

Lecture Notes in Civil Engineering

Nguyen-Viet Thanh ·  
Long Nguyen-Ngoc · Thanh Bui-Tien ·  
Tuan Nguyen-Quang ·  
Guido De Roeck *Editors*

# Proceedings of the 5th International Conference on Sustainability in Civil Engineering— Volume 1

ICSCE 2024, 23–25 October, Hanoi,  
Vietnam

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Editors


# Proceedings of the 5th International Conference on Sustainability in Civil Engineering—Volume 1

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# Preface

The International Conference on Sustainable Development in Civil Engineering is held biennially at the University of Transport and Communications, starting in 2016. Over the past five years, it has become a prestigious event, attracting the attention of experts and the global scientific community. This conference has become an important forum for scientists in the field of civil engineering to come together, discuss, and exchange views on pressing and critical issues, drawing active participation from both national and international scholars as well as government agencies.

This year, the conference theme continues to build upon the topics discussed in previous editions while also expanding and deepening the important issues that the scientific community and experts are particularly concerned about. We hope that through this conference, a common voice will emerge, contributing to the sustainable development of the civil engineering sector not only in Vietnam but also across the Asia-Pacific region and globally.

Vietnam is one of the early signatories to international conventions on sustainable development, and we have committed to achieving net-zero carbon emissions by 2050. It demonstrates our responsibility in the international community, especially among developing countries, to contribute to the shared goal of sustainable development across the region and the world.

The University of Transport and Communications is honored to welcome you to the autumn atmosphere of Hanoi—a city known not only for its rich cultural heritage but also as a center for scientific and economic development. We hope that this conference will not only be scientifically successful but will also offer opportunities for connection, collaboration, and exploring the beauty of Vietnam and its people.

This year's conference welcomes the enthusiastic participation of scientists from 13 countries, with nine keynote speeches and 110 full papers focusing on ten core topics in civil engineering. Contributions have come from countries such as Algeria, India, the United States, Belgium, Canada, France, Portugal, China, Taiwan, Japan, South Korea, Australia, and Vietnam. In particular, presentations by leading professors worldwide have provided vital insights into issues such as **sustainable development, high-speed rail, structural health monitoring, smart cities, green transportation, artificial intelligence** applications in construction, digital twins, new materials, and urban traffic management.

On behalf of the Organizing Committee, I would like to express my deep gratitude to the scientists and organizations, both domestic and international, who have come to attend the conference. I look forward to hearing new ideas and knowledge. I hope today's discussions will bring practical value to every participant while also contributing to the sustainable development of the civil engineering sector globally.

I would like to sincerely thank the International Science Committee, the Local Organizing Committee, authors, reviewers, the editorial boards, and the logistical teams who have worked diligently to ensure the success of this conference.

Finally, I would like to express my heartfelt thanks for the presence and valuable contributions of the professors and scientists, both international and local, in the plenary and thematic sessions of the conference. I also extend my thanks to our sponsors: Thang Loi (Diamond Sponsor), Nippon Steel and Dat Phuong (Gold Sponsors), Dong Son (Silver Sponsor), and Kawakin Core-Tech Vietnam and ADCo (Bronze Sponsor).

People Teacher. Prof. Dr. Long Nguyen-Ngoc  
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## About the Editors

**Assoc. Prof. Dr. Nguyen-Viet Thanh** is a vice dean of the Faculty of Civil Engineering at the University of Transport and Communications, Hanoi, Vietnam.

He graduated Ph.D. program in 2012 at Hohai University, China, and he won an outstanding Ph.D. Candidate Award in 2013.

Dr. Thanh's research areas are estuary and coastal hydrodynamics, sediment transport, and harbor and inland waterways engineering. He published more than 60 scientific papers, of which 31 papers on Web of Science and Scopus and one book published by Springer Nature.

Dr. Thanh is the principal investigator of two international research projects, four ministerial-level research projects, and two National Standards in the field of maritime and inland waterway transport. He also project manages international projects funded by the Mekong River Commission, GIZ, and Au4Transport.

