



GLOBAL JOURNAL OF RESEARCHES IN ENGINEERING
CIVIL AND STRUCTURAL ENGINEERING
Volume 13 Issue 8 Version 1.0 Year 2013
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN: 2249-4596 & Print ISSN: 0975-5861

Effect of Size on Compressive Strength of Concrete Cylinder Specimens using Sand and Sulfur Cap

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GJRE-E Classification : FOR Code: 670904, 090502



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Abstract- In the majority of structural concrete design, the compressive strength is obtained from testing of 150x300 mm concrete cylinders under standard laboratory controlled conditions with different capping system. Some testing machines are unable to produce the force needed to break high-strength 150x300 mm concrete cylinders. If 100x200 mm cylinders are to be used in quality assurance testing, the relationship between f_{c4} and f_{c6} needs to be understood in order to ensure that concrete with sufficient strength is provided. 100x200 mm cylinders are lighter and can easily be handled, collection of quality control and assurance specimens would be easier for contractors and inspectors. This research work was born from the need to determine a correlation between the strength of the standard size 150x300 mm and 100x200 mm cylindrical specimen. A total 72 no. of 100x200 mm and 150x300 mm cylinders were tested according to ASTM. Cylinders prepared by sand and sulfur capping reveals a little difference in the strength level, 150x300 mm and 100x200 mm sulfur capped cylinders shows 23% and 21% higher strength than sand capped cylinders and 100x200 mm cylinder gives 39% higher strength than 150x300 mm cylinder.

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I. INTRODUCTION

Concrete is a versatile material with tremendous applications in civil engineering construction. Here test of compressive strength of concrete cylinder is done by two methods. One is sulfur capping method and another method is sand capping. Thus, capping at the end of concrete cylinder should satisfy the specific standards set forth in American Society for Testing and Materials (ASTM) in order to obtain accurate test results for the compressive strength of concrete. Sand-capping method, which is introduced in this study, uses a simpler device compared to other complicated sand-box system. It is to be shown that this new capping system is not only more economical in terms of the test time and process but more reliable in the test results than any other unbounded methods. These results are verified by the average compressive strength of concrete as compared to sand capping methods pursuant to ASTM C1231. The new trend of using high-strength concrete in construction has caused a need for

100 x 200 mm cylinders for assurance testing. Some testing machines are not able to produce the force needed to break high-strength 150 x 300 mm. concrete cylinders. As laboratories and testing agencies are very often equipped with testing machines having full load capacities no greater than 300,000 lb, the maximum compressive strength of concrete that can be tested on 150 x 300 mm. specimens is just over 10,000 psi when operating at full load, which is not safe on a routine basis [2]. The required force to break a 100 x 200 mm cylinder is 44% of that required to break a 150 x 300 mm cylinder of the same strength solely based on a ratio of the two circular cross-sectional areas [3]. This would allow machines that could not break 150 x 300 mm cylinders with strengths over 10,000 psi to break 100 x 200 mm cylinders with strengths in excess of 20,000 psi. A 100 x 200 mm cylinder weighs about 9 lb compared to a 150 x 300 mm. cylinder, which weighs about 30 lb, almost three times as much. This might suggest that because 100 x 200 mm cylinders are lighter and can easily be handled, collection and storage of quality control and assurance specimens would be easier for contractors and inspectors. One aspect of concern when using 100 x 200 mm cylinders is the size of maximum coarse aggregate used in concrete. Mixes containing a nominal maximum coarse aggregate size of 1.5 inches, or greater in some instances, are used in today's concrete industry. AASHTO T 126 states that, "the size of a cylinder mold shall not be smaller than 3 times the nominal maximum coarse aggregate size." This limits 100 x 200 mm cylinders to having a 1-inch nominal Maximum coarse aggregate size. Also there is no standard aggregate size between 1 inch and 1.5inches, leaving a #57 coarse aggregate the largest possible gradation for a 100 x 200 mm cylinder. The obvious advantages of using smaller specimens are: a) ease in handling and transportation; b) smaller required storage space; c) lower capacity required of testing machines; and d) the economic advantages of reduced costs for molds, capping materials, and concrete [3].

$$f_{csul} = k_s \times f_{csand} \quad (1)$$

$$f_{c4} = k_{si} \times f_{c6} \quad (2)$$

where,

f_{csul} = Compressive strength of a sulfur capped cylinder,

f_{csand} = Compressive strength of a sand capped cylinder,

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k_s = The strength conversion factor, correlating the sulfur and sand capped cylinder strength,
 f_{c4} = Compressive strength of a 100 x 200 mm cylinder,
 f_{c6} = Compressive strength of a 150 x 300 mm. cylinder,
 k_{si} = The strength conversion factor, correlating the 100 x200 mm cylinder to the 150 x 300 mm cylinder strength.

