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Experimental investigation on permanent UHPC formwork based on the axial compression test on the concrete core of NSC-UHPC columns

Khảo sát thực nghiệm ván khuôn UHPC bền vững dựa trên thí nghiệm nén dọc trục trên lõi bê tông cột NSC-UHPC

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ABSTRACT

The paper aims to present the test results of circular ultra-high performance concrete (UHPC) formworks filled inside by normal strength concrete (NSC) without steel reinforcements, called NSC-UHPC columns. Several UHPC formworks were produced to fill NSC inside. Three steel fiber volume fractions, including 0%, 1%, and 2%, were added to the UHPC mixture. The material strengths were tested on the cylinder samples under concentric loading, and the NSC-UHPC columns were compressed on the NSC core. The test results indicated that the ultimate loads of the columns, confined by UHPC formworks adding steel fibers, are significantly increased. Besides, the effect of UHPC thickness and steel fiber volume fractions on the strength enhancement was clarified. It is recommended that UHPC is a potential material to produce permanent formwork for casting on-site the normal strength concrete.

Keywords: UH; steel fibers; composite columns; UHPC formwork.

TÓM TẮT

Bài báo trình bày kết quả thí nghiệm ván khuôn tròn làm bằng bê tông tính năng siêu cao (UHPC) với bê tông cường độ thường (NSC) được đổ vào bên trong, không có cốt thép, được gọi là cột NSC-UHPC. Ván khuôn UHPC đã được sản xuất để đổ NSC vào bên trong. Thử nghiệm sử dụng ba tỷ lệ thể tích sợi thép, là 0%, 1% và 2%, trong hỗn hợp UHPC. Cường độ vật liệu được thử nghiệm trên các mẫu lăng trụ trong điều kiện nén đúng tâm, và các cột NSC-UHPC được nén trên lõi NSC. Kết quả thử nghiệm cho thấy tải trọng cực đại của các mẫu cột, được hạn chế nở hông bởi ván khuôn UHPC có sợi thép, tăng lên đáng kể. Bên cạnh đó, ảnh hưởng của chiều dày UHPC và tỷ lệ thể tích sợi thép đến việc tăng khả năng chịu nén đã được làm rõ. Có thể thấy rằng UHPC là vật liệu tiềm năng để sản xuất ván khuôn vĩnh cửu cho bê tông cường độ thường đổ tại chỗ.

Từ khóa: UHPC; sợi thép; cột composite; ván khuôn UHPC.

1. INTRODUCTİON

Several investors do not want to destroy the natural environment due to the construction process. They have been looking for permanent formwork applied to their construction. Besides, fixed formwork is an approach to reduce the time of structure construction and simplify the construction process. Fixed formwork is an innovation of construction technology that could increase the speed of structure construction, strength, and architectural expressiveness [1]. Several studies of permanent formwork have been conducted with various types, such as concrete blocks and slabs. However, the permanent formwork from UHPC is rarely investigated.

Reinforced concrete columns (reinforced concrete) are subject to many objective impacts of the surrounding environment under different forms such as chemical, physical and mechanical effects [2]. In addition, subjective factors such as errors in design and construction, earthquakes, fires, and explosions [3] can all lead to cracked reinforced concrete columns, reduced load capacity, and reinforcement in columns corroded over time, damaged locally or the entire column. All impacts that cause damage to the reinforced concrete column make it unsafe in terms of load-bearing and unresponsive in terms of use. The formwork made of UHPC, a based-concrete material, could not only ensure durability and integrity level but also limit the impacts that cause damage to the reinforced concrete columns.

The advantages of the UHPC formwork include the following aspects: (1) a durable protective formwork prevents the effects of aggressive elements; (2) prevention from spalling of the concrete cover of steel reinforcements; (3) reduced costs since the durability of UHPC promises no maintenance in long life-cycle; (4) interfacial solid bond strength between UHPC formwork and concrete columns [4-8]; (5) applicability to reinforcement concrete columns with various shapes.

