EFFECT OF GLASS FIBER LENGTH ON THE PROPERTIES OF HIGH STRENGTH SELF-COMPACTING MORTAR

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Abstract: *High strength concrete and/or mortar is known as more brittle in comparison with conventional concrete, which in turn limits the application of such material into practical engineering. The brittleness of concrete can be relieved by using dispersed fibers (steel, glass, synthetic, and natural). Thus, in this paper, the authors studied the effect of glass fiber length on the properties of high strength self-compacting mortar at both the fresh and hardened state. The experimental results have shown that the higher glass fiber length, the lower the resultant slump flow of Self-Compacting Mortar (SCM) mixture. At the hardened state, fiber length does not affect the compressive strength of SCM. However, the higher the fiber length was added, the higher the flexural, and the splitting tensile strength could be observed. In terms of durable properties such as waterproof grade and abrasion resistance, fiber length does not influence on these properties. The outcomes of this research are useful for further study on the application of high strength SCM with glass fiber for the rehabilitation of hydraulic structure in general and marine structure in particular.*

Keywords: Self-Compacting Mortar (SCM), alkali-resistant glass fiber, fiber length, fresh and hardened state.

1. INTRODUCTION

Concrete in general is considered as a brittle material, which is characterized by brittle failure or the nearly complete loss of loading capacity, once the crack is initiated (Neville A.M. (2002)). The brittleness, which limits the application of concrete, can be overcome by the addition of a small amount of short randomly distributed fibers (steel, glass, synthetic and natural) and can be practiced among others that remedy weaknesses of concrete, such as low growth resistance, high shrinkage cracking, low durability, etc (Balaguru & Shah, 1992). The introduction of fiber into concrete forms fiber-reinforced concrete. Thus, it is a composite material essentially consisting of conventional concrete or mortar reinforced by fibers.

Literature review revealed that many studies have been carried out to investigate the performance of concrete, in which different types of fiber were included (Bentur & Mindess, 1990, Ferrara et al., 2011, Sahmaran et al., 2015). It has been reported that the inclusion of different fiber types resulted in the increment of concrete toughness, or the ability to resist crack growth. Also, the fibers help to transfer loads at the internal micro-cracks (Torrijos et al., 2010, Nguyen, 2015).

In practice, cracks are catalysts for the change of concrete structures into permeable elements and consequently with a high risk of corrosion. Cracks not only reduce the quality of concrete and make it aesthetically unacceptable but also make structures out of service (Neville, 2002). Therefore, it is important to reduce the crack width and this can be achieved by adding different fibers to concrete

The fibers can be imagined as an aggregate with an extreme deviation in shape from the rounded smooth aggregate (Ferrara et al., 2007, Vairagade & Kene, 2012). The fibers interlock and entangle around aggregate particles and considerably reduce the workability, while the mix becomes more cohesive and less prone to segregation. The fibers are dispersed and distributed randomly in the concrete during mixing and thus improve concrete properties in all directions. Fibers help to improve the post-peak ductility performance, pre-crack tensile strength, fatigue strength, impact strength, and eliminate temperature and shrinkage cracks (Grunewald, 2004, Torrijos et al., 2010).

Essentially, fibers act as crack arresters restricting the development of cracks and thus transforming an inherently brittle matrix, i.e. cement concrete with its low tensile and impact resistances, into a strong composite with superior crack resistance, improved ductility, and

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distinctive post-cracking behavior prior to failure (Nguyen, 2015).

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 explore the role of glass fiber in concrete, this paper intends to study in detail the effect of glass fiber length on Self-Compacting Mortar (SCM) fresh and hardened properties. The outcome would serve for further investigation on the application of this glass-fiber reinforced SCM for the rehabilitation of marine structure.

2. MATERIALS AND METHODS

The constituent materials used for this study are presented as follows:

2.1. Cement and silica fume

Ordinary Portland cement OPC40 with commercial band But Son, 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.

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

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

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

2.2. Fine aggregate

This study promotes the implementation of crushed stone sand as the replacement of costly natural river sand. The sand from Kien Khe - Ha Nam Province has opted for proportioning of SCM.

