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Original Article

Investigation on HPC Performance Using Local Materials in Cambodia

Cheanorin Khim[1], Hor Yin[2]

[1,2]*Graduate School, National Polytechnic Institute of Cambodia, Phnom Penh, Cambodia.*

[1]*Corresponding Author : cheanorinkhim@gmail.com*

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Abstract *- The paper examines the evolution of High-Performance Concrete (HPC) utilizing regional aggregate and sand in Cambodia. The evolution of this study was based on the constituents and properties of concrete in engineering technology, which is to be accomplished as an HPC in Cambodia. The local materials for mixing HPC were tested to ensure the quality control of the HPC. In this study, 186 100-mm cubes and 84 100×100×400 mm prismatic beams with various mixing proportions were prepared and tested to observe the properties of HPC, including compression strength, elastic modulus, and flexural strength. The result suggests that the HPC gave promising performance to the properties of local materials with compressive strength of over 80 MPa and flexural strength of about 10 MPa. In addition, the elastic modulus was conservative relative to the equation given by ACI 318.*

Keywords *- High performance concrete, Material testing, Compressive strength, Flexural strength, modulus of elasticity, Local Aggregate.*

1. Introduction

High-performance concrete was distinguished by three main features: strength, durability, and ductility. Accordingly, much attention has been given to the study of mix formulations that provide workable fresh concrete and resilient, enduring hardened concrete. Published research indicates that high-performance concrete made with a low water-to-binder (W/B) ratio demands a considerable quantity of cement and reduced water-to-binder ratio [1, 2], increasing the risk of long-term creep and shrinkage issues [3]. Furthermore, the normal weight concrete that uses increased cement dosage will lead to higher water requirements, which may cause detrimental issues like bleeding, segregation, and poor interfacial bonding between aggregates [4, 5].

Consequently, achieving high workability with reduced water and binder usage requires more in-depth research. It is widely recognized that increased cement proportion contributes to high-strength concrete [6]. Hence, a resolution to the previously discussed issue may be based on concrete mix designs. Additionally, only a small number of studies have explored applying recycled aggregates in the production of HPC, teeming from the challenges posed by the fundamental weaknesses of recycled aggregates [7, 8]. For fibres, including steel, carbon, and polymer, enhance the mechanical properties of concrete. Polypropylene fibres are noted for their cost-effectiveness, toughness, and ability to reduce shrinkage cracking, while steel fibres are recognised for their superior tensile strength and stiffness. Fibres can significantly enhance compressive strength, splitting tensile strength, and flexural strength [9]. On the other hand, the elastic modulus of high-performance concrete is a fundamental property of concrete that is essential for modelling its behaviour in structural applications. Understanding how it varies with time and the factors influencing it is critical for predicting concrete structures' long-term performance and durability [10]. More producers must know the factors affecting compressive strength and know how to vary those factors for the best result [11].

In this study, the properties of local constituents available in Cambodia for mixing HPC were tested and reported. Compression and flexural strength were obtained accordingly to ACI & ASTM. This research contributes to the use of concrete in Cambodia. Results of the properties of HPC were presented.

2. Materials and Methods

2.1. Constituent Materials

2.1.1. Cement

While mixing concrete, we used Ordinary Portland Cement (Type I) to mix with other materials in concrete. At this stage, the properties of cements are described in Table 1.

Table 1. Mechanical properties of compositions of cement

Properties	Unit	Cement
unit weight	**(kg/m^3)**	3,068
Fineness	**(m^2/kg)**	352.6
Soundness	(%)	0.05
Vicat test		
Initial Set	min	113
Final Set	min	185
Air Content of Mortar	%	9.5
Compressive strength		
Mortar Cubes		
Age 3 (days)	N/mm^2	25.1
Age 7 (days)	N/mm^2	32.8

2.1.2. Fine Aggregate

In mixing concrete, natural sand locally available in Cambodia has a bulk density of 2,605 kg/m^3. For sand, we tested it in the laboratory to confirm the ASTM C33-18 standard. The gradation test of natural sand for percentage retained and Passing is given in Table 2.

