JOURNAL OF MATERIALS & CONSTRUCTION
Journal of Materials and Construction
ISSN 2734-9438
Website: www. jomc.vn

The effects of fine aggregates on the workability and compressive strength of high-strength fine-grained concrete

Le Huy Viet[1,2 *], Nguyen Sy Duc[1], Ngo Ton Hieu[1], Ngo Trung Hieu[1], Do Manh Nam[1]

[1] Civil engineering faculty, Hanoi University of Mining and Geology

[2] GESM research group, Hanoi University of Mining and Geology

KEYWORDS

Compressive strength
High-strength fine-grained concrete
Silica sand
Crushed quartz sand
Workability

ABSTRACT

Concrete is the most commonly used construction material in Vietnam and worldwide for building projects. With the development of the socio-economic sector, infrastructure projects and high-rise buildings are being constructed on an increasingly larger scale, making the demand for manufacturing and utilizing concrete materials with high compressive strength more urgent. This study aims to investigate the feasibility of producing high-strength fine-grained concrete (HSFGC) with a compressive strength of over 100 MPa using locally available materials in Vietnam. The mixtures were designated based on the composition of ultra-high performance concretes (UHPCs), which contain no coarse aggregates. River sand, silica sands, crushed quartz sand, and ceramic powder were used as fine aggregates, while PCB 40 But Son and silica fume SF90 were used as binders in the matrix compositions. The water-to-cement (W/C) ratios used varied from 0.2 to 0.26, combined with a superplasticizer-based polycarboxylate to ensure the flowability of the HSCs. The test results indicated that silica sand produced the highest compressive strength of HSFGCs in comparison with river sand and crushed quartz sand. As the W/C decreased from 0.26 to 0.2, the workability of HSFGCs (flow value) decreased from 26 to 23 cm, but the compressive strength of HSFGC with silica sand increased from 70.4 to 101.9 MPa. HSFGCs with silica sand produced a compressive strength of 101 MPa, while HSFGCs with a combination of silica sand and 10 % ceramic powder can reach a compressive strength of up to 108.1 MPa, making it a promising mix for developing UHPC with economic advantages.

1. Introduction

Along with the socio-economic development, large-span infrastructure, and high-rise building projects are being constructed, making the demand for manufacturing and high-strength concretes (HSCs) and ultra-high-performance concretes (UHPCs) more urgent. The higher the concrete strength generated the thinner the structural design, reducing component sizes, increasing usable space, and enabling structures to span larger distances. Additionally, high-strength concrete has a denser structure, and greater resistance to water penetration and cracking, thereby enhancing the durability and lifespan of buildings.

According to the Vietnamese national standard TCVN 10306:2014 [1], high-strength concrete is defined as concrete with a characteristic compressive strength of 55 MPa or higher at 28 days, tested according to ASTM C39 using cylindrical specimens with a diameter of D = 150 mm and a height of H = 300 mm. The TCVN 10306:2014 standard provides guidelines for mix design and production of high-strength concrete in the range of 62 to 83 MPa, with a maximum limit of 100 MPa. A key feature of high-strength concrete is its low water-to-cement ratio (typically below 0.4), along with the use of reactive mineral admixtures such as silica fume, fly ash, ground granulated blast-furnace slag, or metakaolin, combined with superplasticizers to enhance workability. However, Vietnam currently lacks standards for designing high-strength concrete exceeding 100 MPa or ultra-high-strength concrete over 150 MPa.

The research on mix design and production of high-strength concrete exceeding 100 MPa is crucial for application in high-rise and super high-rise buildings, as well as large-span bridge structures, which are increasingly in demand in Vietnam. Recently, some studies in Vietnam investigated the effects of GGBS, metakaolin, and silica fume on the compressive strength of UHPCs and HSCs [2], [3], [4], [5], [6], [7], [8], [9], [10]. However, the effect of fine aggregates on the mechanical properties of HSCs has not been investigated.

This study investigated the effects of different fine aggregates including river sand, silica sand, crushed quartz sand, and waste ceramic powder on the fresh and hardened properties of high-strength fine-grained concretes (HSFGCs). This research serves as a foundation for applying new materials in construction, contributing to improving building quality and safety. The findings of this study can serve as reference material or be used as lecture content for undergraduate and

*Corresponding author: lehuyviet@humg.edu.vn
Received 03/04/2025, explanation 23/04/2025, accepted 24/04/2025
Link DOI: https://doi.org/10.54772/jomc.v15i01.892

postgraduate students. Additionally, it provides valuable references for construction companies, design consultants, contractors, and government agencies to better understand the characteristics and production methods of HSFGCs.