This paper focused on the confining effect of external UHPC formworks on the compressive strength of concrete columns. The thickness of the UHPC formwork and steel fiber content determined the confining-force efficiency and cost of the approach method. It is necessary to study their influences on the compressive behavior of concrete columns based on experimental investigation.

The NSC column samples are reinforced with UHPC or UHPC adding steel fibers (UHPFRC), called NSC-UHPC samples. The specimens are compressed on the inner NSC core to simulate a concrete column reinforced with a UHPC formwork. Experimental results help evaluate the practical applicability in UHPC permanent formwork.

During the experiment, the maximum load (P_{max}) is recorded. This value was used to determine the enhanced compressive strength of the plain concrete column specimens confined by UHPC permanent formwork. In addition, an important parameter reflecting the plasticity of a concrete column having external UHPC formworks is the ductility index (DI). Column ductility is defined as the ability of the column to deform after the elastic period while maintaining its load-carrying capacity until the column fails. The ductility of the column is expressed by the ductility index DI. Several methods are calculating the ductile index, but for conjugated columns, according to previous studies, the ductile index DI is calculated as follows:

$$DI = \frac{\Delta_{90\%}}{\Delta_y} \quad (1)$$

Where,

$\Delta_{90\%}$ is displacement as the load is reduced to 90% of P_{max}, during the softening phase;

Δ_y is the displacement as the load increases to 75% of P_{max}, during the loading phase.

2. EXPERIMENTAL PROGRAM

Material

Materials used in the experiment were the composition material of UHPC having an average compressive strength of 120MPa, including cement, silica fume, crushed sand, fine-grained clean sand, superplasticizer, clean water, and steel fibers.

Cement

The experiment cement was PC50 according to the requirements of UHPC. The compressed strength reached 52.5 MPa after 28 curling days, which is suitable for the fabrication of UHPC.

Silica fume

The Silicafume, SikaCrete PP-1 provided by Sika Vietnam, was a mineral additive with more than 95% silicon content.

Fine-grained sand and crushed sand

The sand used in the experiment was taken from the Cam-Ranh to ensure purity and fineness. The average diameter of particles was about 0.50 mm. Crushed sand powder containing an average of 99% silica by volume, produced after crushing quartz sand with the highest average aggregate diameter of 0.075 mm.

Superplasticizer

Superplasticizer is manufactured by the GRACE company and imported to Vietnam. This additive could help the water reduce by up to 40%.

Fiber

Microfiber with corrosion-resistant has a diameter (0.2±0.008) mm, length (13±0.05) mm, yield strength of 2850 MPa, and density of about 7.85 g/cm^3.

Specimen Fabrication

The mixing composition used for the UHPC and UHPFRC formworks has PC50 cement content of 1000 kg/m^3, and the ratio of water/binder is 0.2 to create a more liquid UHPC mixture for easy pouring into the mold with a small thickness. In addition, the superplasticizer content is used at a ratio of 3% compared to the amount of cement to help the UHPC fresh mixture to have flexibility - high flowability and easy pouring. The content of Silicafume compared to cement is 25%. This ratio is commonly used in UHPCs.

Table 1. Material composition in UHPC grade with steel fiber and without steel fiber

Aggregate type	Mixing composition with variable steel fiber content		
	UHPC	UHPFRC (1% steel fiber)	UHPFRC (2% steel fiber)
PC50 Cement (kg/m^3)	1000	967.9	966.8
Silicafume (kg/m^3)	250	242.0	242.0
Fine-grained sand (kg/m^3)	665	643.7	642.0
Crushed sand (kg/m^3)	250	242.0	242.0
Superplasticizer (liters)	30	29.05	29.0
Water (kg/m^3)	250	242.0	242.0
Steel Fiber (kg/m^3)	-	78.5	157.0
Water/binder	0.2	0.2	0.2

The concrete mix composition used for the NSC column is presented in Table 2. The concrete mix includes the following essential ingredients such as PC40 cement, crushed stone the size of 10x20, sand, and water. The components were estimated for a cubic meter of concrete mix.

