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Effect of Specimen Size and Shape on the Compressive Strength of High Strength Concrete

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ABSTRAK

Pengaruh bentuk dan saiz spesimen ke atas kekuatan mampat yang diukur telah dikaji untuk konkrit berkekuatan tinggi yang berbeza dicampur. Lebih 260 spesimen daripada 30 campuran konkrit berkekuatan tinggi dituang dan diuji. Didapati bahawa secara purata nisbah kekuatan mampat silinder 150 × 300 mm kepada kiub 150 mm adalah 0.80; manakala untuk silinder 100 × 200 mm kepada kiub 150 mm adalah 0.93. Juga, secara purata, isbah kekuatan mampat silinder 150 × 300 mm kepada silinder 100 × 200 mm adalah 0.86.

ABSTRACT

The influence of specimen size and shape on the measured compressive strength was investigated for different high strength concrete mixes. Over 260 specimens from 30 high strength concrete mixtures were cast and tested. It was found, that on average, the ratio of the compressive strength of 150 × 300 mm cylinders to 150 mm cubes was 0.80; while for 100 × 200 mm cylinders to 150 mm cubes was 0.93. Also, on average, the ratio of the compressive strength of 150 × 300 mm cylinders to 100 × 200 mm cylinders was 0.86.

Keywords: High strength concrete, compressive strength, size effect, shape effect

INTRODUCTION

In Saudi Arabia concrete is the dominant construction material for all types of buildings and other structures. Most of the structural concrete elements are made with a compressive strength of 20 to 35 MPa. Lately, there is an increase in use of high strength concrete (HSC) in major construction projects such as high-rise buildings and bridges. The advances in the quality control of concrete production are enabling ready mixed, pre-stressed, and pre-cast concrete plants to achieve higher strength concretes.

Locally, the characteristic compressive strength is usually measured based on 150 mm cubes. But in design practice, the design compressive strength is usually based on the standard 150 × 300 mm cylinders. The use of 100 × 200 mm cylinders gained more acceptance locally as the need to test high strength concrete increases. This is expected since most testing machines used locally have a full capacity of 1300 kN. Hence, to test a standard specimen having a compressive strength of 80 MPa would require a test machine with a capacity greater than 1300 kN.

Several researchers have compared measured strengths achieved with different sizes of cubical and cylindrical specimens for high strength concrete. For cylindrical specimens comparisons were usually made between the compressive strength of 150 × 300 mm cylinders and that of 100 × 200 mm cylinders. Carrasquillo *et al.* (1981) reported that the average ratio of compressive strength of 150 × 300 mm to 100 × 200 mm cylinders was 0.9 regardless of strength and test age. A contradiction to this finding was later reported by Carrasquillo *et al.* (1988) which reported that compressive strength of 100 × 200 mm cylinders were 7 percent lower than those of 150 × 300 mm cylinders. French *et al.* (1993) observed in their study that on average 100 × 200 mm cylinders tested showed 6 percent higher strength than that of their companion 150 × 300 mm cylinders. Aïtcin *et al.* (1994) reported that larger cylinder sizes gave rise to lower apparent compressive strength, and that compressive strength is not sensitive to cylinder size for very high strength concrete.

For comparison between compressive cube strength and compressive cylinder strength (diameter/height = 1/2), a factor of 0.8 to the cube strength is often applied for normal strength concrete (FIP-CEB 1990). The same reference also cited a study that indicated that the cylinder/cube compressive strength ratio is not only a function of the strength grade but also of the mix design parameters. In a recent study, Alsayed (1997) reported that the ratio of 0.8 that is applied for normal strength concrete remains the same for high strength concrete.

In this paper, results of an ongoing research on high strength concrete were presented. A comparison of the compressive strength between 150 mm cubes, 150 × 300 mm and 100 × 200 mm cylinders was performed. These sizes were chosen because it represented the sizes that are most commonly used locally in the construction industry and research. The results were obtained from 30 high strength mixes, 3 of which were provided from a local ready-mixed concrete plant. The study suggested compressive strength conversion factors between the different specimen sizes and shapes used in the study.