2. Material and experiement

Table 1 presents the experimental program and the notation of the HSFGCs (RS_0.2, SS1_0.2, SS2_0.2, RS+SS1_0.2, SS1_0.26, SS2_0.26, and SS1+CP_0.2). The mixtures were designed based on matrix compositions of UHPCs, which contain no coarse aggregates.

2.1. Materials

Figure 1 shows images of the main materials in this study. Cement But Son PCB-40 was produced according to the Vietnam standard TCVN 6260:2009. Silica fume has an average diameter of 0.15 µm and is used to fill the pores in HSFGC microstructures. In addition, SiO_2 in silica fume can increase the pozzolanic reaction to improve the strength of the matrices.

Fine aggregates included river sand, silica sand, crushed quartz sand, and waste ceramic powder. Table 2 summarizes the properties of fine aggregates in this study. The particle size distribution curves of sands are shown in Figure 2. All sands were dried in an oven at 80 ºC. Then, they were used to determine the particle size distribution. In this study, the river sand aggregates with particles passing through a 1.25 mm sieve were used. River sand with particles larger than 1.25 mm was removed. The diameter of silica sand varied from 0.6 to 0.8 mm, while that of crushed quartz sand varied from 0.3 to 0.5 mm. The silica powder had a diameter lower than 0.14 mm. Tap water with a water-to-cement ratio of 0.2 was used for all mixtures. Superplasticizer-based polycarboxylate of Silkroad (SR 5000 F with 1.12 g/m^3 in density) was added to ensure the workability of fresh mixtures.

Figure 1. Images of materials.

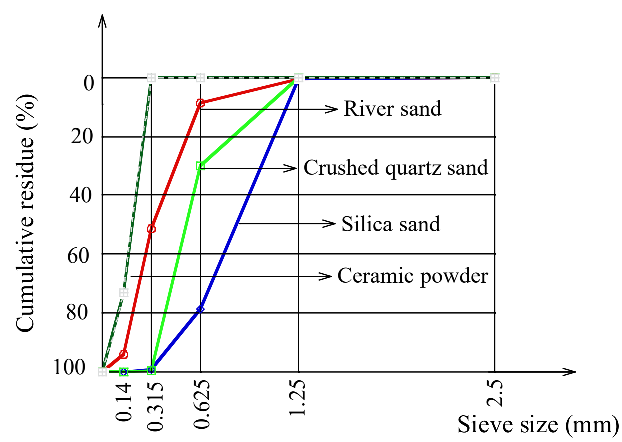

Figure 2. Particle size distribution curve of fine aggregates.

Table 1. Mix Designs for HSFGCs by cement weight ratio.

Materials	RS_0.2	SS1_0.2	SS2_0.2	RS+SS1_0.2	SS1_0.26	SS2_0.26	SS1 + CP_0.2
Cement PCB40	1	1	1	1	1	1	1
River sand	1.25	0	0	0.625	0	0	0
Silica sand	0	1.25	0	0.625	1.25	1.25	1.25
Crushed quartz sand	0	0	1.25	0	0	0	0
Ceramic powder	0	0	0	0	0	0	0.1
Water	0.2	0.2	0.2	0.2	0.26	0.26	0.2
Superplasticizer	0.067	0.067	0.067	0.067	0.067	0.067	0.067
Silica fume	0.15	0.15	0.15	0.15	0.15	0.15	0.15

Table 2. Properties of fine aggregates.

No.	Properties	Unit	River sand	Silica sand	Crushed quartz sand	Ceramic powder
1	Diameter	mm	0.14 ÷ 1.25	0.6 ÷ 0.8	0.3 ÷ 0.6	< 0.14
2	Density	kg/m^3	2650	2680	2710	2560
3	The fineness modulus of sand (Mk)	-	3.1	2.79	2.3	-
4	Cost	VND/kg	500	2000	8000	-

2.2. Specimen preparation

The specimen preparation process is standardized as follows to ensure accurate results and avoid errors during sample casting. Cement, silica fume, and fine aggregates (sands) are dry-mixed thoroughly for 3 minutes to achieve uniformity. Water is gradually added in a clockwise and counterclockwise direction around the mixing bowl to ensure even distribution. The mixture is then mixed for another 3 minutes. The superplasticizer is added to ensure the workability of mixtures. The mixture is then mixed for an additional 2 minutes. The molds are prepared by tightening and applying lubricant (oil) to prevent adhesion. The mixed concrete is poured into a slump cone to measure flowability. The mixture is then poured into the prepared molds. To remove trapped air bubbles and prevent strength reduction, each side of the mold is vibrated. Specimens were demolded after 2 days of curing under room conditions. After demolding, the samples are cured in a hot water tank at 60 ºC for 3 days.

