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TESTS ON HIGH-STRENGTH HIGH-FLUIDITY CONCRETE IN THE LABORATORY AND SITE CONDITIONS

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ABSTRACT :

High-Strength High-Fluidity Concrete becomes more and more widely used in construction of high-rise buildings in the World. In Vietnam this type of concrete has just been used in some projects like Hanoi Keangnam Landmark Tower, by a South Korean firm. There are someresearch works related to theHigh-Strength High-Fluidity Concrete by Vietnamese researchers which have been publishedwith the results achieved in laboratory trail phase alone. This paper reports on the test of the High-Strength High-Fluidity Concrete both in the laboratory and site conditions. The targets set for High-Strength High-Fluidity Concretewithslump flow above 600 mm, the 28-day compressive strength >65 MPa and the 56-day compressive strength >75 MPa without segregation and bleeding have been achieved.

KEYWORDS : High-Strength High-Fluidity Concrete.

1. Introduction

The High-Strength High-Fluidity Concrete (HSHFC) first of all is High Strength Concrete (HSC) with excellent workability. According to ACI, concrete grade 55 and higher is characterized as high strength. As usual, strength of concrete is tested at the age of 28 days. Although at present time, test age may be prolonged to 56 days or even 90 days for the reason that high-rise buildings starts full load bearing after 2 to 3 months fromcommencement, [1]. In the buildings higher than 30 storeys, the columns on one third of the height from the top downward are usually made ofconcrete with required designed strengthfrom 30 to 35 MPa, the remaining two thirds from the base upward,columns are made from HSC, [1]. In order for concrete mix to be pumped with several stages and to have excellent filling ability when inner vibrator is used, the workability measured in term of slump flow (SF) must be high enough. There is no technical specification for HSHFC yet. Nevertheless its quality can be classified somewhat between the Flowing Concrete and the Self-Compacting Concrete (SCC). In Vietnam HSHFChas just been used atKeangnam Hanoi Landmark Tower,a 72-storey high-rise building. The concrete for columnswith specified designed strength of 70 MPaon standard cylinder specimen was appointed in the project specification by Korean engineers.According to the site data the average required compressive strength was as high as 75 MPa, [2].

Within the framework of the Scientific Research Assignment105-2012/KHXD-TĐ by The National University of Civil Engineering, Hanoi, [3],tests were intended to be carried out in two phases: in the laboratory conditionand in siteconditionon one of the most advanced ready-mix batching plant, TRANSMEXCO Company, which belongs to the

Ministry of Transport and Communication of Vietnam, (Figure1).The target was set for SF > 600 mm, the average required strength >65 MPa at 28 days and >75 MPa at 56 days. The secondphase is importantbecause concrete quality made in the laboratory and at the site may differ because the quality control at site condition is more difficult for HSHFC. These test resultsarethereforeconsidered to be helpful for Vietnamese engineers to master an advanced concrete technology for construction of high-rise buildingsin Vietnam.

Figure 1 Ready-mix Batching Plant,

TRANSMESCO

2. Test materials and methodology

2.1 Test materials

- Cement: Portland cement produced by But Son Cement Company PC 40, (similar to ASTMC150 OPC) complying with Vietnamese standard TCVN 2680:2009 was used. The main characteristics of this cement are shown in Table 1.
- Aggregates: The river sand and crushed granite of maximum nominal size 12.5 mm complying with Vietnamese standard TCVN 7570 : 2006 and ASTM C33 were used as fine and coarse aggregate, respectively. The main physical characteristics of the aggregate are shown in Table 2.
- Mineral admixture: Silicafume supplied by Elkem Vietnam ltd. complying with Vietnamese standard TCVN 8827:2011 and ASTM C1240-05, [4], was used.
- Chemical admixture: High Range Water Reducer, BASF G113 supplied by a German Company complying with Vietnamese standard TCVN 8828:2011 and ASTM C494-99 was used.

Table1 Main characteristics of Portland cement tested according to Vietnamese standard

Retaining on sieve 0.09, %	Standard consistency, %	Specific gravity	Setting time, min.		Cement strength, MPa.	
			Initial	Final	At 3 days	At 28 days
2.0	29.4	3.16	160	240	38.1	51.1

Table2 Main physical characteristics of aggregates

Aggregate type	Dry-Rodded unit weight, kg/m^3	Specific gravity	Fineness modulus	Void ratio, %	Water absorption, %
River Sand	1650	2.66	2.53	37.97	0.76
Crushed Granite	1614	2.82	-	42.77	0.40