METHODOLOGY

Materials

The use of locally available materials from different sources in the Riyadh area was emphasized in this study. For the cases where locally available materials were not attainable, commercially available materials were used. For the ready-mixed concrete, the material properties used were not collected. The following are the details for the materials used in the laboratory mixes.

Cement: Commercially available Portland cement Type I conforming to ASTM C 150 specification.

Coarse Aggregates: Locally available crushed limestone was used for coarse aggregates. These aggregates were procured from different sources around the city of Riyadh. The physical properties of the coarse aggregates are listed in Table 1. The mineral composition was obtained by Energy Dispersal X-Ray

(EDX) analysis. The crushed limestone typically had Calcite (Ca more than 96%), and clay which provided Potassium (K 1.8%), and Iron (Fe 1.3%).

Fine Aggregates: Locally available crushed sand and white natural silica sand were used in the overall study. These aggregates were also procured from different sources as the case for the coarse aggregates. The physical properties of the fine aggregates are given in Table 2. The crushed sand had typically the following mineral composition: Calcite (Ca more than 90%), and clay which provided Potassium (K 4%), and Iron (Fe 3%). The natural silica sand known as Quartz Arenite typically had Quartz (Si more than 95 %), and Clay which provided Potassium (K 3%), and Iron and Calcium (1% each).

TABLE 1
Physical properties of coarse aggregates

Property	Group I		Group II	Group III
	LM 1-A	LM 1-B	LM 2	LM 3
Maximum size aggregate, mm	10	20	10	10
Dry unit weight, kg/m^3	1650	1550	1616	1536
Absorption, percent	1.95	3.02	1.03	1.83
Specific gravity:				
a. Bulk oven-dry	2.58	2.54	2.57	2.61
b. Bulk saturated surface dry	2.60	2.58	2.63	2.66

Note: Limestone = LM

TABLE 2
Physical properties of fine aggregates

Property	Group I		Group II		Group III	
	silica sand	washed sand	silica sand	washed sand	silica sand	washed sand
Dry unit weight, kg/m^3	1800	1680	1730	1570	1616	1536
Absorption, percent	0.2	3.02	0.42	1.69	1.03	1.83
Specific gravity:						
a. Bulk oven-dry	2.66	2.54	2.56	2.59	2.59	2.62
b. Bulk saturated surface dry	2.68	2.58	2.57	2.66	2.60	2.66
Fineness modulus*	2.8		2.9		2.8	

* combined 50% silica sand and 50% washed sand

Silica Fume: Commercially available powder silica fume was used in the study. The silica fume had a specific gravity of 2.3.

Admixture: Commercially available sulphonated naphthalene-based high performance superplasticizer conforming to ASTM C 494 as Type F.

Mix Proportions

During the course of this study, around 30 high strength mixtures with 28-day compressive strength in the range of 35 to 90 MPa (cylinder strength) and 40 to 102 MPa (cube strength) were cast and tested. Details of the mix proportions for all the mixtures except for the ready-mixed concrete are tabulated in Tables 3 through 5. The composition of cementitious material used for the laboratory mixes were Portland cement ranging from 350 to 550 kg/m^3 and silica fume 0, 10, and 15% replacement by weight of cement. The water-cementitious ratio (w/cm) ranged from 0.22 to 0.35.

Casting and Curing

All laboratory batches of concrete were cast inside the laboratory in a small capacity drum mixer, (except for 2 mixes II-7R and II-13R) a heavy duty pan mixer was used to check if silica fume was properly mixed during initial mixes.

TABLE 3
Mix proportions of group I

Ref. No.	water (kg/m^3)	cement, Type I (kg/m^3)	silica fume (kg/m^3)	coarse aggregate 20mm (kg/m^3)	coarse aggregate 10mm (kg/m^3)	washed sand (kg/m^3)	silica sand (kg/m^3)	super-plasticizer (L/m^3)	w/cm ratio	Slump (mm)
I-1	145	495	49.5	1070	0	290	290	18.75	0.26	230
I-2	122.5	350	0	845	280	372.5	0	8.75	0.35	230

