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SPECIMEN SHAPE AND SIZE EFFECT ON THE COMPRESSIVE STRENGTH OF HIGHER STRENGTH CONCRETE

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ABSTRACT

The specimen size and shape effects on the compressive strength of higher strength concrete were investigated on different sized cylinders having constant length-to-diameter ratio (l/d), different sized cubes, and cylinders with various l/d for 40, 60, and 75 MPa compressive strength levels. The apparent strength values of 75mm diameter cylinder and 75 and 100mm cube specimens were lower than those of the larger specimens used. Also, the compressive strength was determined to be insignificantly affected by changing l/d as the strength of concrete increases. © *1997 Elsevier Science Ltd*

Introduction

The sizes and shapes of compressive strength test specimens of concrete varies from one country to another. Cylinders are used in the United States, Canada, France, Australia, etc. whereas cubes are the standard shapes in the United Kingdom, Germany, and many other European countries. There are several countries where tests are made on both cubes and cylinders. Commonly used standard sizes are 150mm and 150 × 300mm for cubes and cylinders, respectively. However, the advantages such as easy handling, necessitating lower capacity test machines, using less concrete, etc. offered by smaller specimens have caused them to be used more frequently.

Although there had been a vast amount of research on this subject for normal strength concretes, dating back to 1925 (1) there are only a few reported studies on the effect of specimen size and shape for high strength concrete (2, 3, 4, 5). The results of the previous investigations have led to the conversion factors for cube-cylinder strength relations and for strengths of different sized specimens to standard sizes for normal strength concretes.

The strength ratios of different sizes and shapes obtained by various investigators for different levels of strength are summarized in Table 1.

There are correction factors given in many standards for cylinder specimens having l/d less than 2.00. However, no systematic investigations have been carried out so far to study the effect of l/d of the specimens for high strength concrete.

The objective of the present work was to investigate the influence of the specimen size and geometry on the compressive strength of higher strength concrete. For this purpose,

TABLE 1

Strength Ratios of Different Sizes and Shapes of Specimens Reported by Various Researchers

Ref.	Specimen	Strength Level (Mpa)	100mm cube	150mm cube	200mm cube	100x200mm cylinder	150x300mm cylinder
(3)	100mm cube	66	1.00	-	-	-	1.33
		97	1.00	-	-	-	1.30
		115	1.00	-	-	-	1.20
(2)	100mm cube		1.00	1.01	1.05	-	1.22
	150mm cube		-	1.00	1.04	-	1.20
	200mm cube		-	-	1.00	-	1.15
(4)	102x203mm cylinder	48-80	-	-	-	1.00	0.93
(5)	100x200mm cylinder	35-126	-	-	-	1.00	1.06

TABLE 2

Properties of Cement and Silica Fume

Chemical Composition		
Oxide (%)	Cement	Silica Fume
CaO	50.05	1.53
SiO_2	27.29	85.75
Al_2O_3	8.59	2.51
Fe_2O_3	3.70	2.11
MgO	1.36	3.67
SO_3	1.91	-
Na_2O	0.30	-
K_2O	0.10	-
I.R.	5.62	n.d.
L.O.I	1.33	n.d.

Physical Properties		
Blaine fineness (m^2/g)	312	~ 5000
Sp. gravity	2.96	2.28

TABLE 3

Properties of Aggregates

Property	Fine Agg.	Coarse Agg.
SSD Sp.Gr.	2.54	2.70
Abs. (%)	3.55	0.29
Los Angeles Weight Loss (%)	-	24.40
Na_2SO_4 Weight Loss (%)	4.08	1.08
D_{max} (mm)	-	16

three concrete mixes having 28-day characteristic cylinder compressive strengths of 40, 60, and 75 MPa were used.

Experimental Work

Materials and Mix Proportions. Three concrete mixes were prepared by using a blended cement containing 10% volcanic tuff, river sand as fine aggregate, crushed limestone as coarse aggregate, a melamine formaldehyde based high-range water reducer agent (HRWR) and Fe-Si silica fume. The properties of the cement and silica fume are given in Table 2 and those of the aggregates are given in Table 3. Mix designs were made to obtain three series of concretes having 40, 60, and 75 MPa 28-day characteristic cylinder compressive strength. Concrete mix proportions are given in Table 4. All concretes had the same slump value of 60-70mm.

Specimens. From the three concrete mixes (a) different sized cylinder specimens with l/d = 2.00, (b) different sized cube specimens, and (c) cylinder specimens of 150mm diameter with different l/d were prepared. The dimensions of the specimens are given in Table 5. Six specimens were cast from each mix for each strength level. Cylinder specimens with l/d ≠ 2.00 were cut from standard specimens. The ends of the cylinders were capped with sulfur in accordance with ASTM C 617. All specimens were compacted with equivalent compaction effort depending on their sizes and continuously moist cured until the time of test.