2.2 Methodology

In the first phase, tests have been conducted on HSHFC in laboratory condition.Concrete mix design for HSHFC was designed according to ACI 211.4R-08 and the statistic design of experiments, Response Surface Methodology (RSM) in particular, [5]. The HSHFC mix proportions for the first phase are shown in Table 3. For this purpose two variables, ß values (mortar volume tocoarse aggregate void volume ratio), coded as X_1 ranging from 2.4 to 3.4 and W/B (water to binder ratio),coded as X_2 ranging from 0.286 to 0.314 were selected and the central composite design for HSHFC is shown in Table 4. Due to big volume of test carried out in the first phase,only one HSHFC mix was chosen for the test in the second phase,mix No.7, for the reason that this mix showed the best SF and strength characteristics satisfying the set targets.In the second phase HSHFC specimens of both cubic and cylindrical shape were made.In this phase, materials used are from the same source. By comparing the compressive strength on standard cube and standard cylinder made from the same HSHFC mix,one can conclude on the appropriate conversion factor between concretecompressive strengths tested on standard cubes and on standard cylinders for HSHFC.

Table 3 HSHFC mix proportions

Mix	Coded variables		Natural variables		Weight of ingredients per m^3 of concrete						
	X_1	X_2	β	W/B	Sand	Gravel	Cement	Silica fume	Water	Chemical admix.	Total binder
1	-1	-1	2.25	0.29	808	1009	538	19.1	162	6.7	558
2	-1	1	2.25	0.31	800	998	532	18.9	171	6.6	551
3	1	1	3.25	0.31	866	848	576	20.5	185	7.2	597
4	1	-1	3.25	0.29	876	858	583	20.7	175	7.3	604
5	-1.414	0	2.40	0.30	786	1043	524	18.6	163	6.5	542
6	0	1.414	2.90	0.314	833	915	555	19.7	180	6.9	575
7	1.414	0	3.40	0.30	882	826	588	20.9	183	7.3	609
8	0	-1.414	2.90	0.286	847	930	564	20.1	167	7.0	584
9	0	0	2.90	0.30	840	922	559	20.0	174	6.95	579
10	0	0	2.90	0.30	840	922	559	20.0	174	6.95	579
11	0	0	2.90	0.30	840	922	559	20.0	174	6.95	579
12	0	0	2.90	0.30	840	922	559	20.0	174	6.95	579
13	0	0	2.90	0.30	840	922	559	20.0	174	6.95	579

3. Results and discussion

3.1 Results of test on HSHFC in laboratory condition

Results of compression test of HSHFC in laboratory condition are shown in Table 4. [2].

Table4 Central composite design for HSHFC produced in the laboratory (Standard cube specimens)

Mix	Coded Variables		Natural Variables		Responses			
	X_1	X_2	β	W/B	SF, mm	UW.,kg/ m^3	Comp. strength at 28 days, MPa.	Comp. strength at 56 days, MPa.
1	-1	-1	2.25	0.29	560	2526	72.4	75.9
2	-1	1	2.25	0.31	590	2510	63.1	69.0
3	1	1	3.25	0.31	700	2485	67.1	70.9
4	1	-1	3.25	0.29	645	2509	73.5	77.3
5	-1.414	0	2.40	0.30	565	2525	68.2	72.4
6	0	1.414	2.90	0.314	680	2494	65.7	69.8
7	1.414	0	3.40	0.30	690	2496	74.0	78.0
8	0	-1.414	2.90	0.286	595	2520	74.9	78.2
9	0	0	2.90	0.30	630	2500	70.5	74.6
10	0	0	2.90	0.30	635	2497	72.4	76.3
11	0	0	2.90	0.30	640	2502	73.6	76.8
12	0	0	2.90	0.30	630	2501	72.2	75.1
13	0	0	2.90	0.30	625	2499	71.1	72.2

From the test results shown in Table 4, it is seen that almost all mixes satisfied the targets previously set for HSHFC. Mix No.7 is one of the best in term of SF and compressive strength. It is clear that mortar content, which is described in form of ß value strongly affects SF of HSHFC mix, meanwhile water to binder ratio dominantly affects HSHFC compressive strength. The best fit regression functions for HSHFC 28-day and 56-day compressive strengths are as follows:

$$R_{28} = 72.0 + 1.66X_1 - 3.59X_2 - 1.25X_2^2 \quad (1)$$

$$R_{56} = 77.1 + 1.43X_1 - 3.22X_2 - 1.16X_2^2 \quad (2)$$

3.2 Results of test on HSHFC in site condition

As it said earlier, in the second phase the test was carried out on only one HSHFC mix, which was proved to bethe best from the test results conducted in the first phase. At the batching plant, weighing materials was fully automated and computerized with remote control device,(Figure 2).

Figure 2 Remote Control Room

Figure 3 Mixer 4500/3000BHS, Capacity 180 m^3/hr.

After data input to the system, sand, gravel, cement, water andchemical admixture were weighed and loaded into themixer, (Figure 3). As mixing is started, silica fume wasadded from the top hole of the mixer. The total loading time was not more than 20 seconds and total mixing time is about 60 seconds.