2.3. Test setup

Flowability is tested according to the Vietnam standard TCVN 9204:2012. The flow spread test is conducted immediately after mixing is stopped. The fresh mixture is poured into the mini cone, which is 50 mm in diameter and 100 mm in height. The mixture is straightened to level with the top of the measuring cone. The cone is lifted vertically at a 90° angle. The spread diameter of the concrete is measured after removing the cone.

The compressive strength of the samples is determined using the ADVANTEST 9 automatic compression-flexure testing system (Controls - Italy). The loading rate is 0.5 MPa/s. The test specimens have dimensions of $100 \times 100 \times 100$ mm^3, following the TCVN 3118:2022 standard for fine-grained concrete specimens. Besides, the volume weight of HSFGCs is determined by measuring the weight of specimens with sizes of 100x100x100 mm^3.

(a) Flow test (b) Compressive test

Figure 3. Flow and compressive tests.

The workability and volume weight of HSFGCs containing different fine aggregates and water per cement ratio are summarized in Table 3. Fig. 4 compares the flow values of different HSFGCs. In general, as the W/C increased from 0.2 to 0.26, the flow value increased from 22 to 26 cm for SS1_0.2 and from 22 to 27 cm for SS2_0.2. [11] indicated that the free water mainly controlled the flowability of cementitious composites. As the W/C increased, the free water increased and consequently improved the flowability of the matrix.

2.4. Effects of different fine aggregates on the compressive strength

Silica sand produced higher compressive strength for HSFGCs than river sand. As can be seen in Table 3, the compressive strength of SS1_0.2 and SS2_0.2 was 99.3 % and 63.5 % higher than that of RS_0.2. The composition of river sand contains more organic compounds than silica sand because river sand is extracted from rivers, whereas crushed quartz sand and silica sand are crushed from quartz rock or directly mined from silica sand deposits. Organics generated voids and weak zones in the concrete structure, thereby reducing its strength. As can be seen in Figs. 4a, 4e, and 4f, pores in RS_0.2 was significantly more than those in SS1_0.2 and SS2_0.2 matrices. Besides, as summarized in Table 3, the lower volume weight of RS_0.2 matrices also indicated that the density was lower than that of SS1_0.2 and SS2_0.2 matrices.

Besides, the silica sand produced a higher compressive strength than the crushed quartz sand. The compressive strengths of SS1_0.2 and SS2_0.2 are 101.91 and 83.56 MPa for matrices with W/C = 0.2, and 70.36 and 66.22 MPa for matrices with W/C = 0.26, respectively. Finer crushed quartz sand (SS2_0.2) would require a higher amount of water to ensure workability and consequently decrease the compressive strength of HSFGCs. Excess water creates voids in concrete, leading to a decrease in its strength. Conversely, reducing the water content results in fewer voids within the concrete, thereby increasing its strength.

The water content in fresh concrete determines the porosity of hardened concrete, influencing its strength and durability [12]. When the water-to-cement ratio (W/C) decreased from 0.26 to 0.20, the slump flow of HSFGCs using silica sand reduced from 26 cm to 23 cm, while the compressive strength increased from 70.26 MPa to 101.9 MPa. This indicates that lowering the W/C ratio decreased the workability but enhanced the compressive strength of the concrete. This trend aligns with studies showing that a reduced W/C ratio leads to higher compressive strength due to decreased porosity in the concrete matrix [13], [14].

3. Test results and discussion

3.1. Effect of different fine aggregates on the workability of HSFGCs

Table 3. Test results of HSFGCs.