The characteristics conforming TCVN 7572:2006 are given in Table 3. Besides, in order to obtain grading of aggregates, sieve analysis is also carried out, and the results are provided in Table 4.

Table 3. Characteristic of crushed stone sand

Parameters	Units	Test results
Specific density	g/cm^3	2.67
Bulk density	g/cm^3	1.65
Porosity	%	38.2
Moisture content	%	1.0
Clay, silt and dust content	%	0.5
Fineness modulus	-	2.57

Table 4. Gradation of crushed stone sand by sieve analysis

Sieve size (mm)	Crushed sand
5	0.0
2.5	9.0
1.25	23.5
0.63	46.3
0.315	84.0
0.14	94.5
Pan	100

2.3. Glass fiber

Alkali resistant glass fiber conforming to ASTM C1666 is used in this study. Three types of fiber length such as 9 mm, 13 mm, and 17 mm are involved. The characteristic of alkali-resistant glass fiber is provided in Table 5.

Figure 1. Alkaline resistance glass fibers used in this study

2.4. Superplasticizer and water

Superplasticizer (SP) used in this study is a high-range water reducer admixture, which is a third generation polycarboxylate superplasticizer. Water used for the proportion mix is tap water at Hanoi area. Characteristic of superplasticizer and water is shown in Table 6.

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

Table 6. Characteristic of superplasticizer (SP) and water

Parameter	Units	SP	Water
Specific density	g/cm^3	1,075 ÷1,095	1
pH value	-	4 ÷ 6	7

2.5. Mix proportion of SCM

In this study, the SCM mixture corresponding to the strength class of 50 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 authors have followed 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 in mix proportion of SCM with glass fiber. Eventually, there are three mixes with difference fiber length used in this study as can be seen in Table 7.

Table 7. Mix proportion of SCM

Mix	OPC40	Silica fume	Sand	SP	Water	Slump flow without fiber	Glass fiber	Fiber length
	kg	kg	kg	l	l	cm	% volume	mm
M1	390	39	1775	4.8	195	20	0.4	9
M2	390	39	1775	4.8	195	20	0.4	13
M3	390	39	1775	4.8	195	20	0.4	17

2.6. Specimen preparation

After a relevant mixing procedure, SCM mixtures (M1, M2, and M3) were tested at a fresh state to define slump-flow value in accordance with the standard TCVN 9204:2012, as it is illustrated in Figure 2. Besides, the determination of SCM density at fresh was also carried out. Afterward, three cube specimens (150x150x150 mm^3), three prism specimens (100x100x400 mm^3), and three cylindrical specimens (150 mm diameter and 300 mm height) were prepared to determine compressive strength, flexural strength and splitting tensile strength at 28 days, respectively.

Figure 2. Slump-flow test on SCM mixture at fresh state

Besides, several cube specimens of 70.7x70.7x70.7 mm^3 and cylindrical specimens of 150 mm diameter and 150 mm height were cast for determination of abrasion resistance and waterproof grade at hardened state.

After casting the SCM mixture into the corresponding molds, the specimens were kept in the laboratory for 24 hours, as shown in Figure 3, then they were removed from the molds and cured under the standard condition (T=20±2°C; W>95%) up to the testing date.

Figure 3. Casting of SCM mixture into the prism mold

3. RESULTS AND DISCUSSION

3.1. Properties at fresh state

Slump flow of SCM mixtures M1, M2, and M3 corresponding to the fiber length of 9 mm, 13 mm, and 17 mm respectively is shown in Figure 4. It can be seen that the slump flow of SCM mixtures with fiber is lower than that of mixtures without glass fiber, as shown in Table 7. The main reason is evidently due to the addition of fiber. Fibers created an obstacle that influences significantly on mix flowability resulting in a reduction of slump flow value. Among three mixtures M1, M2 and M3, it can be observed that the slump flow of the two first is quite similar, while the third one is similarly lower. This means that the longer length the fibers were added, the lower the slump flow was obtained.