Table 2. Gradation Test of Natural Sand

Opening	Mass Retained (g)	Total Mass Retained (g)	Total Retained (%)	Passing Percent (%)
9.50mm	130	130	4.50	95.50
4.75mm	1,896	2,021	56.58	43.42
2.36mm	790	2,811	78.70	21.30
1.18mm	239	3,050	85.39	14.61
0.600mm	123	3,173	88.83	11.17
0.300mm	145	3,318	92.89	7.11
0.150mm	86	3,404	95.30	4.70
0.075mm	47	3,451	96.61	3.39

2.1.3. Coarse Aggregate

Granite aggregate was used at a bulk density of 2.658 kg/m^3 and grain size ranging from 4.75mm to 9.5mm in this study. Granite aggregate is mostly available worldwide in our region and is durable and workable in concrete casting. The strength grades of the cubes ranged from 30 to 100 MPa. The test sieve analysis of granite aggregate for percentage retained and Passing is shown in Table 3.

Table 3. Gradation test of natural aggregate

Opening	Mass Retained (g)	Total Mass Retained (g)	Total Retained (%)	Passing Percent (%)
19.00mm	5	5	0.11	99.89
12.50mm	7	12	0.27	99.73
9.50mm	105	117	2.65	97.35
4.75mm	3852	3969	89.96	10.04
2.36mm	437	4406	99.86	0.14

2.1.4. Admixture

Admixture used in this concrete mixture is Sikaplast8588. The properties of this admixture are extremely high water reduction, faster development of early strength, more workability, and improved creep and shrinkage resistance characteristics. In the binder, 100 kg of cement, we use this admixture in 0.5-2.4 ltr.

2.2. Mix Proportion

In the procedure for mix design, it is the core content of concrete theory and practice. Moreover, it is a basic problem in concrete production and its application. The concrete mix design in huge amounts determines almost all of the concrete performance, such as workability, strength, durability, and economy. Therefore, mix design plays an important role in the concrete [14]. The ACI procedure was applied to determine the proportions of cement in the constituents of concrete. A study was conducted to evaluate the mass per unit volume of concrete. In this study, an HPC mixing for resistance to compressive force of 80MPa was assigned to apply ordinary Portland cement confirmed to standard in trial-mix with difference amount of sand and aggregate conforming to ASTM C33 [12], crushed natural granite aggregates (maximum 10mm diameter obtained from crushing granite stone with crushing strength around 120MPa) and medium grade sand. Proportions of HPC Mixing are shown in Table 4, and Burg [11] was also provided for comparison purposes. It could be noted that HPC(N) in this study has been taken as the same as Burg [11] to investigate the result as a reference.

Table 4. Mix proportions of constituents of HPC

Strength	W/C	C (kg)	S (kg)	Agg. (kg)	W (L)	SP (L)
Burg [11]	0.28	564	647	1068	158	13.54
HPC(N)	0.28	564	647	1068	158	13.54
HPC(S10)	0.28	564	712	1068	158	13.54
HPC(S20)	0.28	564	776	1068	158	13.54
HPC(S30)	0.28	564	841	1068	158	13.54
HPC(A10)	0.28	564	647	1175	158	13.54
HPC(A20)	0.28	564	647	1282	158	13.54
HPC(A30)	0.28	564	647	1388	158	13.54

Note: C = cement; S = fine aggregate; Agg. = coarse aggregate; W = water; SP = superplascizer

2.3. Progress of Mixing

In mixing, both aggregate and sand were introduced and mixed for 8 minutes in a mixer. Cement is added after the mix of aggregate and sand (in 4 minutes). Next, water was introduced, followed by the air-entraining agent. All the ingredients were mixed in the concrete mixer for approximately five to six minutes. And then we put the super-plasticiser into the mixer, and mix ingredients for six more minutes and wait for finishing in 3 minutes. The batch was then placed into a plate, and equipment was used to pour concrete into a plastic cube of 100 mm in two layers. For each layer, we must vibrate the specimens by using a tamping rod. The mixing procedure in this study was similar to that of well-known literature [16]. The overall step-by-step procedure for this study is illustrated in Figure 1.