Table 2. Material composition in normal strength concrete

Aggregate type	Quantity in 1m^3
PC40 Cement (kg/m^3)	470
Sand (kg/m^3)	596
Stone aggregates (kg/m^3)	1376
Water (liters)	198

The outer UHPC permanent formwork was fabricated first. It is based on the natural concrete casting order. Then the normal strength concrete without the steel reinforcement was filled inside the UHPC formwork. This study concentrated on the effectiveness of UHPC in confining concrete cores. Thus, the steel reinforcements were not placed in the NSC cores because the steel reinforcement frame may affect the hip expansion of the inside concrete core.

Plastic molds were utilized to fabricate the UHPC cylinders. After three days, the UHPC samples were removed from the mold and cured in water for at least seven days. UHPC formwork samples were fabricated with various UHPC thickness and fiber ratios. The experiment was conducted on the NSC columns with a diameter of 60 mm, and a height of 600 mm.

Cylinder samples, 100x200mm, were fabricated to check the compressive strength based on standard TCVN 10303:2014 [9]. The core concrete inside the NSC-UHPC sample has an average compressive strength of 20±2 MPa. For UHPC formworks, the compressive strengths of the UHPC with 0%, 1%, and 2% were 120.76, 126.38, and 144 MPa, respectively.

3. FAILURE MODE OBSERVATIONS

Figure 1(a) depicts the NSC core in the compression strength testing process, while Figure 1(b) depicts a column sample including the NSC core reinforced by a UHPFRC in the testing process. Figure 1(c) shows the cross-section of a destroyed specimen after testing. It could be observed that concentric cracks appeared on the sample, and there was an apparent separation of the inner core and the outer UHPFRC layer. It is well known that the core concrete was lateral expanded when compressed. The external UHPFRC formwork is in tension due to mitigating the NSC core lateral expansion. The concentric crack appeared equally spaced at an angle of 120° apart. It indicates that the UHPFRC formwork was stretched relatively evenly in the tangent direction. As a result, the UHPFRC formwork was destroyed due to tension. Besides, it could be observed from the specimen side that the cracks along the length of the specimen at failure (Figure 1(d)).

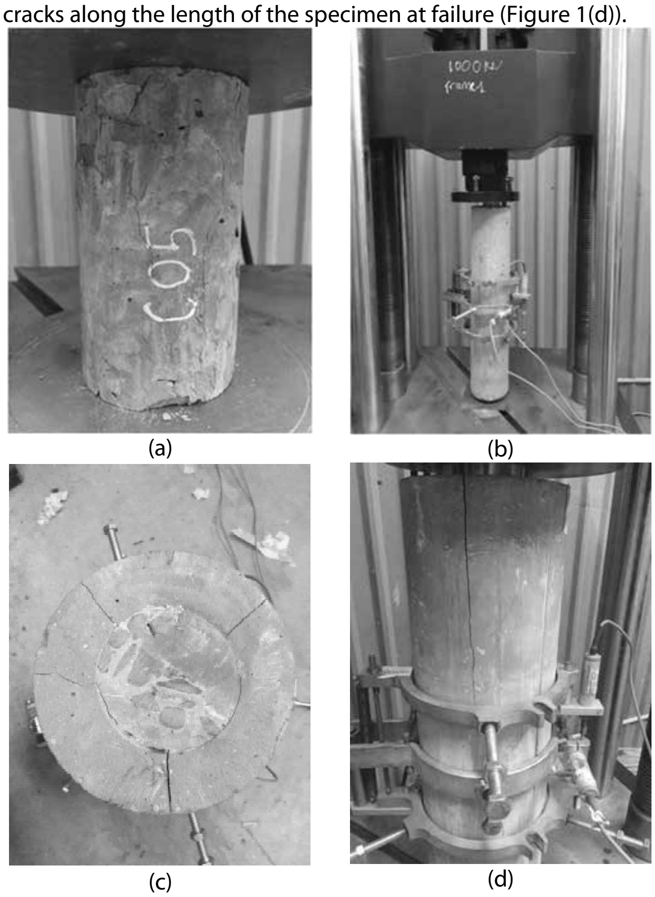

Figure 1. Concrete samples compression test on core.