No.	Matrices		Compressive strength (MPa)	Flow diameter (cm)	Volume weight (kg/m^3)
1	SS1_0.26	SP1	72.8	26	2280
		SP2	70.26		
		SP3	68.03		
		Average	**70.36**		
		ST	1.95		
2	SS2_0.26	SP1	64.23	25	2218
		SP2	67.72		
		SP3	66.71		
		Average	**66.22**		
		ST	1.47		
3	RS_0.2	SP1	50.65	25	2117
		SP2	56.14		
		SP3	46.55		
		Average	**51.11**		
		ST	3.93		
4	SS1_0.2	SP1	103.25	23	2348
		SP2	100.79		
		SP3	101.69		
		Average	**101.91**		
		ST	1.02		
5	SS2_0.2	SP1	83.95	22	2330
		SP2	81.24		
		SP3	85.49		
		Average	**83.56**		
		ST	1.76		
6	RS + SS1_0.2	SP1	85.24	23	2276
		SP2	90.37		
		SP3	77.59		
		Average	**84.40**		
		ST	5.25		
7	SS1 + SP_0.2	SP1	107.43	21	2395
		SP2	107.23		
		SP3	109.56		
		Average	**108.07**		
		ST	1.05		

ST: standard deviation

a) RS_0.2

b) SS1_0.2

c) SS2_0.2

d) SS1_0.26

e) SS2_ 0.26

f) RS + SS1_ 0.2

g) SS1 + CP_0.2

Figure 4. Fracture images of HSFGCs after compression.

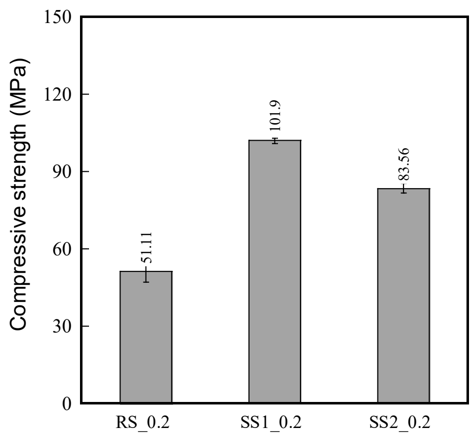

Figure 5. Effects of different fine aggregates on the compressive strength of HSFGCs.

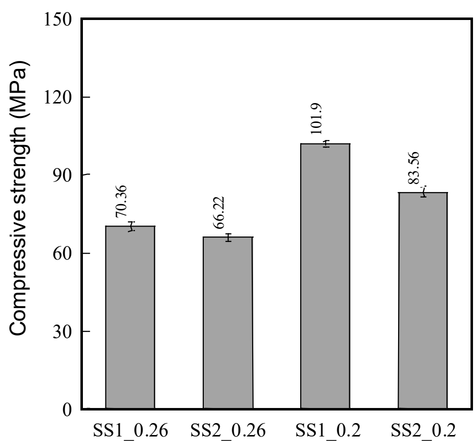

Figure 6. Effects of the different silica sands on the compressive strength of HSFGCs with different W/C ratios.

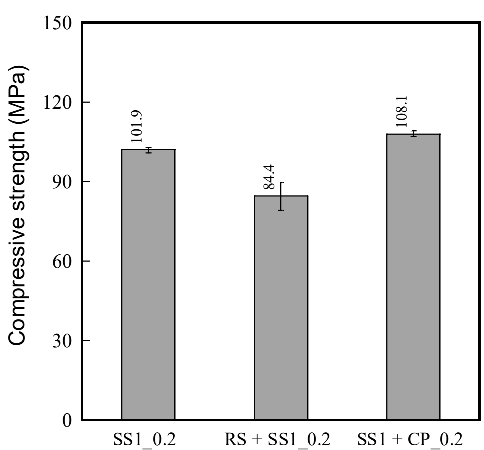

Figure 7. Effects of the combination of fine aggregates on the compressive strength.

3.2. Effects of the combination of different fine aggregates on the compressive strength

The concrete with silica sand, incorporating 10 % ceramic powder content, achieved a compressive strength of 108.1 MPa. Furthermore, as indicated in Table 3, the ceramic powder was used as a filler due to its finer particle size compared to sand. This allowed the ceramic powder to fill the voids within the sand structure of the concrete, enhancing its density and consequently increasing its compressive strength. The results of determining the bulk density of various high-strength concrete types are summarized in Table 3. A combination of silica sand and ceramic powder with different diameters enhanced the packing density in the HSFGC microstructure and improved its compressive strength. Besides, the addition of silica fume in the matrix composition increased the pozzolanic reaction and filled the pores in the microstructures of HSFGCs [15], [16], [17]. Hence, the SS1 + CP_0.2 produced the highest compressive strength. Curing under heat and humidity conditions for 3 days allowed almost complete hydration of the binders [16], [18], [19] and resulted in a compressive strength exceeding 100 MPa of HSFGCs.