TABLE 4

Concrete Mix Proportions

Ingredient (kg/m^3)	Strength Level (MPa)		
	40	60	75
Cement	555	555	555
Water (net)	212	126	109
Fine Agg. (SSD)	782	782	802
Coarse Agg.(SSD)	980	980	981
HRWRA	5.5	28	42.4
Silica Fume	-	-	55

TABLE 5

Specimen Sizes and Upper Bearing Block Diameters

Specimen Shape	l/d	Dimensions (mm)	Bearing Block Diameter (mm)
Cylinder	0.67 1.00 1.33 1.67 2.00	150x100 150x150 150x200 150x250 150x300	210
Cylinder	2.00	75x150 100x200 150x300 200x400	100 150 210 260
Cube		75 100 150 200	100 150 210 260

Method of Testing. Tests were performed on a 200t-capacity testing machine. Loading rate was adjusted for all specimens to be 0.2 MPa/s. The spherical bearing block of the test machine was changed depending on the size of the specimen. The dimensions were in accordance with ASTM C 39-86. Diameters of the upper bearing blocks used are given in Table 5.

Results and Discussions

The strength test results and standard deviations for different sized cylinders and different sized cubes are shown in Figs. 1 and 2, respectively. The scatter of results was found to be not dependent on the specimen size. However, it was observed that as the strength level increases standard deviations also increase. The highest apparent strengths were obtained for 100 × 200mm cylinder and 150mm cube specimens. Specimens both smaller and larger than

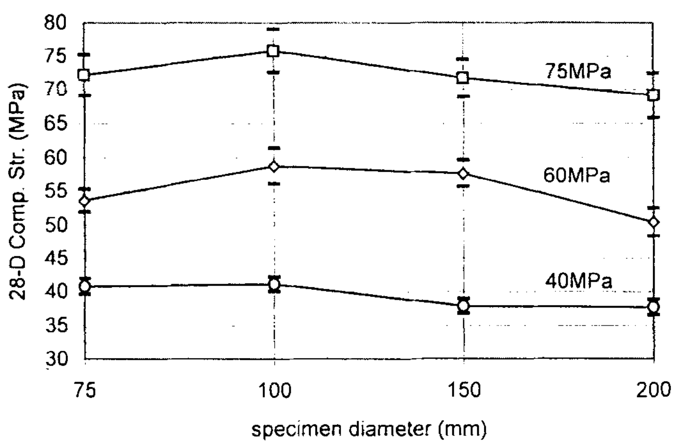

FIG. 1.
Average strength values and standard deviations obtained from different sized cylinders with l/d = 2.00.

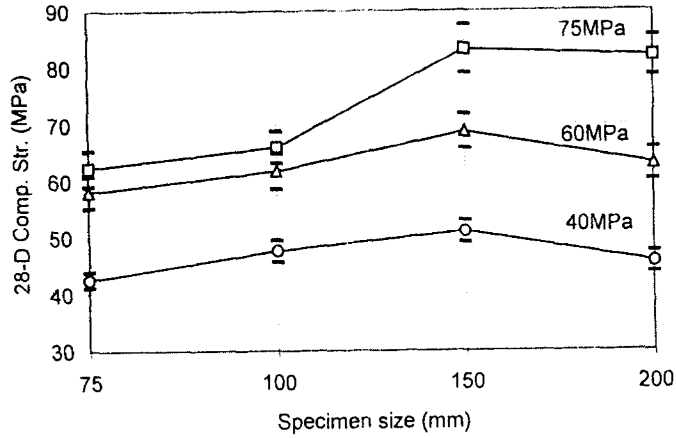

FIG. 2.
Average strength values and standard deviations obtained from different sized cubes.

these had lower strengths. The results are consistent with the literature for large specimens: the larger the volume of the concrete subjected to stress, the more likely it is to contain an element of a given low strength. As a result, the measured strength of the specimen decreases with increase in its size (6). On the other hand, with the same reasoning, the smaller specimens should have resulted in higher apparent strengths. The contradiction for smaller specimens was attributed to the "wall effect": The quantity of mortar required to fill the space between the particles of the coarse aggregate and the wall of the mold is greater than that necessary in the interior of the mass and therefore in excess of the mortar available even in a well-proportioned mix (6). This effect limits the compactibility of specimens and is more pronounced in specimens with larger lateral surface area-to-volume ratio (S_l/V). Indeed, S_l/V values of 75 and 100mm specimens were much greater than those of 150 and 200mm specimens; 0.53, 0.40, 0.27, and 0.20, respectively. In order to overcome a possible wall effect, additional 75 × 150mm cylinder and 75mm cube specimens were prepared with