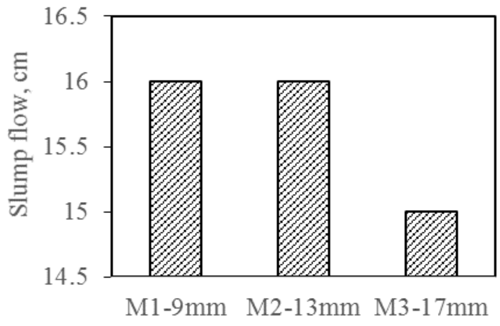

Figure 4. Slump flow value of SCM mixtures

The density of SCM mixtures at fresh state is demonstrated in Figure 5. It shows that the density of those mixtures is about 2.38-2.39 T/m^3, which is slightly lower than the total weight of constituent material in Table 7, this means that air entrainment has involved in the concrete during mixing process.

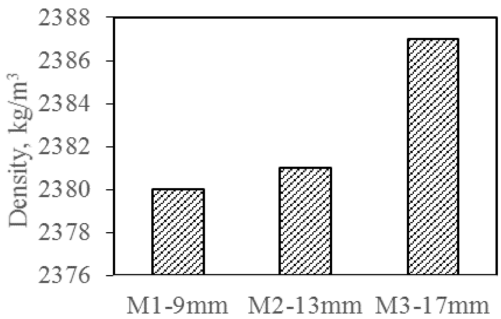

Figure 5. Density at fresh state of SCM mixtures

3.2. Properties at hardened state

Compressive strength of M1, M2, and M3 corresponding to the fiber length of 9 mm, 13 mm, and 17 mm is provided in Figure 6, respectively, strength complies with designed grade of 50MPa and there is no big difference between them. This means that fiber length does not influence on compressive strength at all.

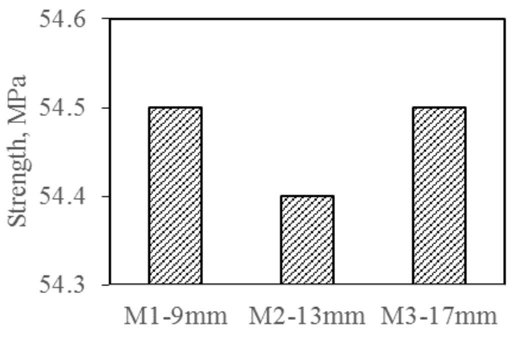

Figure 6. Compressive strength of SCMs

On the other hand, the flexural and the splitting tensile strength are dependent on fiber length as can be seen in the Figure 7 and Figure 8 respectively. Indeed, the higher the fiber length was added, the higher the flexural, and the splitting tensile strength of specimens could be observed. The one with fiber length of 13 mm and 17 mm is 10% and 20% higher than that with fiber length 9 mm. It is remarkable that the addition of glass fiber has brought concrete tougher. During the flexural test the beam has not broken into a piece after crack propagation, even though high strength concrete grade of 50MPa is considered to be quite brittle. With the fiber addition, the brittleness of concrete has been alleviated.

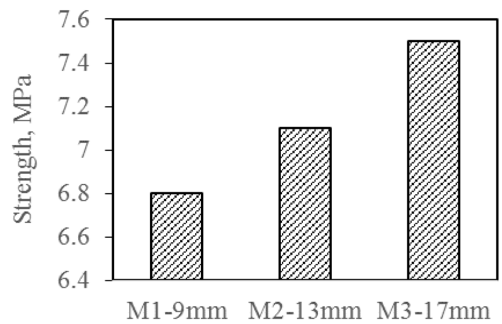

Figure 7. Flexural strength of SCMs

In terms of density of M1, M2, M3 at hardened state, it is in the range of 2357kg/m^3 and 2362 kg/m^3, as shown in Figure 9, which is very slightly lower than that at fresh state. This means that a little of free water has been evaporated during curing process up to testing date at 28 days.