**Prof. Dr. Long Nguyen-Ngoc** is a people's teacher of Vietnam and former President of the University of Transport and Communications, Vietnam.

Professor Long, with over 40 years of experience in civil engineering, has made significant contributions to the field, particularly in bridge engineering, structural health monitoring, and damage detection through vibration analysis. He leads multiple research activities spanning a broad spectrum of domains and has been instrumental in advancing both theoretical and practical aspects of infrastructure engineering.

Since 2018, Prof. Long has chaired the International Conference on Sustainable Civil Engineering (ICSCE), fostering global collaboration and knowledge exchange in civil engineering. He also serves as the main coordinator for numerous national and international projects focusing on the construction and maintenance of bridges, further demonstrating his expertise and leadership in the field.

With over 20 publications collectively garnering more than 420 citations, Prof. Long's research impact is underscored by an h-index of 7, reflecting the recognition of his highly regarded works, and an i10-index of 5, indicating the influential nature of his studies. His extensive experience and contributions continue to shape the development of innovative solutions for sustainable and resilient infrastructure.

**Prof. Dr. Thanh Bui-Tien** is an expert in Civil Engineering, specializing in structural health monitoring, AI, digital twin, intelligent transportation, and structural damage diagnosis of bridges. He is currently the dean of the Faculty of Civil Engineering at the University of Transport and Communications in Vietnam.

He obtained his Bachelor of Engineering degree in Bridge Engineering from the University of Transport and Communications (UTC) in Vietnam in 2000 and his Ph.D. in Civil Engineering from the University of New South Wales (UNSW), Australia, in 2007.

He has held academic positions at various institutions, including lecturing at UNSW and UTC and postdoctoral research at Université de Liège and KU Leuven. Assoc. Prof. Dr. Bui Tien Thanh has published numerous papers in peer-reviewed prestigious journals and has contributed to many conferences and seminars around the world. He has a citation count of 1841, an h-index of 21, and an i10-index of 36. His current work involves developing new methods based on optimization and AI for structural health monitoring and structural damage detection.

**Assoc. Prof. Dr. Tuan Nguyen-Quang**, vice dean of the Faculty of Civil Engineering at the University of Transport and Communications, Vietnam, specializes in the behavior of materials and structures, new construction materials, and technologies. He graduated from this university in 2006 and later earned a master's degree in 2007 and a Ph.D. in 2011 from Ecole Nationale des Travaux Publics de l'Etat (ENTPE) in France. With over 15 years of research experience in transport construction materials, especially asphalt mixtures, he has contributed significantly to the field. Since 2016, he has been a member of the editorial board for the *Road Materials and Pavement Design Journal*. Assoc. Prof. Dr. Tuan Nguyen-Quang has authored 80 scientific papers in both national and international journals and two scientific books, amassing 922 citations (Google Scholar), with an h-index of 14 (Google Scholar) and 12 (Scopus). He has led and participated in over ten ministerial and state-level projects in Vietnam and has also been involved in the international RILEM project focused on sustainable, innovative bituminous materials and systems.

**Emeritus Professor Guido De Roeck** is currently affiliated with the Department of Civil Engineering, Section Structural Mechanics at Katholieke Universiteit Leuven (KU Leuven), Belgium. He obtained a Bachelor of Engineering Science in 1968 and a Master of Science in Civil Engineering in 1971 from KU Leuven. He got a Ph.D. in Structural Mechanics from KU Leuven in 1975, and in 1981, he received his Doctor of Science degree.

Prof. De Roeck has published thousands of papers. His citation count of 27,086, an h-index of 82, and an i10-index of 241 (November 2024). He is a senior specialist in the field of structural health monitoring, static and dynamic analysis of mechanical structures, structure damage detection, dynamic system identification, soil interaction with structures, nonlinear constitutive soil models, and composite materials.