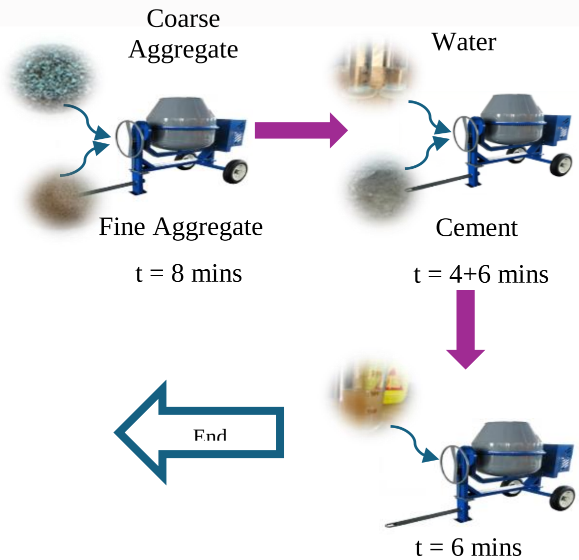


Fig. 1 Mixing procedure of HPC with $f'_c \geq 80$ MPa

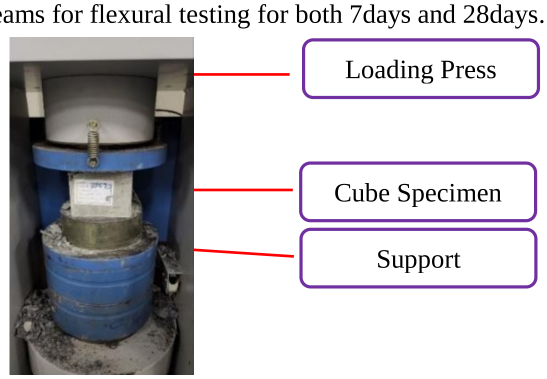
2.4. Specimens and Curing

In testing, concrete samples were arranged with $f'_c \geq$ 80 MPa. Two forms of specimens, including cubes and beams, were prepared as follows:

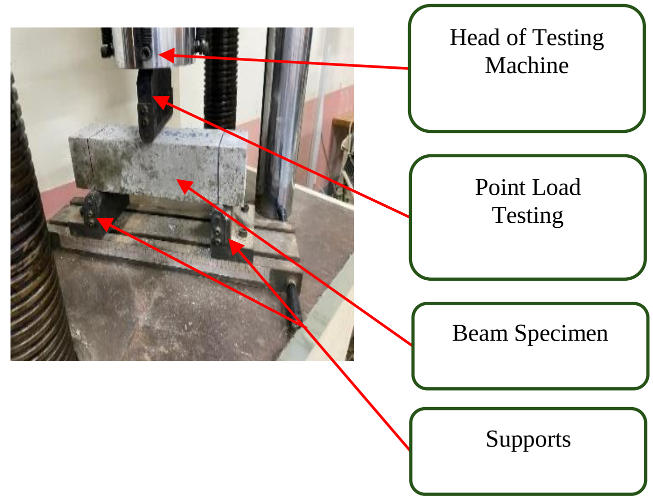
1. For compressive strength and modulus of concrete testing, a 100mm Cube size.
2. For flexural strength testing used 100×100×400mm beams size.

All concrete samples were cured in a laboratory at a temperature of 23 ºC for 28 days prior to testing.