TABLE 4
Mix proportions of group II

Ref. No.	water (kg/m^3)	cement, Type I (kg/m^3)	silica fume (kg/m^3)	coarse aggregate (kg/m^3)	washed sand (kg/m^3)	silica sand (kg/m^3)	super-plasticizer (L/m^3)	w/cm ratio	Slump (mm)
II-1	145	495	0	1070	290	290	7.50	0.283	220
II-2	182	550	0	1050	271	271	5.50	0.331	35
II-3	182	495	55	1050	263	263	7.85	0.331	55
II-4	169	550	0	1050	287	287	7.35	0.307	25
II-5	169	495	55	1050	278	278	13.75	0.307	130
II-6	158	550	0	1050	302	302	10.00	0.287	85
II-7	158	495	55	1050	293	293	15.00	0.287	110
II-7R	158	495	55	1050	293	293	15.00	0.287	250
II-8	149	550	0	1050	314	314	13.37	0.271	150
II-9	149	495	55	1050	305	305	17.37	0.271	110
II-10	149	468	83	1050	301	301	20.12	0.270	100
II-11	138	550	0	1050	328	328	16.50	0.251	200
II-12	138	495	55	1050	319	319	19.75	0.251	160
II-13	138	468	83	1050	315	315	22.60	0.25	145
II-13R	138	468	83	1050	315	315	22.60	0.25	220

TABLE 5
Mix proportions of group III

Ref. No.	water (kg/m^3)	cement, Type I (kg/m^3)	silica fume (kg/m^3)	coarse aggregate (kg/m^3)	washed sand (kg/m^3)	silica sand (kg/m^3)	super-plasticizer (L/m^3)	w/cm ratio	Slump (mm)
III-3	121	550	0	1070	295	295	21.75	0.22	70
III-4	121	495	55	1070	295	295	30.00	0.22	70
III-5	132	550	0	1070	295	295	13.50	0.24	55
III-6	132	495	55	1070	295	295	21.25	0.24	75
III-7	143	550	0	1070	295	295	11.25	0.26	110
III-8	143	495	55	1070	295	295	18.63	0.26	80
III-9	154	550	0	1070	295	295	7.25	0.28	25
III-10	154	495	55	1070	295	295	13.95	0.28	62
III-11	165	550	0	1070	295	295	6.63	0.30	45
III-12	165	495	55	1070	295	295	12.00	0.30	90

The mixing, casting, and curing conformed to ASTM C192. Each batch was used to cast the 3 standard size 150 × 300 mm cylinders, 3 medium size 100 × 200 mm cylinders, and 3 standard 150 mm cubes to obtain the compressive strength. The cylindrical and cubical samples were cast in steel molds to eliminate any effect that could result from plastic or cardboard molds. The standard size cylindrical and cubical specimens were cast in two layers with each layer vibrated in a vibrating table for 35 to 45 seconds. The medium size cylindrical samples were cast in two layers with each layer vibrated in a vibrating table for 30 to 35 seconds. After the compaction operation, the top of the specimen was smooth finished by means of a trowel. The cylindrical specimens were covered by polyethylene bags and the cubical specimens were covered by means of a plastic cover. The specimens were demolded after 24 hours, and then subjected for 28 days to standard moist curing by immersing them in curing tanks containing lime saturated water at 23 C.

Test Procedure

At the age of 28 days, the specimens were taken out from the curing tank. The cylindrical specimens were end-capped with a vitrobond sulfur based capping compound. The compressive strength was measured in compliance with ASTM C39. To perform compression tests, a 3000 kN Auto Comp 2 compression machine manufactured by Controls was used. The load accuracy of this machine is ±1%. The machine used has a high stiffness frame with four pre-stressed columns to ensure maximum rigidity and stability and is suitable for cylinder and cube testing.

TEST RESULTS AND DISCUSSION

During the course of this study, over 260 specimens from 30 high strength concrete mixtures were tested in which 3 of those mixes were obtained from ready-mixed plants. The average 28-day compressive strength for 150 × 300 mm, 100 × 200 mm cylinders and 150 mm cubes are shown in Table 6. The observed strength ratios of 150 × 300 mm cylinders to 150 mm cubes, 100 × 200 mm cylinders to 150 mm cubes, and 150 × 300 mm cylinders to 100 × 200 mm cylinders for each concrete mixture tested are shown in columns 5, 6, and 7, respectively.