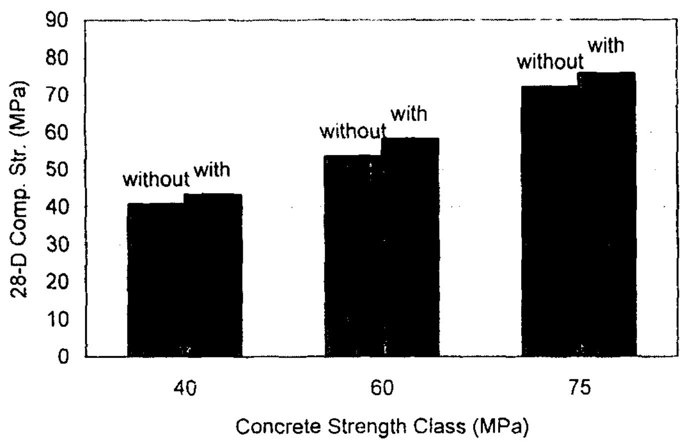

FIG. 3.
Strength comparison of 75 × 150mm cylinder specimens with and without additional mortar.

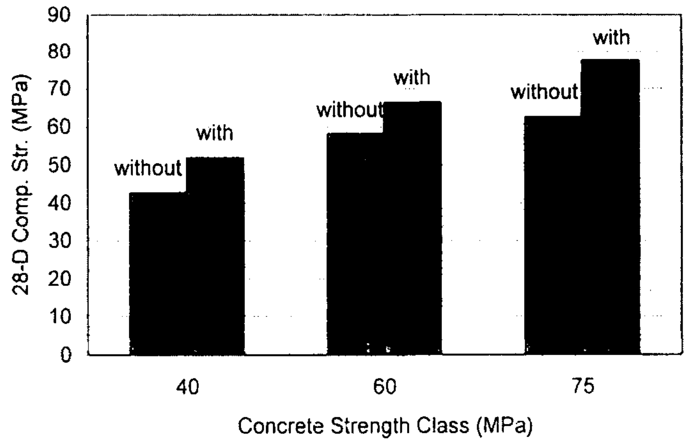

FIG. 4.
Strength comparison of 75mm cube specimens with and without additional mortar.

mortar fraction of the mixes increased. The increase was achieved by a 10% (by weight) increase in fine aggregate and same amount of decrease in coarse aggregate.

The comparison of the strength test results obtained from the specimens with and without additional mortar fraction is given in Figs. 3 and 4 for 75 × 150mm cylinders and 75mm cubes, respectively.

As seen from Fig. 3, 10% increase in the mortar content resulted in 6.28, 8.63, and 5.01% increase in the strength of 75 × 150mm cylinder specimens for the 40, 60, and 75MPa strength levels, respectively. The increase is more pronounced for cube specimens, as illustrated in Fig. 4. The strengths of 75mm cubes with increased mortar were 21.45, 14.04, and 24.18% higher than those of the original specimens for the three strength levels used, respectively.

Murdock and Kesler (7) stated that the influence of strength on the correction factor for l/d ≠ 2.00 is significant only for low- and medium-strength concretes. That is, stronger concretes are less affected by changes in l/d ratio. This statement was found to be valid accord-

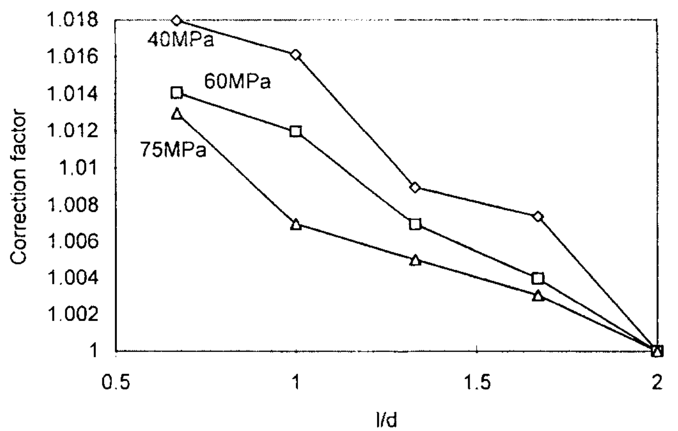

FIG. 5.
Strength test results of cylinders with different l/d.