High-strength concrete offers significant potential applications in the construction of high-rise and super-high-rise buildings. Its superior load-bearing capacity enhances the strength of concrete components, allowing for reduced column sizes and increased usable interior space. Additionally, the use of high-strength concrete can decrease the amount of reinforcement steel required, thereby reducing the overall weight of the structure, improving economic efficiency, and lessening the load on the foundation.

4. Conclusions

The study investigated the effects of different fine aggregates including river sand, silica sand, crushed quartz sand, and ceramic powder on the workability and compressive strength of HSFGCs. Based on the research results within the scope of the laboratory, the following conclusions have been drawn:

Silica sand and crushed quartz sand produced a significantly higher compressive strength than river sand. HSFGSs with silica sand produced the highest compressive strength. A combination of silica sand and river sand (RS + SS1_0.2) generated a compressive strength of 84.4 MPa.

When the water-to-cement ratio decreased from 0.26 to 0.2, the flowability of the mix decreased from 26 cm to 20 cm, but the compressive strength of the HSFGC with silica sand increased from 70.4 to 101.9 MPa.

The study has achieved its goal of producing concrete with a compressive strength exceeding 100 MPa. The HSFGC mix design with cement PCB40, silica sand, water, silica fume, and superplasticizer of 1, 1.25, 0.2, 0.15, and 0.067 by weight ratio of cement, respectively, produced a compressive strength of 101.9 MPa.

The HSFGC with silica sand and 10 % ceramic powder can achieve a compressive strength of up to 108.1 MPa, making it a promising mix for the development of ultra-high-strength concrete (UHSC) with economic advantages. Some potential applications in various fields include high-rise and super-high-rise buildings, large-span bridges, unique architectural structures, and technical infrastructure systems.

Acknowledgments

The research was funded by the Hanoi University of Mining and Geology, for project code T25-42 (Dr. Le Huy Viet is the principal investigator) and student scientific research projects in the academic years 2023-2024 and 2024-2025. The authors would like to thank the Department of Underground and Mining Construction Laboratory, Hanoi University of Mining and Geology for supporting the tests.

Author Contributions

Nguyen Sy Duc – Writing draft version, Data Analysis, Investigation; Ngo Ton Hieu, Do Manh Nam, and Ngo Trung Hieu – Specimen preparation, Evaluation, and Editing; Le Huy Viet - Methodology, Manuscript Writing, Verification, and supervision.

References

[1]. TCVN 10306:2014, "High Strength Concrete - Cylindrical Pattern Component Design" 2014. (Bê tông cường độ cao - Thiết kế thành phần mẫu hình trụ).

[2]. N. V. Tuấn, N. C. Thắng, and P. H. Hanh, "Study on the development of ultra-high-strength concrete using mineral admixtures to partially replace cement in Vietnam towards sustainable development", Journal of Science and Technology in Civil Engineering, 2015. (Nghiên cứu chế tạo bê tông cường độ siêu cao sử dụng phụ gia khoáng thay thế một phần xi măng ở Việt Nam hướng tới phát triển bền vững).

[3]. N. C. Thắng, N. T. Thắng, P. H. Hanh, N. V. Tuấn, L. T. Thành, and N. T. Lâm, "Research and manufacture of ultra-high-quality concrete using silica fume and ground granulated blast furnace slag in Vietnam", Journal of Science and Technology in Civil Engineering, 2013 (Nghiên cứu chế tạo bê tông chất lượng siêu cao sử dụng silica fume và xỉ lò cao hạt hóa nghiền mịn ở Việt Nam).

[4]. N. C. Thắng, N. T. Thắng, P. H. Hanh, N. V. Tuấn, L. T. Thành, and N. T. Lâm, "Study on the production of ultra-high-performance concrete using silica fume and ground granulated blast furnace slag in Vietnam", Journal of Science and Technology in Civil Engineering, 2013 (Nghiên cứu chế tạo bê tông chất lượng siêu cao sử dụng silica fume và xỉ lò cao hạt hóa nghiền mịn ở việt nam).

[5]. T. N. Công, N. V. Tuấn, and P. H. Hanh, "Effect of Mineral Admixtures on the Corrosion Resistance of Reinforcement in Ultra-High Performance Concrete", Journal of Science and Technology in Civil Engineering, 2015. (Ảnh hưởng của phụ gia khoáng đến khả năng ăn mòn cốt thép trong bê tông chất lượng siêu cao).