The ratio of the 150 × 300 mm cylinder to the 150 mm cube was between 0.66 and 0.97. As expected, the 150 mm cubes are always stronger than the 150 × 300 mm cylinders. This is usually attributed to having an overlapped restrained zone in cubes while testing under uniaxial compression, hence a zone of

TABLE 6
Average Compressive strength of 150x300 mm and 100x200 mm cylinders and 150 mm cubes

Ref. No. (1)	f_c'(150×300) (MPa) (2)	f_c'(100×200) (MPa) (3)	f_c'(150 cube) (MPa) (4)	$\frac{f_c'(150\times300)}{f_c'(150\text{ cube})}$ (5)	$\frac{f_c'(100\times200)}{f_c'(150\text{ cube})}$ (6)	$\frac{f_c'(150\times300)}{f_c'(100\times200)}$ (7)
I-1	56	——	70	0.80	——	——
I-2	46	——	57	0.81	——	——
II-1	64.5	72.8	78.7	0.82	0.93	0.89
II-2	53.1	55.9	60.9	0.87	0.92	0.95
II-3	55.0	56.4	69.1	0.80	0.82	0.98
II-4	52.9	64.3	67.2	0.79	0.96	0.82
II-5	68.0	86.3	86.5	0.79	1.00	0.79
II-6	62.6	81.0	71.5	0.88	1.13	0.77
II-7	66.4	69.8	78.4	0.85	0.89	0.95
II-8	71.5	74.3	81.4	0.88	0.91	0.96
II-9	80.6	82.1	92.9	0.87	0.88	0.98
II-10	82.1	84.2	94.0	0.87	0.90	0.98
II-11	58.7	65.4	73.0	0.80	0.90	0.90
II-12	74.0	91.6	91.1	0.81	1.01	0.81
II-13	83.5	86.1	85.7	0.97	1.00	0.97
II-7R	66.9	——	91	0.73	——	——
II-13R	79.7	——	102	0.78	——	——
III-3	58.9	65.5	81.6	0.72	0.80	0.90
III-4	74.6	82.4	92.0	0.81	0.90	0.90
III-5	62.2	76.0	82.7	0.75	0.92	0.82
III-6	72.1	85.8	87.0	0.83	0.99	0.84
III-7	66.8	79.9	87.1	0.77	0.92	0.84
III-8	59.9	72.9	82.1	0.73	0.89	0.82
III-9	47.8	65.3	70.5	0.68	0.93	0.73
III-10	59.6	84.8	87.8	0.68	0.96	0.70
III-11	44.9	65.2	68.0	0.66	0.96	0.69
III-12	49.4	71.8	70.9	0.70	1.01	0.69
RM-1	35.5	——	38	0.93	——	——
RM-2	37	41	47	0.79	0.87	0.90
RM-3	47.5	51	55	0.86	0.93	0.93

triaxial compression develops. On the other hand, cylinders with length/ diameter ratio of 2 have an unrestrained zone away from the ends. The comparison of the 150 × 300 mm cylinder to the 150 mm cube compressive strength test results are plotted in *Fig. 1*. As shown in the figure, from the test results, the ratio of the 150 × 300 mm cylinder to the 150 mm cube compressive strength was on average about 0.80. This result agrees with previously reported results.

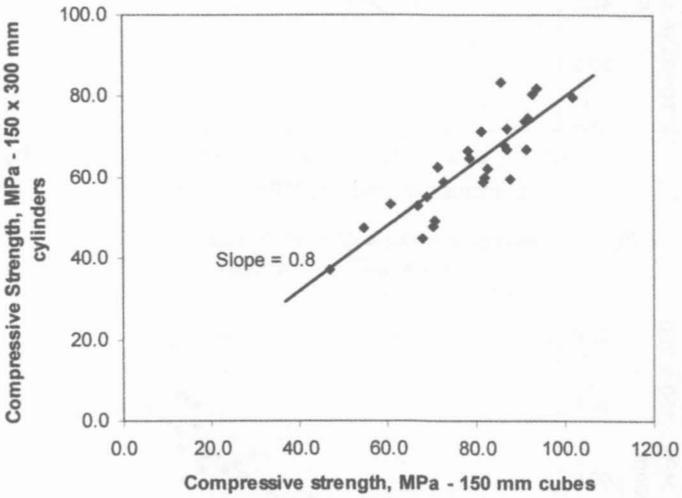

Fig. 1: Compressive strength of concrete 150 mm cubes versus 150 × 300 mm cylinders