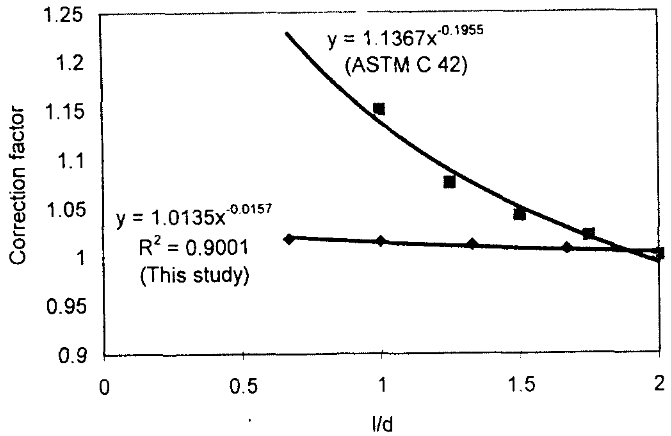

FIG. 6.
Comparison of correction factors obtained in this investigation with those given in ASTM C 42.

ing to the results of the present study too, as shown in Fig. 5. There is a great difference between the correction factors obtained in this investigation and those given by ASTM C 42. On the other hand, they are similar in the sense that they can both be described by power equations as shown in Fig. 6.

The cylinder-cube strength ratios of the specimens with constant l/d = 2.0 ranged between 0.74 to 1.16 with an average of 0.91, as shown in Fig. 7. For the smaller specimens (75 and 100mm) the average ratio was 1.00 whereas for larger specimens (150 and 200mm), it was 0.82 which is a value consistent with the literature. For the case of 75mm specimens with 10% additional mortar, the ratios were 0.84, 0.89, and 0.98 for 40, 60, and 75MPa concretes, respectively. As it can be observed in Fig. 8, cylinder-cube strength ratios of 75mm specimens were lowered to reasonable values by additional mortar.

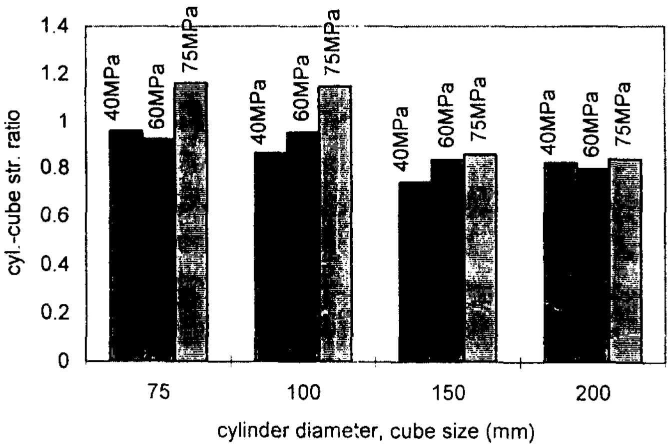

FIG. 7.
Cylinder-cube strength ratios for different specimen sizes.

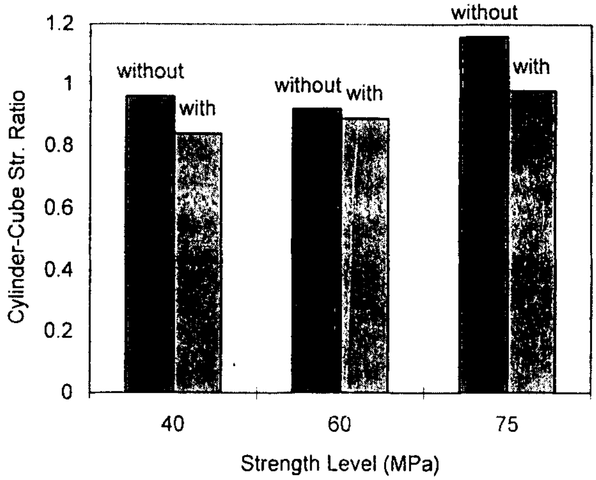

FIG. 8.
Comparison of cylinder-cube strength ratios of 75mm specimens with and without 10% additional mortar.

Conclusions

1. Although the use of small specimens offer certain advantages, their use in the compressive strength testing of higher strength concrete may result in significantly lower apparent strengths when compared with those of standard specimens.
2. Lower strengths of smaller specimens which have high lateral surface area-to-volume ratio may be attributed to the "wall effect". The effect is more pronounced in cube specimens. Furthermore, cylinder-cube strength ratios of smaller specimens are not consistent with the values given in the literature. Therefore, 150mm cubes or 100 × 200 and 150 × 300mm cylinders are recommended for compressive testing of higher strength concrete.
3. The effect of length-to-diameter ratio of cylinder specimens on the compressive strength is not significant in higher strength concrete.

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