BÀI BÁO KHOA HỌC

# STUDY ON THE USE OF DIFFERENT GLASS FIBER CONTENTS FOR SELF-COMPACTING MORTAR

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**Abstract:** *Glass Fiber-Reinforced Self-Compacting Mortar (GFRSCM) is a composite material consisting of a mortar of Portland cement and fine aggregate reinforced with alkali-resistant glass fibers. The properties of GFRSCM depend upon a wide range of variables including mix formulation, fiber type and content, length, orientation, and admixture used... In this paper, the authors intend to study the effect of glass fiber content on properties of GFRSCM at fresh and hardened state. The experimental results have shown that the more the content of glass fiber is used, the lower the resultant slump flow value of GFRSCM mixture. At hardened state, glass fiber content barely affects the compressive strength of GFRSCM. However, the higher the glass fiber content added, the greater flexural and splitting tensile strength is achieved. In terms of durable properties such as waterproof grade and abrasion resistance, glass fiber content does not influence on these properties. The outcomes of this study would be useful for further study on the application of the GFRSCM for the rehabilitation of some types of structures including civil engineering and hydraulic structures.*
**Keywords:** Glass fiber-reinforced self-compacting mortar, alkali-resistant glass fiber, fiber content, slump flow, compressive strength, flexural and splitting tensile strength, durable properties.

## 1. INTRODUCTION

Glass fiber reinforced concrete (GFRC) is a material that is making a significant contribution to the economics, technology, and aesthetics of the construction industry worldwide for over 40 years. GFRC is one of the most versatile building materials available to architects and engineers (Masuelli, 2013). Compared to traditional concrete, it has complex properties because of its special structure. Different parameters such as water-cement ratio, porosity, composite density, inter filler content, fiber content, orientation and length, type of cure influence properties and behavior of GFRC as well as the accuracy of production method (Balaguru & Shah, 1992, Faheem & Branco, 2017).

Glass fibers are available in continuous or chopped lengths. Glass fibers have large tensile strength and elastic modulus but have brittle stress-strain characteristics and low creep at room temperature. Glass fibers are usually round and straight with diameters from 0.005 mm to 0.015 mm. They can be also bonded together to produce the bundle of glass fibers with a diameter of up to 1.3 mm (Bentur & Mindess, 1990).

GFRC can be produced as thin as 6 mm so their weight is much less than traditional precast concrete products. Progressing of 3D–printing technology with glass fiber reinforced ink can build a whole building and complex architectural forms with high reliability as well as the use of premix, spray-up, hybrid methods of GFRC. The use of glass fiber in the fine-grain high-performance concrete class, being a class with extremely high mechanical performance, durability, workability, and aesthetics, has gained momentum in recent years (Ngo, 2020).

The potential of glass as a construction material was realized in the 1940s. But, since

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the glass has very low alkali resistance to corrosion and loss of tensile strength of the glass fibers it became very difficult to be mixed with concrete which is alkaline in nature. Thus, a better glass being alkali resistant was made with the content of a high level of zirconium dioxide in the mid–1960s. From this time such fibers became commercially available and new fibers and their applications were covered by patents (Masood, 2014). In the early 1980s, as an evolved new generation of fibers composites throughout the matrix provided substantially increased tensile, flexural, and impact strength. EN standards were developed, the quality control was increased for the best practice in production and designs supported by the International Glass Fiber Concrete Association. In the early years of the new millennium rapid increase in GFRC production with the construction burst world–wide. Its growth slowed down due to the global economic crisis at one point, but the use of GFRC by major architects of the world was widespread in different areas (Ferreira, 2007).

Intending todeepen the study on the role of glass fiber in concrete, this paper intends to examine in detail the effect of glass fiber content on self-compacting mortar (SCM) properties at both fresh and hardened state. The outcome would serve for further investigation on the application of this glass-fiber reinforced SCM for the rehabilitation of some types of structures including civil engineering and hydraulic structures.

## 2. MATERIALS AND METHODS

The materials used for the preparation of SCM 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.

Besides, silica fume with commercial brand Elkem Microsilica® 940, which is conforming to the Vietnamese standard TCVN 8827:2011, is used assupplementary 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. Sand from Kien Khe - Ha Nam Province has opted for proportioning SCM.

The characteristic conforming TCVN 7572:2006 is 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. The glass fiber is of 17 mm in length. The characteristic of alkali-resistant glass fiber is provided in Table 5.

### 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 with a brand VMAT-PC01. Water used for mix proportion 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 |

*Figure 1. Alkaline resistance glass fibers used in this study*

**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 required slump flow of 20cm and the strength class of 60MPa 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 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 mix design steps are described elsewhere in the published document (Ngo, 2020).