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# Uniaxial Tensile Resistance of Hybrid Steel Fiber-Reinforced Concrete

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**Abstract.** This paper deals with the tensile resistance of hybrid steel fiber-reinforced concrete (HSFRC). Two forms of steel fibers are employed for three hybrid fiber systems having the exact total of 2% volume fraction steel fibers as follows: macro hooked (MH) with a length/diameter ratio of 35/0.5 mm, micro smooth (MS) with a length/diameter ratio of 13/0.2 mm. The hybrid fiber systems are designed as follows: MH 0.5% & MS 1.5% (MH0.5/MS1.5), MH 1.0% & MS 1.0% (MH1.0/MS1.0), MH 1.5% & MS 0.5% (MH1.5/MS0.5). With a total fiber content of 2%, as the MH volume fraction increases from 0.5 to 1.5%, the tensile strength of the HSFRCs significantly increases while the strain capacity notably decreases. Additionally, the energy absorption capacity of HSFRCs is superior to that of fiber-reinforced concrete (FRC) and normal strength concrete (NS-C), yet lower level compared to ultra high-performance fiber reinforced concrete (UHPFRC). Furthermore, fiber orientation varies between 2D and 3D, emphasizing the need to consider the influence of structural member size on fiber orientation in HSFRC design.

**Keywords:** HSFRC · hybrid fiber · tensile resistance · strain capacity · energy absorption capacity

## 1 Introduction

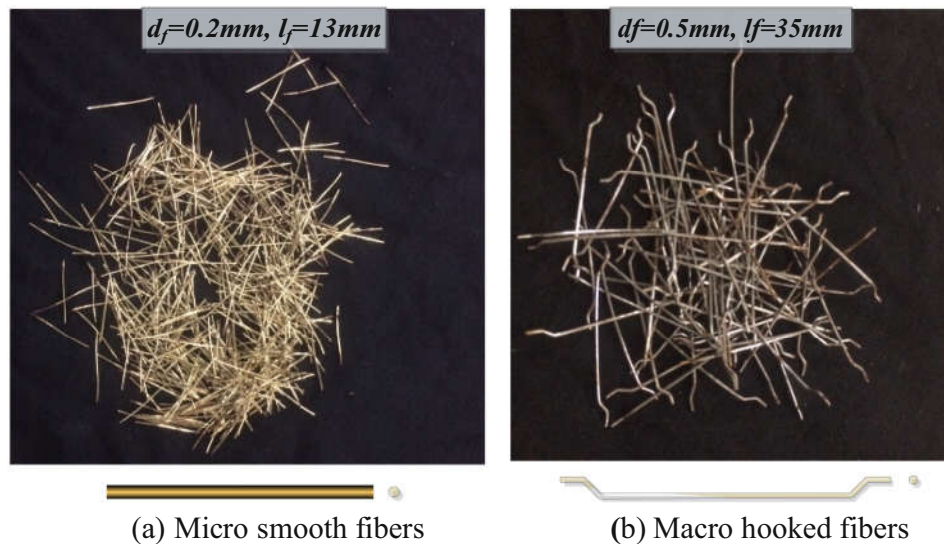
The demand for high-strength materials with superior load-bearing capabilities has become increasingly critical, especially in projects requiring long-term durability and high load resistance. Hybrid steel fiber-reinforced concrete (HSFRC), a type of high-performance fiber-reinforced concrete (HPFRC), can meet the demand with its high strength in both compression and tension, high ductility, and energy absorption capacity [1–3]. The performance characteristics of HSFRC largely depend on the concrete and the characteristics of the reinforcing fibers, including fiber content, distribution, size, aspect ratio, geometry, and tensile strength [4–9]. Some scientists around the world have investigated the effect of volume fraction on the tensile behavior of HPFRC [7–11]. In general, the higher fiber content results in better tensile resistance [7–9] as well as strain

hardening response with multiple tiny cracks [10, 11]. However, there has still been little research on the response of HSFRCs with hybrid steel fibers. Therefore, this study focuses on the uniaxial tensile behavior of HSFRCs by evaluating their tensile strength ( $\sigma_{pc}$ ), strain capacity ( $\varepsilon_{pc}$ ), and energy absorption capacity ( $G_{hd}$ ). The research results expectedly contribute to a deeper understanding and open up broader applications of HSFRCs in modern construction.