[6]. P. D. Hòa, K. Đ. Tùng, N. T. Phát, N. M. Hùng, L. B. Danh, and N. C. Thắng, "Proposal of several standardized I-shaped cross-sections for pre-tensioned prestressed bridge girders using UHPC materials manufactured in Vietnam", Journal of Science and Technology in Civil Engineering, vol. 14, pp. 1–13, 2020, (Đề xuất một số tiết diện chữ I định hình cho dầm cầu dự ứng lực căng trước sử dụng vật liệu UHPC sản xuất tại Việt Nam).

[7]. L. H. Viet, D.P. Lam, N. S. Duc, N. T. Thuong, T. N. Thanh, N. D. Liem, K. D. Joo, "Damage sensing characteristics of smart ultra-high-performance concrete containing electrically conductive fiber and particle fillers under high compressive stress", Sensors Actuators A Phys., vol. 383, Mar. 2025, doi: 10.1016/j.sna.2025.116242.

[8]. L. H. Viet, N. V. Manh, P. T. Nhan, T. V. Lam, P. X. Nui, N. D. Liem, K. D. Joo, "Self-sensing characteristics of smart high-performance cementitious composites containing multiwall carbon nanotubes, steel fibers, and steel slag aggregates under compression," Sensors Actuators A Phys., vol. 365, Jan. 2024, doi: 10.1016/j.sna.2023.114920.

[9]. L. H. Viet; N. V. Khuay; L. N. Nam; P. V. Khai; T. D. Tu; T. V. Lam; P. X. Thuy, "Study on the fine-grained concrete with compressive strength over 100 MPa using steel slag particles as a replacement for sand", Journal of Materials and Construction, vol. 13, no. 6, pp. 5–12, 2023. (Nghiên cứu chế tạo bê tông hạt mịn cường độ chịu nén trên 100 MPa sử dụng hạt xỉ thép thay thế cát).

[10]. L. H. Viet; Đ. A. Duc, N. V. Manh; N. T. Khanh; N. D. Liem, "Compressive and electrical resistivity properties of UHPC containing different steel fibers" Xây dựng, pp. 110–114, 2023. (Đặc trưng nén và điện trở suất của bê tông cường độ siêu cao sử dụng các loại sợi thép khác nhau).

[11]. M. Zhao, X. Zhang, and Y. Zhang, "Effect of free water on the flowability of cement paste with chemical or mineral admixtures," Constr. Build. Mater., vol. 111, pp. 571–579, 2016, doi: 10.1016/j.conbuildmat.2016.02.057.

[12]. K. C. Hover, "The influence of water on the performance of concrete," Constr. Build. Mater., vol. 25, no. 7, pp. 3003–3013, 2011, doi: 10.1016/j.conbuildmat.2011.01.010.

[13]. C. Hu, "Microstructure and mechanical properties of fly ash blended cement pastes," Constr. Build. Mater., vol. 73, pp. 618–625, 2014, doi: 10.1016/j.conbuildmat.2014.10.009.

[14]. T. Akçaoğlu, M. Tokyay, and T. Çelik, "Assessing the ITZ microcracking via scanning electron microscope and its effect on the failure behavior of concrete," Cem. Concr. Res., vol. 35, no. 2, pp. 358–363, 2005, doi: 10.1016/j.cemconres.2004.05.042.

[15]. R. Hela, L. Bodnarova, and L. Rundt, "Development of Ultra High Performance Concrete and Reactive Powder Concrete with Nanosilica," IOP Conf. Ser. Mater. Sci. Eng., vol. 371, no. 1, 2018, doi: 10.1088/1757-899X/371/1/012017.

[16]. M. K. Maroliya, "Micro Structure Analysis of Reactive Powder Concrete," Int. J. Eng. Res. Dev., vol. 4, no. 2, pp. 68–77, 2012.

[17]. B. A. Graybeal and H. G. Russel, "Ultra-High Performance Concrete: A State-of-the-Art Report for the Bridge Community. The Federal Highway Administration, p. 176, 2013.

[18]. L. T. Thành, "Effect of curing regimes on the compressive strength of Ultra-High-Performance Concrete", Journal of Construction Science and Technology, pp. 23–29, 2017. (Ảnh hưởng của chế độ dưỡng hộ đến cường độ chịu nén của bê tông chất lượng siêu cao).

[19]. H.V. Le, M.K. Kim, D.J. Kim, J. Park, "Electrical properties of smart ultra-high performance concrete under various temperatures, humidities, and age of concrete", Cem Concr Compos, vol. 118, 2021.