Comparison of the compressive strength test results from 100 × 200 mm cylinders and 150 mm cubes are shown in column 6 of Table 6 and plotted in *Fig. 2*. The ratios ranged from 0.8 to 1.13. The 1.13 ratio was only from one data point and all other data points were less than 1.0. Hence, one could comfortably expect that 150 mm cube compressive strength would be higher than 100 × 200 mm cylinders. On average, the ratio of the 100 × 200 mm cylinders to the 150 mm cube was 0.93, as can be seen in *Fig. 2*.

Similarly, comparison of the compressive strength test results of the 150 × 300 mm cylinders versus the 100 x 200 mm cylinders are shown in column 7 of Table 6 and plotted in *Fig 3*. On average, the ratio of the 150 × 300 mm to 100 × 200 mm cylinders was 0.86, as can be seen in *Fig. 3*. This also confirms the presence of a size effect where the nominal compression strength at failure decreases as the specimen size increases (Sener 1997).

A plot of the compressive strength of 150 mm cubes versus 150 × 300 mm cylinders for concrete mixture groups II and III is shown in *Fig. 4*. Each of the mixes within the group had the same source of coarse and fine aggregates and each group had a different source of aggregate. It can be seen from *Fig. 4* that each group had a different but close ratio of compressive strength of 150 x 300

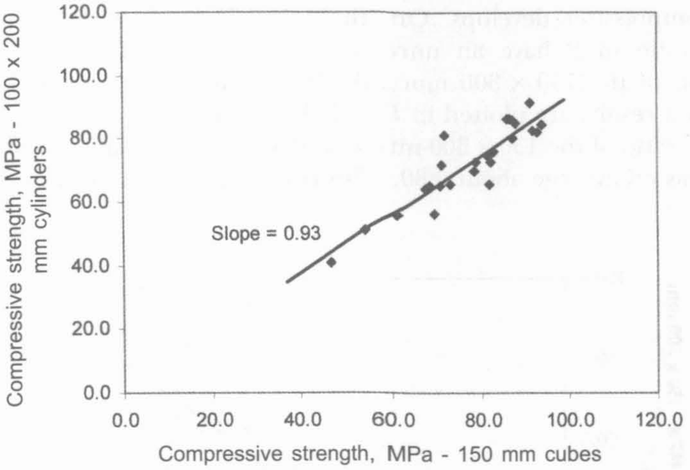

Fig. 2: Compressive strength of concrete 150 mm cubes versus 100 × 200 mm cylinders

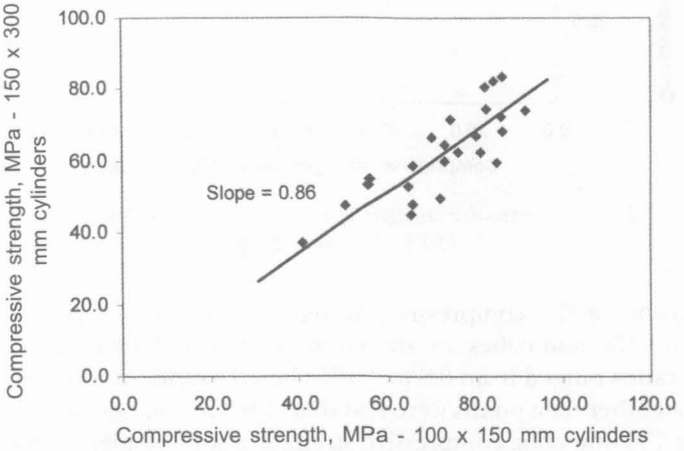

Fig. 3: Compressive strength of concrete cylinders cast in 100 × 200 mm versus 150 × 300 mm

mm cylinders to 150 mm cubes. This seems to indicate that the mix design parameters influence the cylinder/cube strength ratio. A recent study using locally available materials indicated that the quality of coarse aggregate has a significant effect on the compressive strength of high strength concrete (Beshr *et al.* 2003).