Both samples are 100mm cube, and 100(100(400mm beam were demoulded after 24 hours, and the specimens were cured in a laboratory environment before testing in a machine. For each mix, 18 cubes are tested for compressive strength and 12 beams for flexural testing for both 7days and 28days.



(a) Cube specimen



(b) Prismatic beam specimen

Fig. 2 Test setup for compression and flexural strength

2.5. Instrumentation and Test Methods

The compressive strength is tested to conform to ASTM C-39 [17]. For a concrete sample of cube size 100mm, compressive strength, elastic modulus and beam size 100x100x400mm were tested for flexural strength at 7 and 28days in each mixing.

The specimens were loaded using a 2,000 kN hydraulic testing machine equipped with control of the rate of stroke. The data acquisition was used to collect strains for selected levels of load. The speed of stress increment was controlled and assumed to be about 0.3MPa/s. For the characteristic of concrete, the elasticity modulus is confirmed to ASTM C469 [18]. For all specimens, characteristic concrete testing was conducted at 7 and 28 days.

A stress-strain curve shown in Figure 3 has been plotted using equation (1) as an example for $f'_c = 80$ MPa. This is for the ease of the present study to show stress-strain relationships with various values of f'_c (section 3.1):

$$\frac{\sigma_c}{f'_c} = \frac{k \times x}{k - 1 + x^k} \quad (1)$$

Where σ_c Stress in concrete

f'_c Compressive strength of concrete

$x = \frac{\varepsilon_c}{\varepsilon_{c1}}$ Normalized strain

ε_c Strain in concrete

ε_{c1} Strain at peak stress

k Shape parameter that depends on the compressive strength

For shape parameter k:

$$k = \min(1.05\frac{E_c \times \varepsilon_{c1}}{f'_c}, 2.0$$

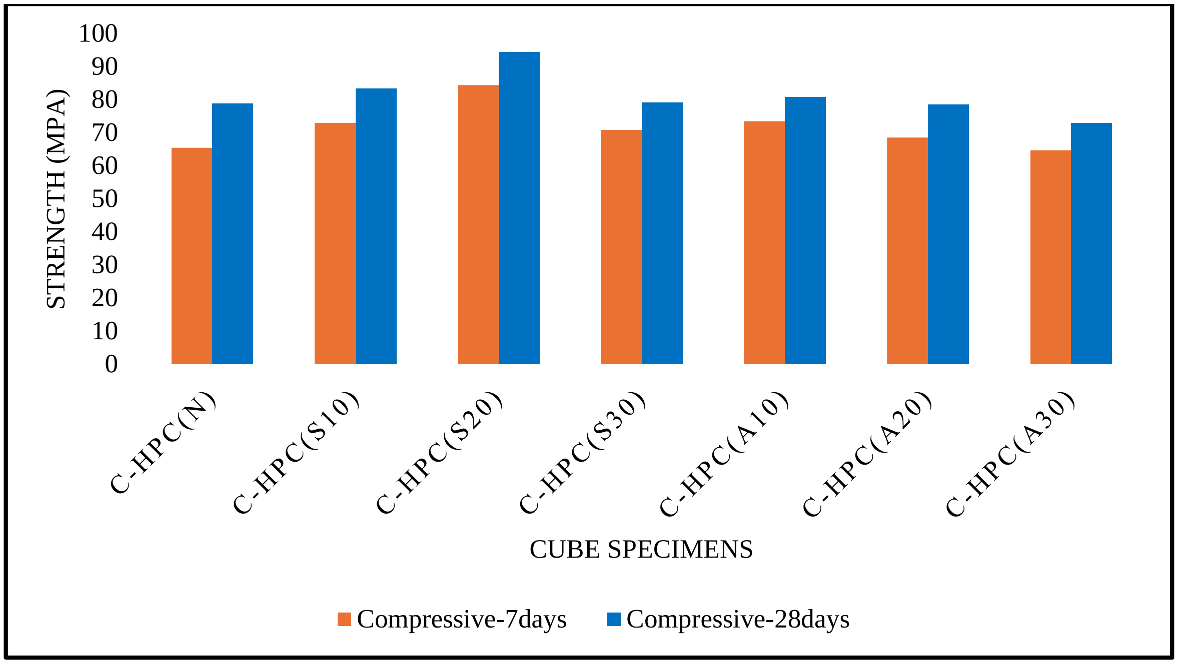


Fig. 3 Stress-stain curve obtained from equation (1) with $f`_c = 80MPa$

Table 5. Compressive strength results for HPC

Author	Mix	7-Day Cube Compression (MPa, Avg.)	28-Day Cube Compression (MPa, Avg.)	*28days Cylinder compression $f`_c$ (MPa, Avg.)
Burg [11]	**HPC (Ref.)**	-	-	79.00
Present Study	**C-HPC(N)**	65.47	78.88	69.49
	C-HPC(S10)	72.99	83.35	73.85
	C-HPC(S20)	84.42	94.48	84.75
	C-HPC(S30)	70.80	79.06	69.65
	C-HPC(A10)	73.41	80.81	71.36
	C-HPC(A20)	68.52	78.60	69.25
	C-HPC(A30)	64.67	72.90	63.71

Note:* $f_c^{'}$ is converted from cube strength at 28 days given by [19].

3. Result and Discussion

3.1. Strength under Compression

Table 5 illustrates the compressive performance of HPC at 7 and 28 days. Figure 4 displays the stress-strain relationship of HPC at 28days. The concrete mix reached maximum compressive strengths of 84.42 MPa and 94.48 MPa at 7 and 28 days, respectively.

Conversely, the compressive strength results of HPC specimens at 7 and 28 days, depicted in Figure 5, reflect the progression of concrete strength. With a 20% increase in sand, C-HPC(S20) outperformed HPC(N) in terms of compressive strength. Strength development persisted until 28 days, by which time the specimens had achieved their intended strength levels.

At 7 days, C-HPC(S20) reached around 28.94% of its intended strength, and by 28 days, it exhibited a 19.77% improvement over the reference mix, HPC(N).C-HPC(A30), with a 30% increase in coarse aggregate, showed the lowest compressive strength result, with 72.90MPa. During the test, it was noticed that the specimen failed with brittle behaviour. This failure of the concrete sample is typical of HSC concrete [4, 5]. The unexpected failure of concrete specimens may result in harm or damage, making the adoption of safety precautions imperative. HPC(S20) compared to HPC(Ref.) concrete strength improves by 7.27% in 28days for cylinder strength. Based on this result, we noticed on the HPC(S20), the concrete has higher compressive strength and ductility.

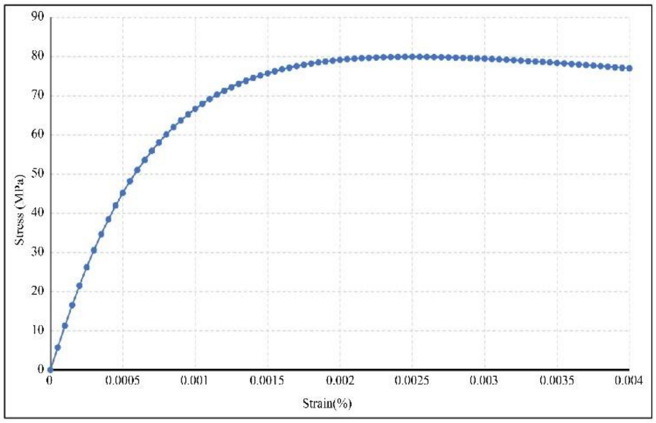


Fig. 4 Stress-stain curves at 28 days obtained from Equation (1)

