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UHPC compressive strength test specimens: Cylinder or cube?

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Abstract

Ultra High Performance Concrete (UHPC) is a new cement-based material developed in the era of modern concrete technology. The present of fiber in UHPC composition is necessary to increase strengths and durability, which then lead to name the material as Ultra High Performance Fiber Reinforced Concrete (UHPFRC). However, the exact determination of UHPC and UHPFRC have challenges due to its very high compression strength. Some issues are the limited capability to purchase high load capacity testing machines, and the surface preparation requirement for cylinder specimens. In this study, three series of experimental programs were conducted to investigate the compressive strength of UHPC and UHPFRC using cylinder and cube specimens, and to determine its converting factors (ratio). The results show that the compressive strength relationships between specimens differ from those of conventional concrete.

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Keywords: compressive strength; cube; cylinder; UHPC; UHPFRC

1. Introduction

At the present time, High Strength Concrete (HSC) is not the strongest and best high performance concrete. After years of careful thinking and efforts, researchers have found a remarkable technological breakthrough named Ultra High Performance Concrete (UHPC), a natural extension of the existing HSC which has many enhancements in its

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material properties. UHPC is a new class of concrete which is developed in the latest concrete technology since the year of 1990 [1]. The existence of fiber in its composition offers increase strengths and durability, which then promotes the name of Ultra High Performance Fiber Reinforced Concrete (UHPFRC).

UHPC compressive strength can approach a value exceeding 150 MPa. Current research shows that UHPC is able to reach a compressive strength until 250 MPa [2]. In addition of its high compressive strength, UHPC offer multitude enhancements of HSC such as: having a very high tensile (over 15 MPa) and flexural (over 50 MPa) strengths, a very high ductility, and a very high durability to freeze-thaw cycles, chloride penetration, abrasion resistance and carbonation. The enhanced properties contribute to overall performance of the structure, improve the construction safety, provide longer service life and lower the maintenance cost.

Regards on these superior properties, especially on its very high compression strength, however, issues towards UHPC and UHPFRC occur. These are, the limited capability to purchase high load capacity testing machines, and the surface preparation requirement for testing by using cylinder specimens. In order to solve these issues, a straightforward solution to solve the barring purchase of high load capacity testing machines is by using small specimens. While, to solve the surface preparation requirement, is simply by using cube specimens [3]. As the main property in concrete, investigating the compressive strength of UHPC is significant for structural design needs, as it relates to the structure's load bearing capacities.

There are two types of standard testing specimens used to investigate the compressive strength of concrete, namely cylinder and cube. Generally, cylinder specimens are used in US, Canada, France, Australia and New Zealand. However, cube is more common to use in UK, Europa and Singapore [4, 5]. For normal concrete and HSC, the concrete compressive strength test results from cube specimens are generally higher than cylinders specimens [6]. As states in BS 1881, the compressive strength of concrete gained by cylinder specimens is equal to 0.8 times of the compressive strength gained by cube specimens. However, in fact, this ratio is not always precise in the applications [5]. It is generally assumed, in normal concrete, cube specimens produce 20-25% higher concrete compressive strength, with a decrease difference either at higher or increase compressive strength [3].

This study aims to investigate the compressive strength and the converting factors (ratio) of cylinder and cube specimens of UHPC and UHPFRC. Current guidelines and previous research will also be adapted into the investigation. In order to determine the compressive strength of UHPC and UHPFRC, French guideline proposes the use of cylinder specimens having a diameters of 70 or 110 mm [7], while Japanese guideline proposes a diameter of 100 mm [8]. In other countries, such as US, a diameter of 102 mm or larger diameter of cylinders and larger dimension of cubes are accepted [3].

2. Experimental investigation

In this study, relationships between UHPC and UHPFRC compressive strength test results gained from cylinder and cube specimens are compared. The specimens used are: a diameter of 100 mm and a height of 200 mm (for cylinder specimens) and a dimension of 100 mm x 100 mm x 100 mm (for cube specimens).