Although conversion factors between the standard sizes and shapes are obtained, it is strongly recommended that in reporting the compressive strength values of high strength concrete, the size and shape used for strength determination must be specified.

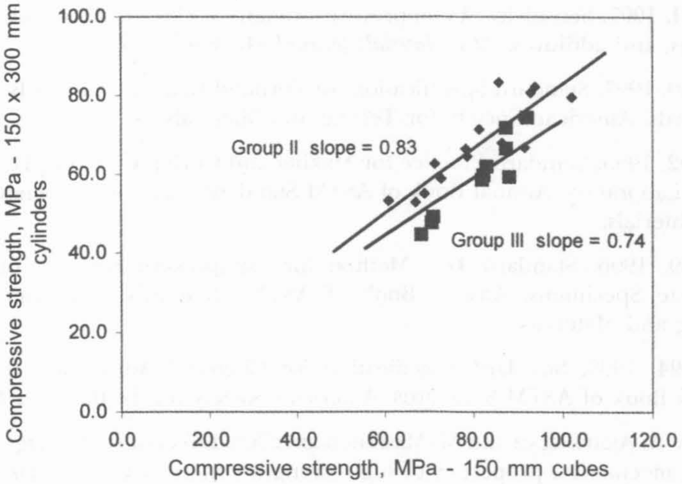

Fig. 4: Compressive strength of concrete 150 mm cubes versus 150 × 300 mm cylinders for groups II and III

CONCLUSIONS

Based on the results of this study, the following conclusions can be made.

1. On average, the ratio of the compressive strength of high strength concrete of 150 x 300 mm cylinders to 150 mm cubes was 0.80.
2. On average, the ratio of the compressive strength of high strength concrete of 100 x 200 mm cylinders to 150 mm cubes was 0.93.
3. On average, the ratio of the compressive strength of high strength concrete of 150 x 300 mm cylinders to 100 x 200 mm cylinders was 0.86.
4. The obtained results indicate that mix design parameters influence the strength ratios of cylinder to cube.

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REFERENCES

AÏTCIN, P.C., B. MIAO, W. D. COOK and D. MITCHELL. 1994. Effects of size and curing on cylinder compressive strength of normal and high-strength concretes. *ACI Materials Journal* **91(4)**: 349-354.

ALSAYED, S.H. 1997. Sensitivity of compressive strength of HSC to hot-dry climate, curing regimes, and additives. *ACI Materials Journal* **94(6)**: 472-477.

ASTM C 150. 1997. Standard Specification for Portland Cement. Annual Book of ASTM Standards. American Society for Testing and Materials.

ASTM C 192. 1995. Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory. Annual Book of ASTM Standards. American Society for Testing and Materials.

ASTM C 39. 1996. Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens. Annual Book of ASTM Standards. American Society for Testing and Materials.

ASTM C 494. 1999. Standard Specification for Chemical Admixtures for Concrete. Annual Book of ASTM Standards, American Society for Testing and Materials.

BESHR, H., A. A. ALMUSALLAM and M. MASLEHUDDIN. 2003. Effect of coarse aggregate quality on the mechanical properties of high strength concrete. *Construction and Building Materials* **17**: 97-103.

CARRASQUILLO, P.M. and R.L. CARRASQUILLO. 1998. Evaluation of the use of current concrete practice in the production of high-strength concrete. *ACI Materials Journal* **85(1)**: 49-54.

CARRASQUILLO, R., A. NILSON and F. SLATE. 1981. Properties of high strength concrete subject to short-term loads. *ACI Journal* **78(3)**: 171-178.

FRENCH, C.W. and A. MOKHTARZADEH. 1993. High strength concrete: effects of material, curing and test procedures on short-term compressive strength. *PCI Journal* **38(3)**: 76-87.

Joint FIP-CEB Working Group on High Strength Concrete. 1990. High Strength Concrete: State of the Art Report. CEB Bulletin No. 197 (FIP SR 90/1), Federation Internationale de la Prescontrainte, London, England.

SENER, SIDDIK. 1997. Size effect tests of high strength concrete. *Journal of Materials in Civil Engineering* **9(1)**: 46-48.