## 2 Experiment

### 2.1 Materials Preparation and Specimen Fabrication

Two steel fibers are employed for three hybrid fiber systems having the same total of 2% volume fraction as follows: macro hooked steel fibers (MH) with a length/diameter ratio of 35/0.5 mm, micro smooth steel fibers (MS) with a length/diameter ratio of 13/0.2 mm. The hybrid fiber systems are designed as follows: MH 0.5% & MS 1.5% (MH0.5/MS1.5), MH 1.0% & MS 1.0% (MH1.0/MS1.0), MH 1.5% & MS 0.5% (MH1.5/MS0.5). Figure 1 shows the photos of the two types of steel fibers used in this paper and their tensile strengths  $\geq 1200$  MPa for MH and  $\geq 2500$  MPa for MS. The mix proportions of HSFRC mortar by weight ratio: 1.00 for silica sand, 0.08 for portland cement (PC40), 0.07 for silica fume, 0.20 for fly ash, 0.04 for superplasticizer, and 0.26 for water. The compressive strength of non-fiber reinforced HSFRC is 79.6 MPa using a cylinder size of 100 × 200 mm.



**Fig. 1.** Photos of large and small steel fibers employed in this paper

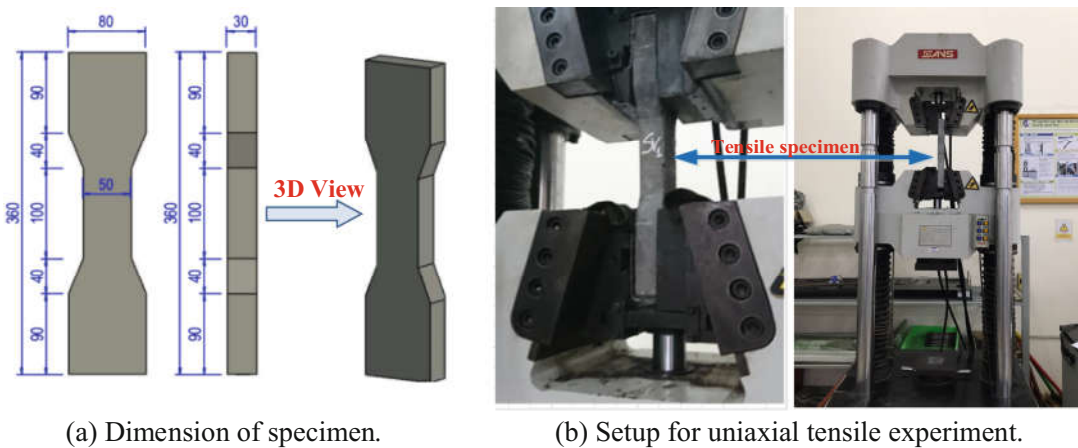
### 2.2 Setup for Experiment

Figure 2a, b show the specimen detail and setup for the uniaxial tensile experiment, respectively. The curing work for the specimens was conducted for 28 days underwater with a temperature range of 22–29 °C. The specimens were then dried naturally in

the laboratory for about 2 days before testing. All specimens were tested using a universal testing machine with a crosshead speed of 1.0 mm/min. The axial load ( $P$ ) and displacement ( $\Delta$ ) were taken at a frequency of 1 Hz.

The tensile strain ( $\varepsilon$ ) was calculated using the equation,  $\varepsilon = \Delta/L$  where  $L = 100$  mm is the effective gauge length (excluding the grip-embedded protrusions at both specimen ends),  $\Delta$  is the displacement along the axis recorded by the machine.