Some “trial-and-error” were involved in mix proportion of SCM with glass fiber. Eventually, in total there are three mixes used in this study as can be seen in Table 7. Among them, it is noted that the only difference is the fiber content varying from 0.2% to 0.4% volume fraction.

**Table 7. Mix proportion of SCM**

| | OPC40 | Silica fume | Sand | SP | Water | Glass fiber | Glass fiber |
|---|---|---|---|---|---|---|---|
| | kg | kg | kg | l | l | % volume | kg |
| M1 | 450 | 45 | 1705 | 5.1 | 195 | 0.2 | 5 |
| M2 | 450 | 45 | 1705 | 5.1 | 195 | 0.3 | 7.5 |
| M3 | 450 | 45 | 1705 | 5.1 | 195 | 0.4 | 10 |

### 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 following 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 height) were prepared to determine compressive strength, flexural strength and splitting tensile strength respectively at 28 days.

*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 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$^o$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 glass fiber (GF) content of 0.2%, 0.3%, and 0.4% 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 because all of them are less than 20cm (slump flow in case of motar without fiber). 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 more glass fiber is added, the lower value of slump flow.

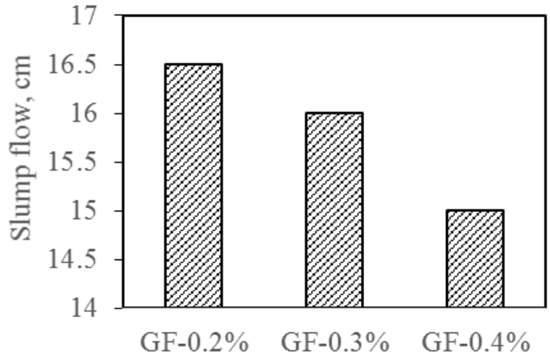


*Figure 4. Slump flow value of SCM mixtures*

Regarding the density of SCM mixtures M1, M2, and M3 at fresh state, the result is demonstrated in Figure 5. It shows that the density of those mixtures is about 2.37-2.39 T/m$^3$, which is slightly lower than the sum of constituent material weight in Table 7, this means that air entrainment has been involved in the motar during the mixing process.

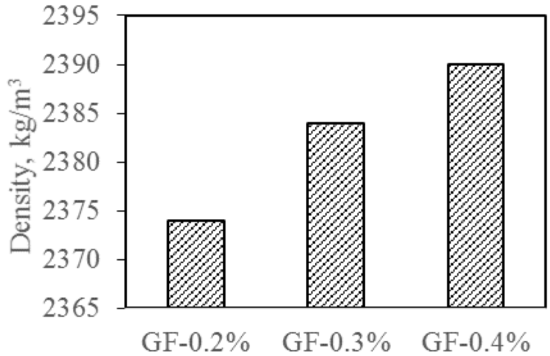


*Figure 5. Density at fresh state of SCM mixtures*

**3.2. Properties at hardened state**

Compressive strength of M1, M2 and M3 corresponding to the glass fiber content of 0.2%, 0.3%, and 0.4% respectively is provided in Figure 6, strength is in agreement with concrete grade design of 60MPa and there is no big difference between them. This means that fiber length does not influence on compressive strength at all.

On the other hand, looking into Figure 7 and Figure 8, in which flexural and splitting tensile strength respectively are represented, they are dependent on fiber content. Indeed, the higher fiber content, the higher flexural, and splitting tensile strength. The flexural strength of the one with a glass fiber content of 0.3% and 0.4% is 3% and 10% higher than that with a fiber content of 0.2%.