Figure 4 SF Measurement of HSHFC

SF of HSHFCwas then tested according to ASTM C1611. Just a few minutes after mixing, the measured SF was about 700 mm, and in 45 minutes later the SF became about 630 mm. This SF value was as high as that intended for transporting and multi-level pumping at construction site. HSHFC mix unit weight was also determined according to Vietnamese standard TCVN 3108:1993, and a value about 2500 kg/m^3 was recorded. Then concrete cubes 150x150x150 mm size and cylinders D150xH300 mm size were made and cured for 24 hours in place. After demolding, HSHFC specimens were transported to the attested concrete laboratory of The Hydraulic Institute, TheHanoi Institute of Water

After mixing completed, concrete mix was discharged to the concrete agitator and transported to the test area, there an appropriate amount of HSHFC mix was discharged to a wheelbarrowfor SF measurement,(Figure 4) and specimen preparation, (Figure 5).

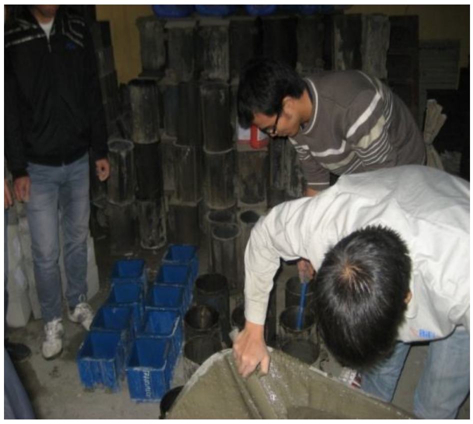

Figure 5 HSHFC Specimen Preparation

Resources for continuing curing in standard condition. Test on the compressive strength of HSHFC was conducted at 28 and 56 days of age, (Figure 6). The test results for the cube and cylinder specimens are shown in Tables5 and 6, respectively.The test on modulus of elasticity of HSHFC at 28 and 56 days according to Vietnamese standard TCVN 5726:1993 (similar to BS but slightly different fromASTM C469 – 98.) was also conducted, (Figure 7) in order to verify whether the empirical formula suggested by American Concrete Institute for normal strength concrete could be appliedin the case of HSHFC. Test results are shown in Tables7 and 8, respectively.

Figure 6 Compression Test on HSHFC on the Compression Machine Mates 3000KN - Italy

Figure 7 Test on Modulus of Elasticity of HSHFC

Table 5 Compressive strength test on HSHFC at 28 days and 56 days (Standardcube specimens)

Test specimen	Area, (mm^2)	Fracture load (KN)	Comp.strength at 28 days, (MPa)	Fracture load (KN)	Comp. strength at 56 days, (MPa)
1	22500	1590.8	70.7	1676.3	74.5
2	22500	1617.8	71.9	1707.7	75.9
3	22500	1638.0	72.8	1719.0	76.4
Average	22500	1606.5	71.8	1701.0	75.6

Table 6 Compressive strength test on HSHFC at 28 days and 56 days (Standard cylinder specimens)

Test specimen	Area, (mm2)	Fracture load (KN)	Comp. strength at 28 days, (MPa)	Fracture load (KN)	Comp. strength at 56 days, (MPa)
1	17662.5	1200	67.9	1259.4	71.3
2	17662.5	1201	68.0	1243.4	70.4
3	17662.5	1202	68.1	1270.0	71.9
Average	17662.5	1201	68.0	1257.6	71.2

Tests results on HSHFC show that the compressive strengths of HSHFC at both 28 days and 56 days tested in laboratory condition is slightly higher than those tested in site condition,and difference is about 3%. The relationship between the compressive strength tested on standard cylinder to the compressive strength tested on standard cubes, (k factor) is about 1.06,that is quite lower than those recommended for normal strength concrete by Vietnamese standard TCVN 3118:1993(k = 1.20), and BS as well, (k = 1.25). It is generally known that the values of cube strength and cylinder strength become closer when strength is higher , [6]. This situation states that when it needs both concrete cube and cylinder specimens must be prepared from the same HSHFC mix and the relationship between their compressive strength can be derived by the test.

