and storms and, make a very important contribution to the socio-economic development strategy of coastal communes. The main materials used for these marine construction works are concrete and reinforced concrete (Cao, 1999).

Generally speaking, concrete and reinforced concrete structures working in the marine environment are often subjected to intense destructive effects caused by water ingress and harmful components in the water as well as other mechanical and physical impacts, therefore they are much less durable than river works. In such a harsh environment and erratic changes in climate in recent years, the life expectancy of many marine structures was much lower than the original design (Nguyen, 2016). Detrimental defects like cracking (surface pitting, eroded concrete, peeling the protective layer of reinforcement, etc.) have appeared at the very early-age (Hoang, 2011). The generation of such failures not only affects the bearing capacity of the structure but also provides an opportunity for water and harmful components to easily penetrate deeply into the structure, causing erosion, thereby breaking the bonds and damaging structures, eventually the

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whole work is damaged. Therefore, it is very necessary to maintain and repair these works to prolong the service life instead of re-building with a very high cost that cannot be done in the short term (Nguyen & Nguyen, 2020).

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 the marine structure, this paper intends to present in detail the rehabilitation work of structural elements by using glass fiber-reinforced high strength self-compacting mortar (SCM). The outcome would serve for further investigation on the application of this SCM not only for the rehabilitation of the marine structure but also for producing other innovative structures for coastal protection in Vietnam.

2. SPECIMEN PREPARATION AND EXPERIMENTAL PROGRAM

In this study, the author takes a beam element as a simple example of rehabilitation for marine structure. Thus, in order to have a comparative study, two types of beam are supposed to be prepared; one is a reference without rehabilitation and the other is the rehabilitated one by using SCM.

2.1. Material used

Ordinary Portland cement OPC40 with commercial band Hoang Thach, which is conforming to the Vietnamese standard TCVN 2682:2009, is used in this study. The physical and mechanical characteristics of cement are given in Table 1.

Table 1. Physical and mechanical characteristic of cement

Parameters	Units	Test results
Specific density	g/cm^3	3.13
Bulk density	g/cm^3	1.31
Blaine fineness	cm^2/g	3730
Consistency	%	28.5
Initial setting time	min.	150
Final setting time	min.	230
Soundness of cement	mm	1.0
3 days compressive strength	N/mm^2	26.1
28 days compressive strength	N/mm^2	47.6

Silica fume with commercial brand Elkem Microsilica® 940, which is conforming to the Vietnamese standard TCVN 8827:2011, is used as supplementary cementitious material in combination with cement in SCM. The physical and chemical characteristics of silica fume are included in Table 2.

Table 2. Physical and chemical characteristic of silica fume

Parameters	Units	Test results
Specific density	g/cm^3	2.1
Bulk density	g/cm^3	0.93
Loss on ignition	%	4.2
Content of SiO_2	%	93.5
Content of Al_2O_3	%	0.92
Content of Fe_2O_3	%	0.52
Content of SO_3	%	0.63
Content of CaO	%	1.57

Natural sand from Lo River- Phu Tho Province, manufactured sand, and crushed stone from Kien Khe - Ha Nam Province were used as fine and coarse aggregates for conventional concrete and SCM mixes. Characteristic of fine and coarse aggregates conforming TCVN 7570:2006 is provided in Table 3. Besides, in order to obtain grading of aggregates, sieve analysis was also carried, the results are shown in Table 4.

Table 3. Characteristic of coarse and fine aggregates

Parameters	Stone	Natural sand	Manufactured sand
Specific density, g/cm^3	2.71	2.64	2.7

Parameters	Stone	Natural sand	Manufactured sand
Bulk density, g/cm^3	1.48	1.55	1.65
Water absorption, %	0.9	1.5	1.9
Clay, silt and dust content,%	1.5	0.96	1.5
Fineness modulus	-	2.34	3.01

Table 4. Gradation of aggregates by sieve analysis

Sieve size	Crushed stone	Stone dust	Sand
	Cumulative % retained		
70	0.0		
40	2.9		
20	49.5		
10	80.3		
5	98.0	0.0	0.0
2.5		19.5	9.5
1.25		37.8	21.8
0.63		61.6	36.6
0.315		84.2	71.2
0.14		98.4	95.4
Pan	100	100	100

Alkali resistant glass fiber conforming to ASTM C1666 was used for SCM mix. The fiber length of 17 mm was involved. The characteristic of alkali-resistant glass fiber is provided in Table 5.