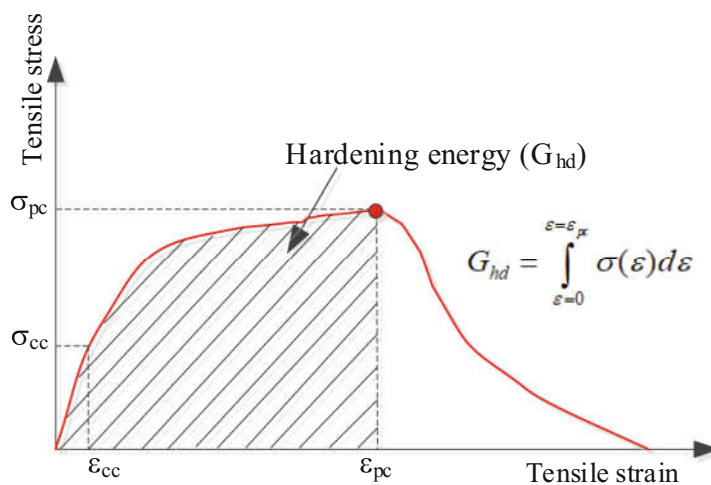
The tensile stress ( $\sigma$ ) was calculated using the equation,  $\sigma = P/F$  where  $P$  is the applied axial load recorded by the machine, and  $F = 30 \times 50 \text{ mm}^2$  is the cross-sectional area within the effective gauge length. At the peak of the response curve, the tensile strength ( $\sigma_{pc}$ ) and the corresponding strain capacity ( $\varepsilon_{pc}$ ) are the two main engineering parameters used to assess HSFRCs. The test was carried out based on the direct tension test method for HSFRC developed by Graybeal and Florent Baby [12]. The energy absorption capacity (hardening energy) is defined as the region below the response curve of  $\sigma$ - $\varepsilon$  with a strain range from 0 to  $\varepsilon_{pc}$ , as illustrated in Fig. 3 [1].



(a) Dimension of specimen.

(b) Setup for uniaxial tensile experiment.