The UHPC mixture formula, M3Q_210, was developed by and made in the Official Material Testing Institute for Construction Industry - AMPA (Amtliche Materialprüfanstalt für das Bauwesen) of Kassel University. In the composition, cement type of CEM I 52,5R HS-NA made by HOLCIM was used. The expected compressive strength of UHPC and UHPFRC after 28 days was ± 200 N/mm^2. The steel fiber content in the UHPFRC has a variety percentage of 1 and 2 vol.-%. An example of UHPC and UHPFRC mixtures composition used for the casting process is shown in Table 1.

For making UHPC, Zyklos ZK 150 HE, a stationary hydraulic concrete mixture machine having a maximum capacity of 170 L was used. Prior to testing, the moulds of the specimens were removed one day after casting and the specimens were left to cure under room temperature. Towards the test, no capping were applied on both top and bottom surfaces of cylinder specimens. However, both surfaces were cut (grinded) to form flat surfaces. The UHPC specimens were tested under an increasing load until failure by using Toni Technik Compression Testing Machine which have a maximum load of 4000 kN. Next, Fig. 1 shows the laboratory UHPC compressive strength tests.

Table 1. UHPC composition (M3Q_210)

UHPC mixture	Unit	Fiber content		
		0%	1%	2%
Cement	kg/m^3	795.40	795.40	795.40
Sika silicoll uncompacted	kg/m^3	168.60	168.60	168.60
Sika viscocrete 2810	kg/m^3	24.10	24.10	24.10
Fine quarz W12	kg/m^3	198.40	198.40	198.40
Sand quarz 0.125/0.5	kg/m^3	971.00	971.00	971.00
Steel fiber	kg/m^3	0.00	79.31	160.25
Water	kg/m^3	187.98	187.98	187.98
Total	kg/m^3	2345.480	2424.790	2505.730
Water cement ratio	-	0.255	0.255	0.255
Water binder ratio	-	0.210	0.210	0.210

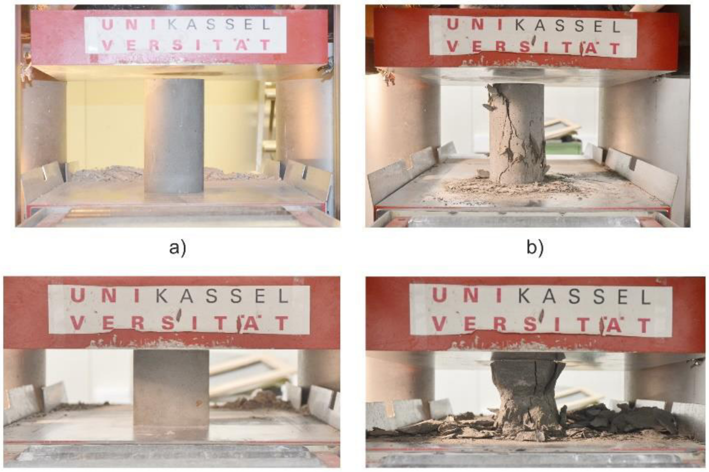

Fig. 1. The laboratory UHPC compressive strength tests: a-b) cylinder specimens, c-d) cube specimens

3. Test results and analysis

A total of 3 series of mixtures (Series 1, 2 and 3), each consists of UHPC, UHPFRC 1% (UHPC contains 1 vol.-% of fiber) and UHPFRC 2% (UHPC contains 2 vol.-% of fiber) were made and casted using cube and cylinder specimens. After treatment days was over, the specimens were tested to investigate its compressive strengths. Next, the resulted data was used to calculate the compressive strength ratios between cube and cylinder specimens. Table 2 illustrates a typical experimental data which has been investigated in the study, namely Serie 1.

Table 2. An experimental data for Serie 1

Mixture	Specimens	Compressive strength (MPa) Value	Mean	Cube: Ratio	Cylinder Mean	Cylinder: Cube Ratio	Mean
UHPC	Cube a	190.80	166.40	1.02	0.89		
	Cube b	177.10		0.95			
	Cube c	131.30		0.70			
	Cylinder a	185.50	186.80			1.11	1.12
	Cylinder b	185.00				1.11	
	Cylinder c	187.30				1.13	
	Cylinder d	189.40				1.14	
UHPFRC 1%	Cube a	170.40	176.27	0.96	0.99		
	Cubeb	178.80		1.00			
	Cubec	179.60		1.01			
	Cylinder a	183.40	178.28			1.04	1.01
	Cylinder b	177.90				1.01	
	Cylinder c	173.20				0.98	
	Cylinder d	178.60				1.01	
UHPFRC 2%	Cube a	180.90	178.03	1.01	1.00		
	Cubeb	179.00		1.00			
	Cubec	174.20		0.98			
	Cylinder a	182.20	178.35			1.02	1.00
	Cylinder b	172.70				0.97	
	Cylinder c	176.40				0.99	
	Cylinder d	182.10				1.02	