Table 5. Characteristic of glass fiber

Glass fiber conforming to ASTM C1666	Units	Value
Content of ZrO_2	%	18.5
Specific density	g/cm^3	2.5
Tensile strength	MPa	1700

Superplasticizer used in this study 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. Characteristic of superplasticizer and water is shown in Table 6.

Table 6. Characteristic of superplasticizer and water

Parameter	Superplasticizer	Water
Specific density, g/cm^3	1.075 ÷1.095	1
pH value	4 ÷ 6	7

2.2. Mix proportion of conventional concrete and SCM

In order to prepare a reference beam element or the structure needs to be rehabilitated, conventional concrete of strength class 30MPa was chosen to be proportioned. The mix design of this concrete was carried out by using the Bolomay-Skramtaep method. Water content was adjusted by mean of the slump test, as shown in Figure 1, and the final mix proportion is provided in Table 7.

Figure 1. Slump-flow test on SCM mixture at fresh state

Regarding the SCM mix used for rehabilitating the marine structure, the strength class of 60 MPa at the age of 28 days is designed. Since there is no particular standard or guideline on mix design of SCM with glass fiber, the author has followed the mix design recommendation of self-compacting concrete (SCC) developed by Professor Okamura, who was considered as the first person introduced SCC to the scientific society (Okamura & Ouchi, 2003).

Besides, several guidelines on SCC from EFNARC have been taken into consideration (EFNARC, 2002, 2006). The detailed steps for mix design are described elsewhere in (Ngo, 2020). Some "trial-and-error" were involved to justify the slump flow of 20cm conforming to the standard TCVN 9204:2012, as shown in Figure 2, for the mix proportion of SCM with glass fiber. Eventually, the SCM mix used in this study can be seen in Table 8.

Table 7. Mix proportion of conventional concrete strength class 30MPa

Mix	OPC40	Crushed stone	Natural sand	Water	Slump
	kg	kg	kg	l	cm
	377	1180	653	185	6

Table 8. Mix proportion of SCM strength class 60MPa

Mix	OPC40	Silica fume	Manufactured sand	Superplasticizer	Water	Glass fiber	Slump flow
	kg	kg	kg	l	l	% volume	cm
	450	45	1705	5.0	195	0.1	20

Figure 2. Slump-flow test on SCM mixture

2.3. Specimen preparation

After a relevant mixing procedure, conventional concrete and SCM mixtures were placed into cubic moulds (150x150x150 mm^3) to determine compressive strength at 7, 28, and 56 days. For the further experimental plan, fifteen prism specimens (100x100x400 mm^3) of conventional concrete (9) and of SCM (6) were prepared for the determination of flexural strength at different ages. Besides, the other five prism specimens (70x100x400 mm^3) of 70 mm height with conventional concrete were cast and would be served for the rehabilitation subsequently. Moreover, SCM mixture was poured directly into several cubic moulds of 70.7x70.7x70.7 mm^3 and cylindrical moulds of 150 mm diameter and 150 mm height for determination of abrasion resistance and waterproof grade at hardened state.

Figure 3. Conventional concrete prism specimen after standard curing

Since the concrete is conventional, it needs to vibrate during the placement into the mould.

After casting, the specimens were kept in the laboratory for 24 hours, then they were removed from the moulds and cured under the standard condition (T=20±2^{o}C; W>95%) in the curing chamber up to the testing date, as shown in Figure 3.

2.4. Rehabilitation method

At the age of 28 days, the five prism specimens (70x100x400 mm^3) of conventional concrete were taken out of the curing chamber, and two of them were subjected to third-point bending up to failure. Afterward, all of them were placed again into the metallic moulds of 100x100x400 mm^3, and fresh SCM was poured directly onto the beam surface without any rehabilitation treatment, as shown in Figure 4. The SCM filled fully the mould, which means SCM thickness is 30 mm. These specimens were left in the moulds for 24h, then they were removed from the moulds and placed into the curing chamber up to the testing date.

Figure 4. Pouring SCM onto conventional concrete beam surface to rehabilitate

2.5. Experimental program

Apart from the compression test, abrasion test, waterproof test for the determination of hardened properties, the third-point bending test was the main one used for the analysis of rehabilitation effect. After SCM application 28 days, the rehabilitated beams were subjected to a bending test to define flexural strength, as illustrated in Figure 5. 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 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.