**Fig. 2.** Specimen detail and setup for uniaxial tensile experiment.

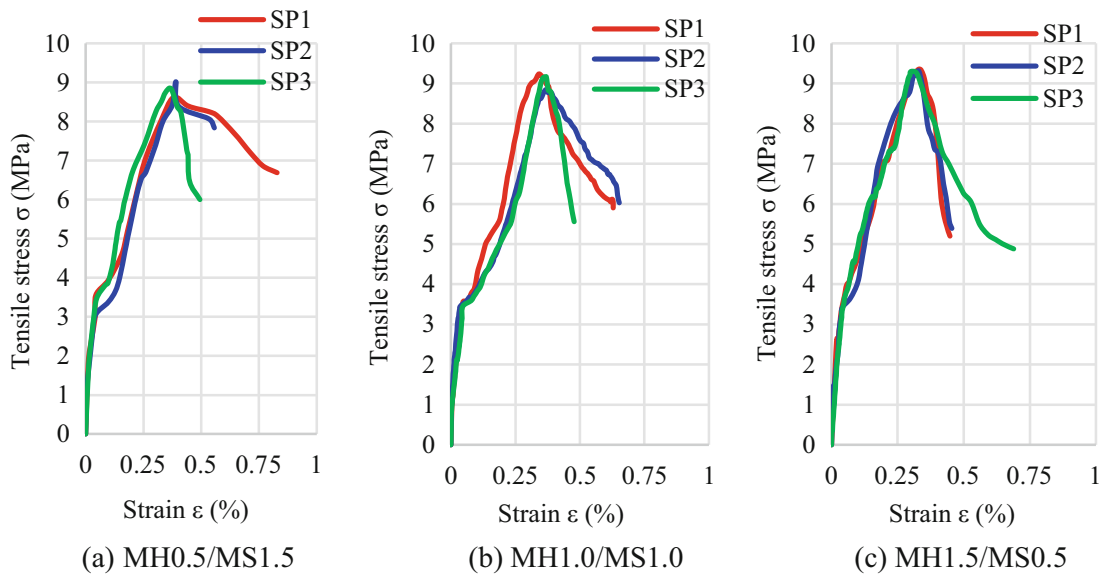


**Fig. 3.** Illustration of hardening energy of HSFRC under tension [1].

### 3 Research Results and Discussion

#### 3.1 Uniaxial Tensile Resistance of Hybrid Steel Fiber-Reinforced Concrete

Figure 4 illustrates the  $\sigma$ - $\varepsilon$  curves for the uniaxial tensile of three types of HSFRC: MH0.5/MS1.5 (Fig. 4a), MH1.0/MS1.0 (Fig. 4b), and MH1.5/MS0.5 (Fig. 4c). As observed in Fig. 4, there were not many differences between them. However, the MH0.5/MS1.5 produced the weakest HSFRC properties, whereas the MH1.5/MS0.5 demonstrated the best. Table 1 provides the tensile parameters of the HSFRC series. Fig. 5a, b perform the comparison of the tensile strength and corresponding strain capacity of the HSFRCs, respectively.



**Fig. 4.** Uniaxial tensile behavior of HSFRC.

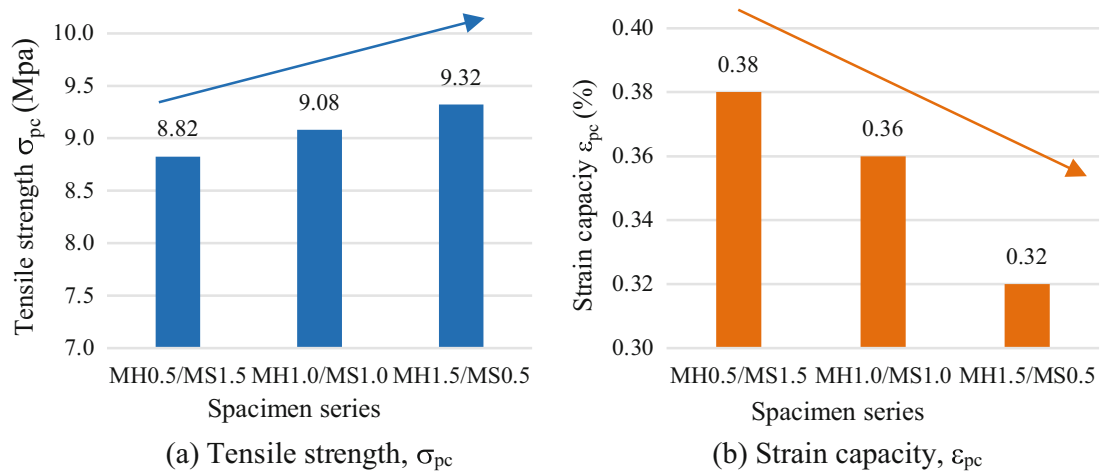
As observed in Fig. 5a, when the volume fraction of hooked steel fiber increases from 0.5 to 1.5%, the  $\sigma_{pc}$  of the HSFRC clearly increases. The order of HSFRCs in terms of the  $\sigma_{pc}$  is observed: MH0.5/MS1.5 (8.82 MPa) < MH1.0/MS1.0 (9.08 MPa) < MH1.5/MS0.5 (9.32 MPa). As displayed in Fig. 5b, the  $\varepsilon_{pc}$  considerably decreases as the volume content of tiny steel fibers increases from 0.5 to 1.5% with order: MH0.5/MS1.5 (0.38%) > MH1.0/MS1.0 (0.36%) > MH1.5/MS0.5 (0.32%). Porosities or small cracks are always present in concrete, where stress concentrations occur under loading, leading to crack initiation and propagation. Macro fibers in a hybrid fiber system play a key role in determining the general shape of tensile response curves of HSFRC [13]. As a result, MH1.5/MS0.5, with the highest macro fiber content, achieved the greatest tensile strength.