Fig. 2 shows bar graph relationships of the mean values of 3 series, among the compressive strength, mixtures of UHPC, and specimen types; and a line graph relationship between mixtures of UHPC versus the ratio of cube and cylinder specimens. From Fig. 2, it can be identified that UHPC and UHPFRC used in this study have mean compressive strengths of 165.43 MPa (for UHPC, using cube specimens) and 186.03 (for UHPC, using cylinder specimens), 183.03 MPa (for UHPFRC 1%, using cube specimens) and 188.97 MPa (for UHPFRC 1%, using cylinder specimens), and 182.27 MPa (for UHPFRC 2%, using cube specimens) and 186 MPa (for UHPFRC 2%, using cylinder specimens). The steel fibers give influence into the UHPC by increasing the compressive strength. However, the final values of compressive strength is less than the design of UHPC compressive strength which is 200 N/mm^2. UHPC specimens which contains no fiber experience sudden explosive and brittle failures. On the other hand, UHPC specimens contains fibers have rupture failures, which marked the rupture of fibers.

Also it can be seen that the mean compressive strength converting factors (ratio) of 3 series between cube and cylinder specimens, namely: 0.89 (for UHPC), 0.94 (for UHPFRC 1%) and 0.94 (for UHPFRC 2%). These ratio ranges of UHPFRC 1% and 2% is closed to the range of converting factor (ratio) proposed by Leutbecher which is 0.96 [9], and by AMPA which is 0.95 [10]. These finding is interesting as it is opposite to the converting factors of normal concrete and HSC, which says that cube specimens produce higher concrete compressive strength, though practically it is not always precise. It should be noted that the compression strength of UHPC obtained using cube specimens is not a uniaxial strength, thus converting its value to the cylinder specimen values is necessary. In order to determine the compression strength of UHPC, by considering barring factors occurred by using both specimens, either cube and cylinder specimens can be used.

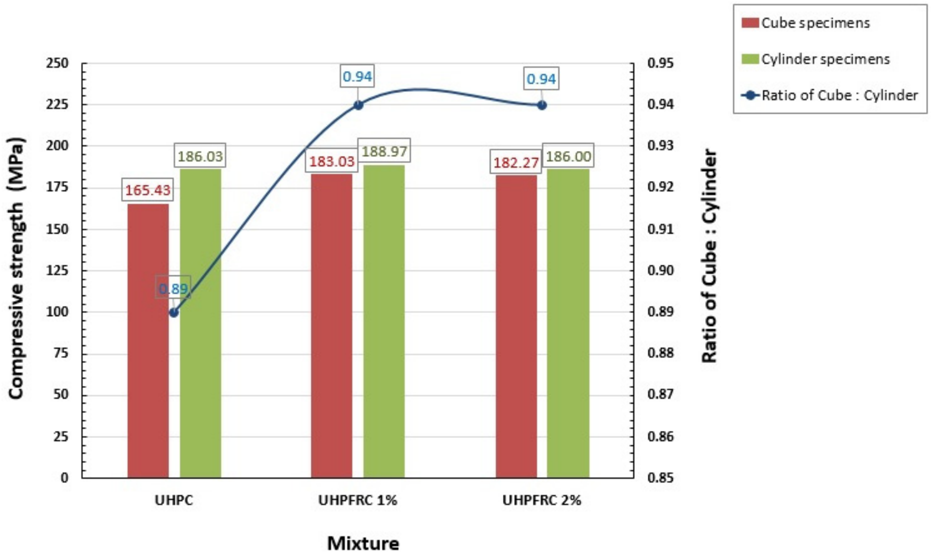

Fig. 2. Relationships among compressive strengths - mixtures of UHPC - specimen types, and the converting factors (ratio) of cube and cylinder specimens

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