Figure 5. Rehabilitated beam subject to third-point bending test

3. RESULTS AND DISCUSSION

3.1. Hardened properties of conventional concrete and SCM

The compression and flexural strength of conventional concrete at different ages are provided in Table 9. It is seen that this concrete achieves a strength class of 30MPa properly as designed. In general, the compression and flexural strength of this concrete at 7 days are about 71% and 72% respectively that at 28 days. Besides, the strength at 56 days is quite similar to that at 28 days. It implies that after 28 days the strength hardly increases.

On the other hand, hardened properties of SCM can be found in Table 10. SCM also reaches a strength class of 60MPa as expected. It is important to note that in comparison with compression and flexural strength of conventional concrete, that of SCM are almost two-fold. Moreover, waterproof grade and abrasion resistance of SCM, as shown in Table 10, implythat this is anti-corrosive material, which can be used effectively in the marine environment in compliance with TCVN 9139:2012 "Hydraulic Structures - Concrete and reinforced concrete Structures in coastal areas - Technical Specifications".

Table 9. Hardened properties of conventional concrete

Compressive strength			Flexural strength		
7 days	28 days	56 days	7 days	28 days	56 days
MPa	MPa	MPa	MPa	MPa	MPa
22.5	31.6	32.5	2.21	3.06	3.09

Table 10. Hardened properties of SCM

Compressive strength		Flexural strength		Waterproof grade	Abrasion resistance
7 days	28 days	7 days	28 days		
MPa	MPa	MPa	MPa		g/cm^2
48.4	64.5	5.42	7.11	W12	0.172

3.2. Performance of rehabilitated beams

Table 11 provides a detailed result of non-rehabilitated and rehabilitated beams of the same size (100x100x400 mm^3) under the bending test. As mentioned above, the non-rehabilitated beam consists of conventional concrete, while the rehabilitated contains a 30 mm SCM layer at the bottom apart from conventional concrete. As a result, the flexural strength of non-rehabilitated beam at 28 days is elsewhere presented in Table 9, because the beam and the prism specimen have the same size and curing time.

Table 11. 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	3.75
	3.77
	3.63
	1.49*
	1.53*

(*) cracked beam before rehabilitation

Figure 6 shows an average result of flexural strength of non-rehabilitated and rehabilitated beams under third-point bending. It is observed that flexural strength of rehabilitated beam with SCM application has improved 22% higher than that of non-rehabilitated one.

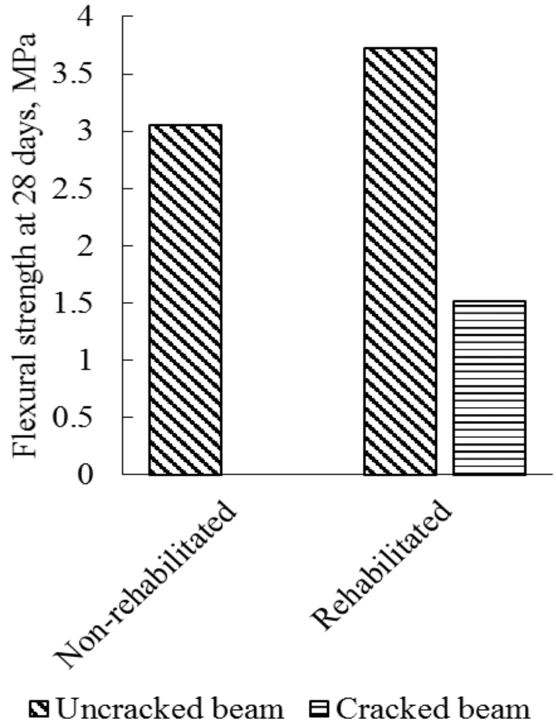

Figure 6. Average result of flexural strength of non-rehabilitated and rehabilitated beams under third-point bending

Visual observation on rehabilitated beam cross-section after the third-point bending test, as shown in Figure 7, depicts that there is no delamination or crack between conventional concrete and SCM, even though there was a cold-joint, as SCM was cast onto the conventional concrete when it has hardened. Yet, there is no difference between cross-sections of rehabilitated and non-rehabilitated beam, as shown in Figure 8, in terms of failure mode. In case of a cracked beam before rehabilitation, the rehabilitated beam failed at the same crack that has been appeared previously.

Figure 7. Rehabilitated beam cross-section after third-point bending test

Figure 8. Non-rehabilitated beam cross-section after third-point bending test

Moreover, Table 11 and Figure 6 also reveal the results of the flexural strength of rehabilitated beam, which has been cracked or broken into pieces before rehabilitation due to concrete brittleness (Neville, 2002). It is noteworthy that after rehabilitation this broken beam still has carried more load. This proves the efficiency of SCM application for the rehabilitation, even in a severe case of crack appearance in the marine structure.