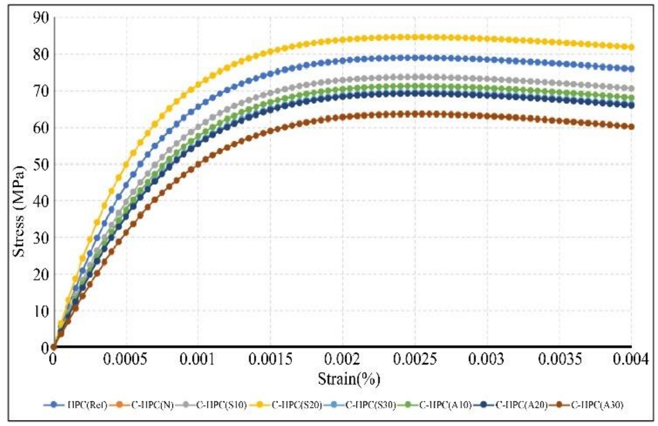


Fig. 5 Compressive strength of concrete mixing

3.2. Flexural Strength

The data in Table 6 and Figure 6 demonstrate that HPC attained a maximum flexural strength of 10.80 MPa.

The flexural strength tests of HPC concrete specimens, as shown in Figure 6, illustrate the development of strength over time. B-HPC(S10), with a 10% increase in sand content compared to the original mix, exhibited slightly slower strength gain than B-HPC(N). In contrast, B-HPC(S20), which included a 20% increase in sand, demonstrated higher flexural strength compared to B-HPC(A20), which had a 20% increase in aggregate content. Flexural strength continued to increase up to 28 days, at which point the specimens reached their design strength. B-HPC(S20) developed approximately 15.99% of its design strength within 7 days, while B-HPC(N) showed an increase of 8.98% at 28 days.

Table 6. Flexural strength result obtained from beam tests.

Author	Mix	Flexural Strength at 7 Days (Avg., MPa)	Flexural Strength at 28 Days (Avg., MPa)
Burg and Ost (1994) [11]	HPC (Ref.)	5	5.7
Present Study	B-HPC(N)	6.44	9.91
	B-HPC(S10)	6.98	9.82
	B-HPC(S20)	7.47	10.80
	B-HPC(S30)	6.84	9.25
	B-HPC(A10)	6.80	9.02
	B-HPC(A20)	6.61	8.97
	B-HPC(A30)	6.72	9.36

Table 6 highlights the performance of HPC(S20) in terms of the flexural strength increase of sand from original mixing, which was higher strength compared with the existing result from Burg and Ost [11] for reference, developed strength in 49.40% for 7 days and 89.47% for 28days.

3.3. Concrete Elasticity Modulus

The average modulus of elasticity of concrete is presented in Table 7. For C-HPC(S20), which contains a 20% increase in sand, the modulus of elasticity was found to be approximately 5.88% higher than that of the HPC(N) specimen. The modulus of elasticity for HPC mixes ranges from about 31 GPa to 52 GPa for concrete made with Portland cement only [20].

$$E_c = 9500 f`_c^{0.3} (MPa) \quad (2)$$

3.4. Hardened Concrete Density

The drying density of HPC mixing concrete was observed to be 2437 and 2757 kg/m^3. HPC(S20) with a 20% sand increment shows saturated and dry densities about 2.08% above HPC(N). Better packing and hydration of finer materials in HPC(S10) with a 10% increase in aggregate contribute to decreased absorption and lower density than HPC(N).