4. TEST RESULTS

Figure 2 shows the compressive strength of NSC-UHPC samples with 0-2% fiber content. For the compression column on core, the NSC-UHPC column without steel fibers gave a small load capacity, lower than the strength of the inside concrete core, 20MPa. The reason is that when there is no fiber, the inside concrete core expands, even if it is small, causing the UPHC formwork to be destroyed before the inside concrete core is destroyed. However, for the compression column on the core with the UHPFRC formwork, using steel fiber, the failure process lasts longer than that of UHPC not using steel fibers, thus maintaining better lateral expansion control. The figure shows that the NSC-UHPC column with 1% fibers and the NSC-UHPC column with 2% fibers have increased load capacity by 57% and 115% compared to the NSC core strength of 20MPa.

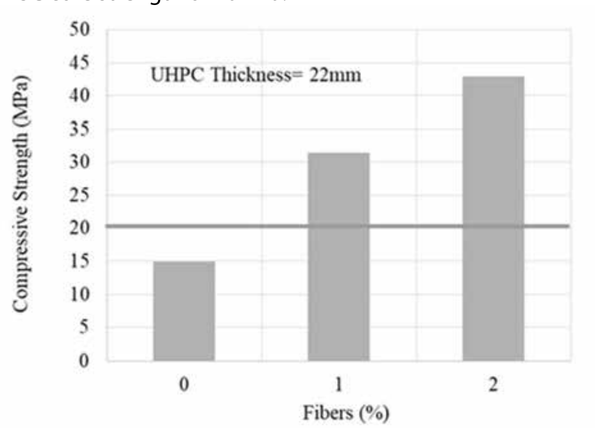

Figure 2. NSC-UHPC compressive strength variation according to steel fiber volume fractions.

Figure 3 shows the compressive strength of NSC-UHPC samples with different UHPC formwork thicknesses in the case of 0% steel fiber and 1% steel fiber content. For the compression column on the core, the NSC-UHPC column with 0% steel fiber (Figure 3a) has a small loading capacity than the NSC core, 20MPa, with a thickness less than 32mm. The reason was that when the thickness of the UHPC formwork was not thick enough, the tensile strength of the UPHC formwork was not high enough, and the concrete core was expanded, causing the UPHC formwork to be destroyed before the concrete core was destroyed. NSC-UHPC column with 46mm UHPFRC layer thickness increased 45% compared to the compressive strength of the NSC core.

Figure 3 shows the compressive strengths of the NSC-UHPC column with 1% fiber were higher than that of the NSC-UHPC column with 0% fiber. The maintenance of tensile strength lasts longer in the case of a UHPC formwork strengthened by steel fiber, thus maintaining better lateral expansion control. As a result, the compressive strengths of the NSC-UHPC column with 1% fiber were higher than the strength of the NSC core.

Figure 3 also shows that the compressive strength of NSC-UHPC specimens increased when the thickness of the UHPFRC formwork was increased. The reason is that the lateral expansion of the core is mitigated by the UHPFRC formwork thickness rising, leading to an increase in the compressive strength of the entire NSC-UHPC specimens. NSC-UHPC column with a layer thickness of UHPFRC 22, 32, and 46 mm increased the compressive strength by 57%, 97%, and 249%, respectively, compared with the NSC strength.