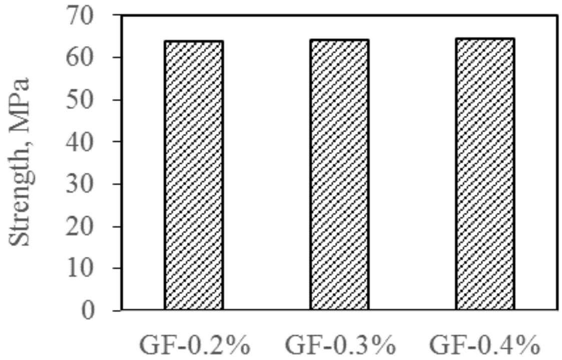


*Figure 6. Compressive strength of SCMs*

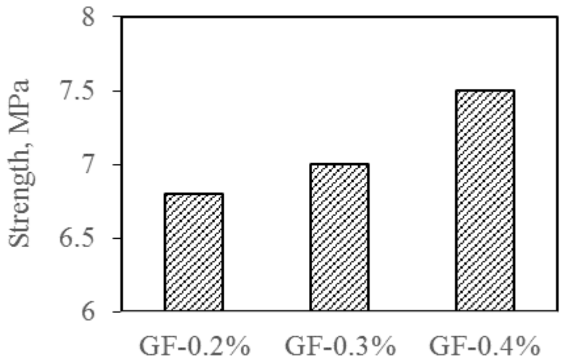


*Figure 7. Flexural strength of SCMs*

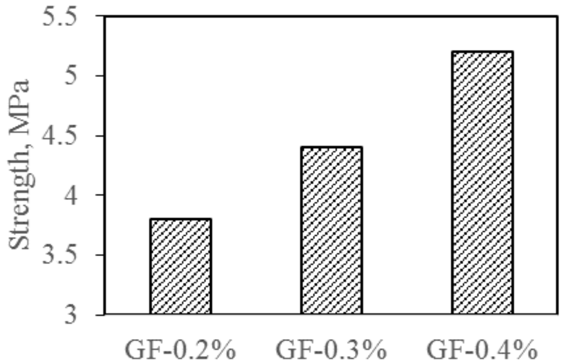


*Figure 8. Splitting tensile strength of SCMs*

Also, the splitting tensile strength of the one with a glass fiber content of 0.3% and 0.4% is 13% and 24% higher than that with fiber content of 0.2%. Besides, it is remarkable that the addition of glass fiber has brought concrete tougher. During flexural and splitting tensile tests, the beam has not broken into a piece after crack propagation, even though high strength concrete grade of 60MPa is considered to be quite brittle. With the fiber addition, the brittleness of concrete has been alleviated (Bentur & Mindess 1990).

Take a close look at 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 glass fiber content does not affect these characteristics of SCM. All three of them present 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 a hydraulic structure in general and marine structure in particular.

**Table 8. Durable properties of SCM**

| **Properties** | **M1 (GF-0.2%)** | **M2 (GF-0.3%)** | **M3 (GF-0.4%)** |
|---|---|---|---|
| Waterproof grade | W12 | W12 | W12 |
| Abrasion resistance, $g/mm^2$ | 17.2 | 17.2 | 17.2 |

## 4. CONCLUSION

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

On the other hand, fiber content does not significantly affect the compressive strength of SCM in hardened state. However, the experimental results showed that the higher content of glass fiber, the higher flexural and splitting tensile strength. In terms of durable properties such as waterproof grade and abrasion resistance, fiber content 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 some types of structures including civil engineering and hydraulic structures.


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**Tóm tắt:**

**NGHIÊN CỨU ẢNH HƯỞNG CỦA HÀM LƯỢNG SỢI THỦY TINH ĐẾN CÁC TÍNH CHẤT CỦA VỮA TỰ LÈN**

*Vữa tự lèn cốt sợi thủy tinh (GFRSCM) là vật liệu hỗn hợp bao gồm vữa xi măng poóc lăng và cốt liệu mịn được gia cường bằng sợi thủy tinh chịu kiềm. Tính chất của GFRSCM phụ thuộc vào nhiều tham số bao gồm thành phần hỗn hợp, loại sợi và hàm lượng sợi, chiều dài, định hướng sợi và các loại phụ gia được sử dụng... Trong bài báo này, tác giả định hướng nghiên cứu ảnh hưởng của hàm lượng sợi thủy tinh đến các đặc tính của GFRSCM. Các kết quả thực nghiệm cho thấy lượng sợi thủy tinh sử dụng càng nhiều thì độ chảy của hỗn hợp GFRSCM càng giảm. Ở trạng thái rắn, hàm lượng sợi thủy tinh hầu như không ảnh hưởng đến cường độ nén của GFRSCM. Tuy nhiên, hàm lượng sợi thủy tinh được thêm vào càng cao thì độ bền kéo đứt và uốn càng lớn. Về các đặc tính liên quan đến tính bền như khả năng chống thấm và chống mài mòn, hàm lượng sợi không ảnh hưởng đến các đặc tính này. Kết quả của nghiên cứu này sẽ hữu ích cho việc nghiên cứu sâu hơn về khả năng ứng dụng của GFRSCM để phục hồi một số loại kết cấu cho cả công trình dân dụng và công trình thủy công.*

**Từ khóa:** Vữa tự lèn cốt sợi thủy tinh, sợi thủy tinh chịu kiềm, hàm lượng sợi, độ chảy, độ bền nén, độ bền kéo uốn và tách, đặc tính bền

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