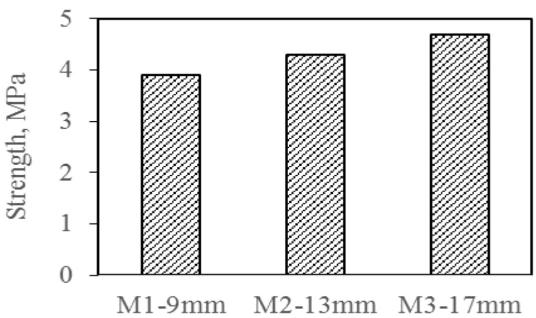

Figure 8. Splitting tensile strength of SCMs

As can be seen from the results in Table 8, there is no difference in terms of waterproof grade and abrasion resistance among M1, M2, and M3, which depicts that fiber length does not affect these characteristics of SCM. All three of them present a waterproof grade of W12, which complies with TCVN 9139:2012 "Hydraulic Structures - Concrete and reinforced concrete Structures in coastal areas - Technical Specifications". This indicates straightforwardly that SCMs M1, M2, and M3 from this study can be used for hydraulic structures in general and marine structures in particular.

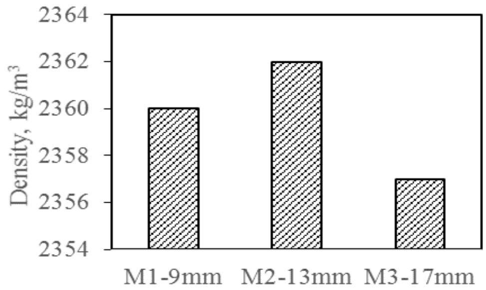

Figure 9. Density at hardened state of SCMs

Table 8. Durable properties of SCM

Properties	M1 (9mm)	M2 (13mm)	M3 (17mm)
Waterproof grade	W12	W12	W12
Abrasion resistance, g/mm^2	17.1	17.1	17.1

4. CONCLUSION

The effect of glass fiber length on properties of high strength self-compacting mortar (SCM) at fresh and hardened state were studied in this paper. Indeed, glass fiber has played a key role in the slump flow of SCM, the higher fiber length, the lower the resultant slump flow. At both fresh and hardened states, the density of SCMs with different fiber lengths was quite similar.

At hardened state, fiber length does not affect the compressive strength of SCM. However, the experimental results showed that the higher fiber length, the higher flexural, and splitting tensile strength. In terms of durable properties such as waterproof grade and abrasion resistance, fiber length does not influence on these properties.

Last but not least, the outcomes of this study are useful for further study on the application of high strength SCM with glass fiber for the rehabilitation of hydraulic structure in general and marine structure in particular.

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Tóm tắt:

ẢNH HƯỞNG CỦA CHIỀU DÀI SỢI THỦY TINH ĐẾN CÁC TÍNH CHẤT CỦA VỮA TỰ LÈN CƯỜNG ĐỘ CAO

Bê tông và/hoặc vữa cường độ cao sẽ trở nên giòn hơn so với loại bê tông thông thường, do đó làm hạn chế khả năng ứng dụng của loại vật liệu này. Độ giòn của bê tông có thể được giảm bớt bằng cách sử dụng các sợi phân tán (thép, thủy tinh, tổng hợp và tự nhiên). Trong bài báo này, các tác giả đã nghiên cứu về ảnh hưởng của chiều dài sợi thủy tinh đến các tính chất của vữa tự đầm cường độ cao ở cả hai trạng thái tươi và đóng rắn. Các kết quả thí nghiệm đã chỉ ra rằng chiều dài sợi thủy tinh càng lớn thì độ sụt của hỗn hợp vữa càng thấp. Ở trạng thái đóng rắn, chiều dài sợi không có ảnh hưởng đến cường độ nén của vữa. Tuy nhiên, sợi có kích thước càng dài thì cường độ uốn và cường độ ép bửa sẽ càng cao. Xét về các chỉ tiêu liên quan đến độ bền như độ chống thấm nước, khả năng chịu mài mòn thì chiều dài sợi không có ảnh hưởng đến các tính chất này. Kết quả thu được là hữu ích cho các nghiên cứu sau này về khả năng ứng dụng của vữa tự lèn cường độ cao sử dụng sợi thủy tinh để sửa chữa các công trình thủy công nói chung và công trình biển nói riêng.

Từ khóa: Vữa tự lèn; Sợi thủy tinh kháng kiềm; Chiều dài sợi; Trạng thái tươi và đóng rắn

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