#### 3.2 Uniaxial Tensile Resistance of Hybrid Steel Fiber-Reinforced Concrete

Table 2 gives the  $G_{hd}$  of the HSFRCs averaged from three specimens tested for each HSFRC type. According to the results in Table 2, the  $G_{hd}$  were as follows: 2.118 MPa.%

**Table 1.** Results of uniaxial tensile test parameters.

HSFRC type	Specimen	Strain capacity $\varepsilon_{pc}$ (%)	Tensile strength $\sigma_{pc}$ (MPa)
MH0.5/MS1.5	Spe.1	0.38	8.06
	Spe.2	0.39	9.02
	Spe.3	0.37	8.84
	<b>Average (SD)</b>	<b>0.38 (0.010)</b>	<b>8.82 (0.21)</b>
MH1.0/MS1.0	Spe.1	0.34	9.24
	Spe.2	0.37	8.84
	Spe.3	0.37	9.16
	<b>Average (SD)</b>	<b>0.36 (0.017)</b>	<b>9.08 (0.21)</b>
MH1.5/MS0.5	Spe.1	0.33	9.35
	Spe.2	0.33	9.31
	Spe.3	0.30	9.30
	<b>Average (SD)</b>	<b>0.32 (0.017)</b>	<b>9.32 (0.03)</b>

**Fig. 5.** Comparing tensile parameters of HSFRC.**Table 2.** Energy absorption capacity of HSFRCs.

HSFRC type	$G_{hd}$ (MPa.%)
MH0.5/MS1.5	2.118
MH1.0/MS1.0	1.953
MH1.5/MS0.5	1.904
<b>Average</b>	<b>1.992 (0.112)</b>

for MH0.5/MS1.5, 1.953 MPa.% for MH1.0/MS1.0, 1.904 MPa.% for MH1.0/MS1.0, and average value of 1.992 MPa.%. Figure 6 displays the comparisons of tensile behaviors and energy absorption capacities of various concrete types, including ultra-high-performance fiber-reinforced concrete—UHPFRC (referred to [14]), fiber-reinforced concrete—FRC (referred to [15]), and normal strength concrete—NS-C (referred to [16]). As shown in Fig. 6, the performance of HSFRC is much better than NS-C, although the UHPFRC is the best.

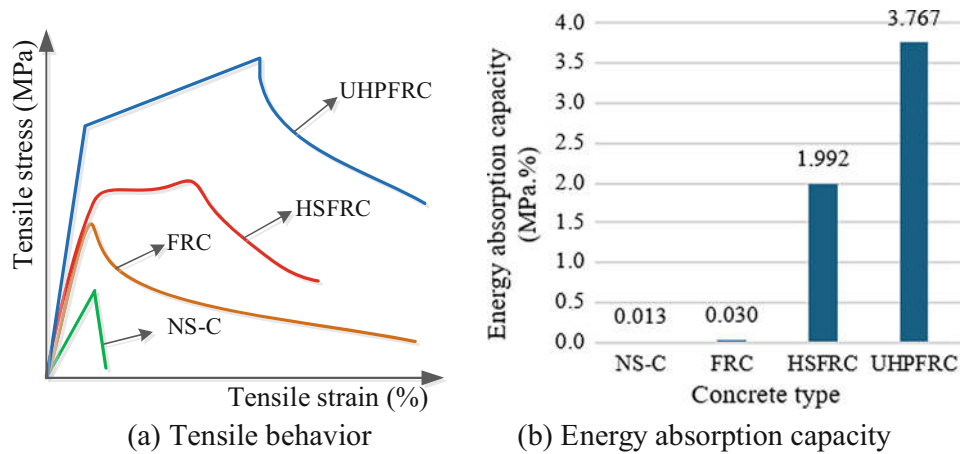


Fig. 6. Comparative tensile behavior and energy absorption capacity of various concrete types.

### 3.3 Investigating the Steel Fiber Distribution across the Cross-Sectional Area of HSFRC

The tensile strength of HSFRC is significantly affected by the distribution of embedded reinforcing fibers. Since the failure-crack sections were not straight, a cross-section located 20 mm away from the failure crack was examined to consider the distribution of steel fibers in the HSFRC. Although the fiber distribution in the examined section might differ from that in the failure-crack section, it still provided a general sense of the fiber distribution uniformity.