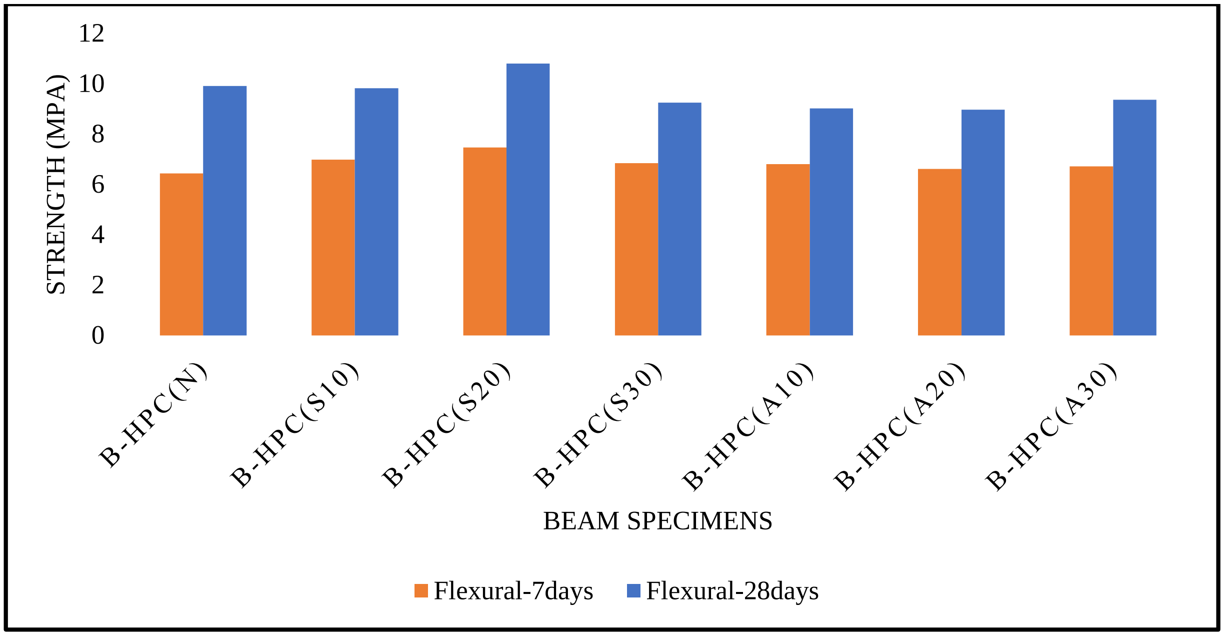


Fig. 6 Flexural strength of concrete mixing

Table 7. Modulus of elasticity of concrete for high-performance concrete

Author	Mix	***E**_c* (from Equ. (1)	***E**_c* from Equ. (2)
Burg and Ost (1994)	**HPC (Ref.)**	34 GPa	35 GPa
Present Study	**HPC(N)**	34 GPa	34 GPa
	HPC(S10)	35 GPa	35 GPa
	HPC(S20)	38 GPa	36 GPa
	HPC(S30)	34 GPa	34 GPa
	HPC(A10)	35 GPa	34 GPa
	HPC(A20)	34 GPa	34 GPa
	HPC(A30)	32 GPa	33 Pa

4. Conclusion

In the article, tests on the properties of local materials available in Cambodia for mixing HPC are conducted. Results of the strength of HPC in compression and flexure were obtained accordingly to ASTM. This research contributes to the use of HPC in Cambodia.

The results indicate that HPC made with local materials demonstrated promising performance, achieving a compressive strength exceeding approximately 80 MPa and a flexural strength of around 10 MPa. Additionally, the modulus of elasticity was conservatively estimated compared to the values predicted by the ACI 318 equation.

HPC(S20) mixes with a 20% increase of sand in the mixture, which can be considered in the mix proportion. HPC(S20) concrete specimens developed about 19.77% in advance for compressive strengths, 8.98% in advance for flexural strength, and 2.08% in advance for modulus of elasticity and resistance compared to control mixing, HPC(N).

For the flexural strength of HPC(S20), the increase of sand from the original mixing was higher than the existing result from Burg and Ost [11], for reference, developing strength at 89.47% for 28 days.

These findings highlight the potential benefits of mixing HPC Concrete with various proportions in Cambodia environments, demonstrating improved compressive and flexural strength, durability, and workability performance compared to HPC concrete without steel fibre.

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