4. CONCLUSION

The rehabilitation work of a simple beam structure was carried out in this paper. The rehabilitation was performed by simply pouring the fresh glass fiber-reinforced high strength self-compacting mortar or SCM onto the surface of the beam that needs to be rehabilitated. SCM of strength class 60 MPa was chosen to design, while the existing structure was prepared with conventional concrete of strength class 30 MPa. The third-point bending test has been used for the evaluation of rehabilitating effectiveness.

The experimental results showed that the flexural strength of rehabilitated beam with SCM application has improved 22% higher than that of non-rehabilitated one. In case of the rehabilitated beams that have cracked before, they still sustained a certain sagging and hogging moment after rehabilitation.

Visual observation on the cross-section of the rehabilitated beam after the third-point bending test indicated that there was no delamination or crack between layers of SCM and conventional concrete of existing structure. In case of cracked 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 useful for further study on the application of SCM for not only the rehabilitation of hydraulic structure in general and marine structure in particular, but also for producing other precast structure for coastal protection in Vietnam.

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REFERENCES

Cao D.T. et al. (1999). *Proceeding of Conference on Anti-corrosive measure for concrete and reinforced concrete structure in Vietnam - Challenges and Solutions*, Hanoi (In Vietnamese).

EFNARC. 2002. *Specification & guidelines for self-compacting concrete.* English ed. Norfolk, UK: European Federation for Specialist Construction Chemicals and Concrete Systems.

EFNARC. 2006. *Guidelines for Viscosity Modifying Admixtures for Concrete.* English ed. Norfolk, UK: European Federation for Specialist Construction Chemicals and Concrete Systems.

Hoang V.T. et al. (2011). *Scientific report "Research on high performance concrete used for hydraulic structures under high flow rate".* Ministry of Construction, Vietnam (In Vietnamese).

Neville A.M. (2002). *Concrete Properties 4th edition. Person Education Limited,* Edinburgh.

Ngo, T.L. (2020). *Study on the implement of fine-grain concrete with glass fiber for rehabilitation of marine structure at Giao Thuy - Nam Dinh,* Master Thesis document, Thuyloi University (In Vietnamese).

Nguyen T.T.H. (2016) *Research on solutions to improve the durability of concrete - reinforced concrete of the coastal protection structure of Vietnam*. PhD Document, Thuyloi University.

Nguyen V.D. & Nguyen T.T.H, (2020). *Effect of glass fiber length on the properties of high strength self-Compacting mortar.* Scientific Journal of Thuyloi University No. 69.

Okamura, H. & Ouchi M. (2003). *Self-Compacting Concrete. Journal of Advanced Concrete Technology,* Vol. 1, No.1, p. 5-15.

Tóm tắt:

ỨNG DỤNG VỮA TỰ LÈN CƯỜNG ĐỘ CAO CỐT SỢI THỦY TINH CHO SỬA CHỮA CÁC CÔNG TRÌNH BIỂN

Duy tu và sửa chữa các công trình biển hiện đang rất cần thiết ở Việt Nam nhằm kéo dài tuổi thọ thay vì phải xây mới với chi phí rất cao mà trong ngắn hạn chưa thể đáp ứng được. Bài báo này nghiên cứu việc sửa chữa kết cấu dầm sử dụng vữa tự lèn cường độ cao cốt sợi thủy tinh (SCM). Việc sửa chữa được thực hiện với thao tác đơn giản khi rót vữa tươi lên trên bề mặt cấu kiện hay công trình cần được sửa chữa. Thí nghiệm uốn hai lực tập trung chia ba cách đều được sử dụng để đánh giá việc sửa chữa dầm. Kết quả thí nghiệm cho thấy cường độ uốn của dầm được sửa chữa cao hơn dầm không được sữa chữa là 22%. Đối với dầm đã bị nứt trước vẫn có thể chịu thêm tải trọng sau khi sửa chữa. Ngoài ra, khi nghiên cứu mặt cắt của dầm được sửa chữa sau thí nghiệm uốn, hoàn toàn không phát hiện vết nứt hay sự tách lớp xảy ra giữa lớp SCM và cấu kiện hiện hữu.

Từ khóa: Sửa chữa; Công trình biển; Sợi thủy tinh kháng kiềm; Vữa tự lèn cường độ cao

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