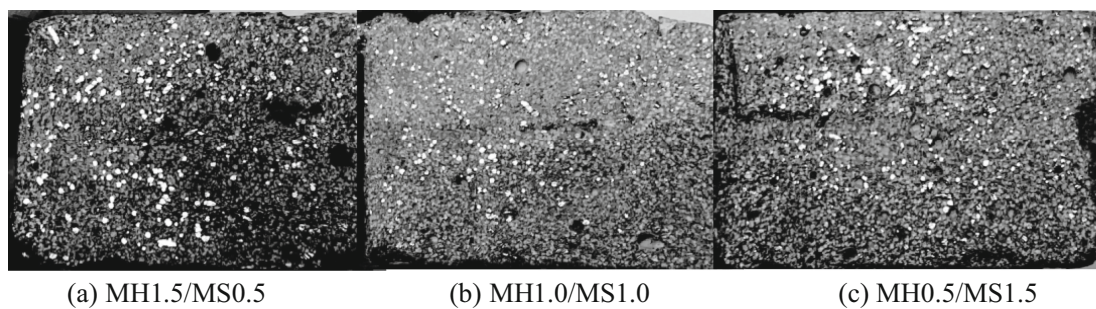


Fig. 7. Photos of the typical distribution of steel fibers of three HSFRCs.

Figure 7 presents photos showing the typical distribution of steel fibers in the three studied HSFRCs. As seen in Fig. 7, the steel fibers were not well distributed, possibly due to the poor mixing of fiber, which should be addressed in further study. The number of fibers present in the cross-sectional area of each HSFRC type was manually counted and averaged as follows: 423 for MH0.5/MS1.5, 313 for MH1.0/MS1.0, and 199 for MH1.5/MS0.5. The theoretical number of fibers, calculated using Eq. (1) [11], was compared to the counted ones regarding Table 3. According to Table 3, the examined fiber orientation is distributed between 2D and 3D theoretical values. This result can be attributed to the specimen thickness being lower than the length of the large steel fibers, leading to the unfree orientation of the fiber.

$$N = \alpha \times \left( \frac{V_{f,hooked}}{A_{f,hooked}} + \frac{V_{f,smooth}}{A_{f,smooth}} \right) \times A_g \quad (1)$$

where  $N$  denotes the amount of steel fibers,  $V_{f,hooked}$  and  $A_{f,hooked}$  are the volume fraction and cross-sectional area of the large fibers, respectively;  $V_{f,smooth}$  and  $A_{f,smooth}$  are the volume fraction and cross-sectional area of the tiny fibers, respectively;  $A_g$  is the cross-sectional area of the HSFRC specimen ( $30 \times 50 = 1500 \text{ mm}^2$ );  $\alpha$  is the coefficient accounting for the fiber orientation with its values of 1,  $2/\pi$ , and 0.5 corresponding to 1D, 2D, and 3D fiber orientations, respectively.

**Table 3.** The average quantity of fibers in the cross-sectional area

HSFRC types	Fiber count observed in a $1500 \text{ mm}^2$ cross-sectional area	Theoretical quantity of fibers:		
		1D	2D	3D
MH0.5/MS1.5	423	754	480	377
MH1.0/MS1.0	313	553	353	277
MH1.5/MS0.5	199	354	225	176

## 4 Conclusions

The main results of this paper can be drawn as follows:

1. With the same total 2% hybrid fibers content, when the content of macro fibers increased from 0.5 to 1.5%, the tensile strength of the HSFRCs increased, whereas the strain capacity decreased. The changes of them were considerable.
2. The uniaxial tensile behavior and energy absorption capacity of HSFRCs are comparatively much better than those of FRC and NS-C but lower than those of UHPFRC.
3. The examined fiber orientation is distributed between 2D and 3D for the studied HSFRCs. Therefore, the influence of structural member size on fiber orientation should be considered in designing work using HSFRCs.

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