Table 7 Test on HSHFC modulus of Elasticity at 28 days

Test specimen	Stress, (MPa)	Length change, $\Delta L.10^{-3}$ (m)	Strain, $\varepsilon.10^{-6}$	Modulus of elasticity, (GPa)
1	22.68	87.2	581.3	39.0
2	22.67	81.0	540.0	42.0
3	22.65	84.8	565.3	40.1
Average	22.66	84.3	562.2	40.4

Table 8 Test on HSHFC modulus of elasticity at 56 days

Test specimen	Stress, (MPa)	Length change, $\Delta L.10^{-3}$ (m)	Strain, $\varepsilon.10^{-6}$	Modulus of elasticity, (GPa)
1	23.73	82.60	550.6	43.1
2	23.73	83.96	559.7	42.4
3	23.73	78.57	523.8	45.3
Average	23.73	81.71	544.7	43.6

The calculation was also made using the empirical formula suggested by ACI for the normal strengthconcrete modulus of elasticity based on the concrete unit weight and its compressive strength, [7], as follows:

$$E_c^{28} = 43\times \rho^{1.5} \times f_c^{'0.5} \times 10^{-6} = 43\times 2500^{1.5} \times 68.0^{0.5} \times 10^{-6} = 44.3\ (GPa) \quad (3)$$

$$E_c^{56} = 43\times \rho^{1.5} \times f_c^{'0.5} \times 10^{-6} = 43\times 2500^{1.5} \times 71.2^{0.5} \times 10^{-6} = 45.3\ (GPa) \quad (4)$$

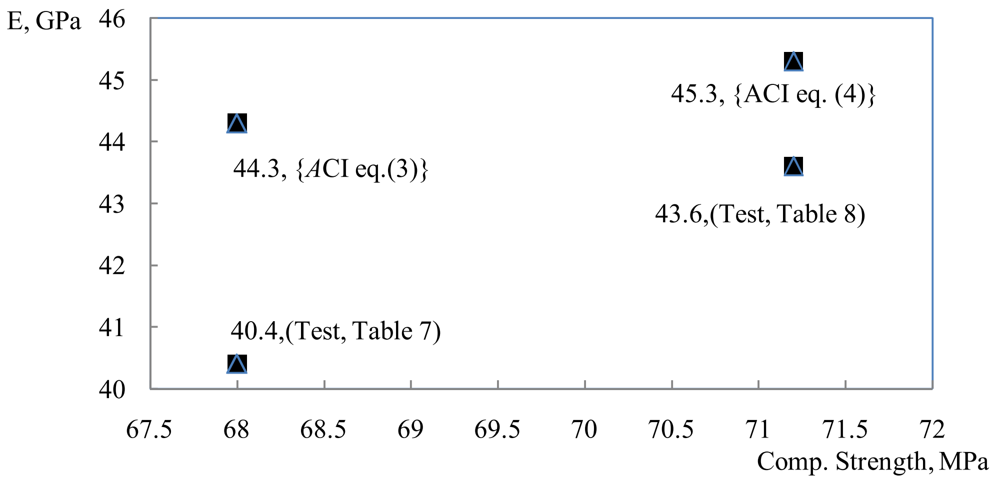

Figure 8 Compressive strength vs. tested, and calculated HSHFC modulus of elasticity

There isa difference between the tested and the calculated modulus of elasticity of HSHFC and thisdifference is quite meaningful, (Figure8). The calculated values of HSHFC modulus of elasticity are higher than the tested. This may beexplained by the reason that there is higher mortar volume in HSHFC compared to that innormal strength concrete and as it was proved that the modulus of elasticity of mortar is less than that of coarse aggregate.This implies that the empirical formula suggested by ACI for calculating modulus of elasticity of normal strength concrete can hardly be used for HSHFC.

4. Concluding remarks

Based on the tested materials and test mothods used in the research, the following conclussion can be drawn:

1) Tests results on HSHFC show that the compressive strengths of HSHFC tested at both 28 days and 56 days in laboratory condition is slightly higher than those tested in site condition, and the difference is about 3%.
2) HSHFC made from Portland cement incorporating silicafume with water to binder ratio ranging from 0.286 to 0.30 tested in laboratory condition has slump flow from 560 mm to 690 mm just after mixing. The compressive strength tested on standard cubes at 28 days ranges from 63.1 MPa to 74.9 MPa and at 56 days ranges from 69.0MPa to 78.2MPa.
3) HSHFC made from Portland cement incorporating silicafume tested in site condition has slump flow about 700 mm just after mixing and 630 mm at 45 minites after mixing. The compressive strength tested on standard cubes at 28 days and 56 days are equal to 71.8 MPa and 75.6 MPa,respectively.The compressive strength tested on standard cylinders at 28 days and 56 days are equal to 68.0 MPa and 71.2 MPa,respectively.
4) The testresults of modulus of elasticity showthat the values of the modulus of elasticity,both at 28 days and 56 days, are slightly lower when compared to those calculated using ACI emperical formulafornormal strength concrerte and the difference is about 10 %, therefore this emperical formula can not be recommended for HSHFC.
5) The tests conducted on HSHFC shows that the relationship between the compressive

strength tested on standard cubes and standard cylinder characterized by k factor is equal to 1.06, that is much smaller than those recomended for normal strength concrete by Vietnamese standard TCVN 3118:199, where k = 1.2 and BS standard, where k = 1.25. So it is recommended that the HSHFC specimens must be prepared in both standard cubes and standard cylinders when it is needed for use.

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