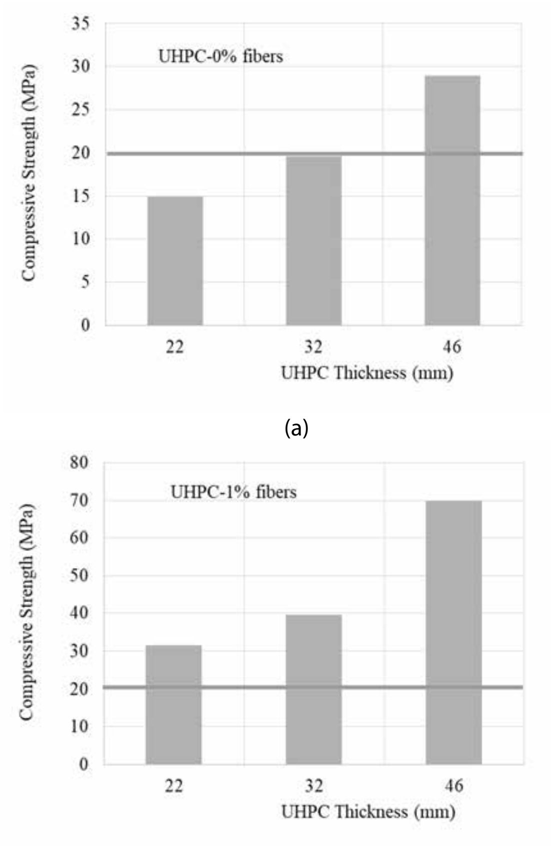

Figure 3. NSC-UHPC compressive strength variation according to UHPC thicknesses.

Figure 4 shows the ductile index of the experimental column samples. NSC-UHPC column samples with 0% fiber did not determine the ductility index. Because the NSC-UHPC specimens were in brittle destroy. All NSC-UHPC columns with the UHPC strengthened by steel fiber could maintain the load-bearing capacity after the compression load on the inside concrete core reaches the maximum value. Then, the ductile index of the NSC-UHPC columns could be determined.

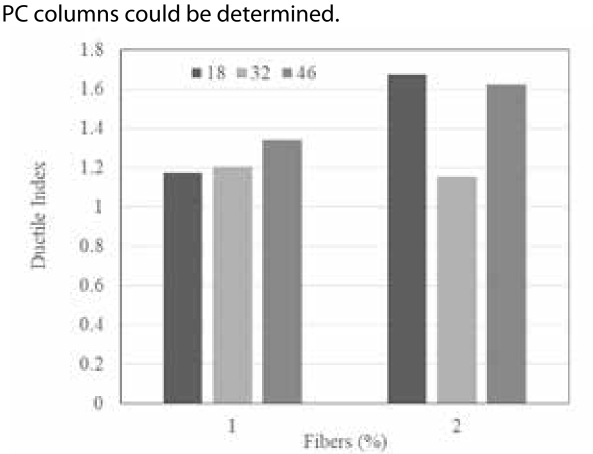

Figure 4. Comparison of ductility index DI of experimental columns

Figure 4 shows that the NSC-UHPC columns with 1% fiber had a lower ductility index than that of NSC-UHPC columns with 2% fiber in the case of UHPFRC layer thicknesses of 18 and 46mm. However, this trend of ductility index was not consistent in the case of the NSC-UHPC of 32mm thickness. The NSC-UHPC column with 2% fiber gave a ductility index 4% lower than that of the NSC-UHPC column with 1% fiber. The reason may be due to the arbitrary distribution of steel fibers and the size effect of the UHPFRC layer. This issue needs to be investigated further.

5. CONCLUSIONS

Experimental investigation on circular UHPC formwork confining NSC columns under axial compression on the core has been done to study the effectiveness of the outer UHPC jacket in confining the inside concrete core. The UHPC and the NSC have been tested for material strength. The compressive strength of UHPC and NSC was 120 Mpa and 20 Mpa, respectively. The following conclusions could be given based on the experiment on the NSC-UHPC samples:

- The 2% steel fiber content of the UHPC formwork gives the highest load capacity of the NSC-UHPC column.
- The NSC-UHPC column with 0% fiber has compressive strength higher than the NSC core strength when the UHPC formwork layer is thick enough. And the compressive strength of the NSC-UHPC column with 0% fiber could be lower than that of the NSC core. The reason is that the UHPC formwork is easily destroyed before the inner concrete core is destroyed.
- Increase in steel fiber content could increase the ductility index of the NSC-UHPC column. However, this trend may not be consistent. The arbitrary distribution of steel fibers and the size effect of the UHPFRC layer could explain this behavior.

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