II. EXPERIMENTAL PROGRAM

a) Mix Design Procedure

The use of locally available materials from different sources was emphasized in this work. Scan cement (Portland composite cement) and locally available brick chips were used for coarse aggregates. The mix proportion was 1:2:4 with a water-cement ratio of 0.4 [5]. At first sand and brick chips were screened by the sieve according to AASHTO T 22. Concrete constructions (Sand, Brick chips) were measured to dry separately by weight according to required proportions. The Brick chips were soaked thoroughly 24 hours and then made them surface dry saturated before use. Sand and cement were mix to dry on a clean platform until the mix was uniform. The coarse aggregate then added to mix of cement and sand admixture and the whole were mixed thoroughly. The moulds were lubricated by lubricating oil, before placing concrete in the mould.

b) Casting and Curing

All specimens were made and cured according to ASTM C192. All 150 x 300 mm cylinders were tamping with a rod for 25 times per layer for three layers of equal height and for 100 x 200 mm cylinders 25 times per layer for two layers of equal height. After strike-off, all specimens were moved from mixing room to curing room. The 36 cylinders were cured for 7 days and rest 36 cylinders for 28 days. All the specimens were carefully cured by immersing in clean water on the water bath of the laboratory.

c) Capping Material and Method

Two kind of capping methods were used to compare the compressive strength of each specimen in this study. Sulfur and locally available white natural silica sand were used for capping the cylinder specimens. Molten sulfur compound capping was formed by a vertical capping apparatus as specified in ASTM C617. In sand capping method as suggested in this project the sand was placed at top of cylinder as simple capping devices. All of the dry fine sand was passed through NO.20 sieve for its use as a sand capping material.

d) Testing

In testing program the specimens were maintained in a moist condition up to the time of compression testing. Compression test are made as soon as practicable after removal from moist storage.

The specimens were tested in this cured moist condition. Applying load was 13.8 N/cm² to 34.5 N/cm² and maintained the rate once adjusted until failure according to ASTM C 39.

III. RESULT AND DISCUSSION

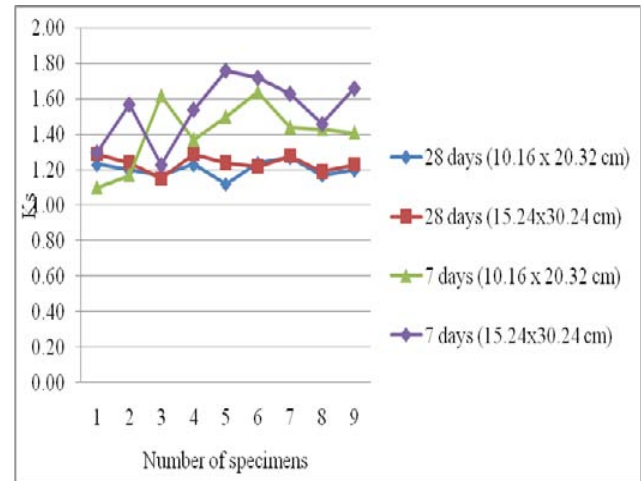


Figure 1 : Comparison of Ks with all ages

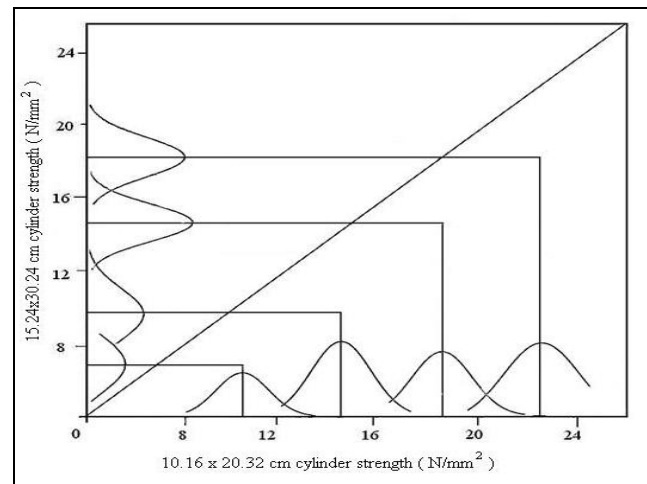


Figure 2 : Normal distributions of test results

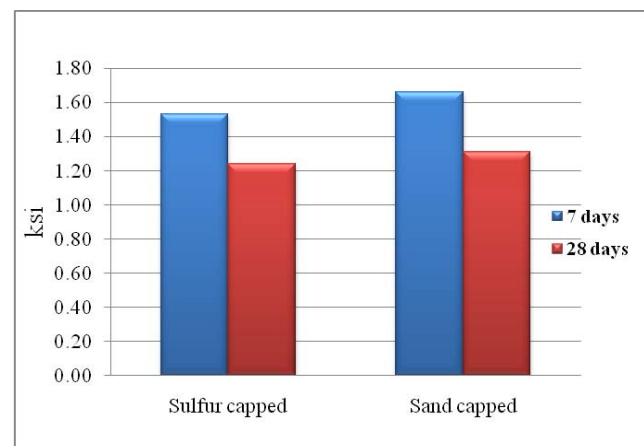


Figure 3 : Strength conversion factor Ksi

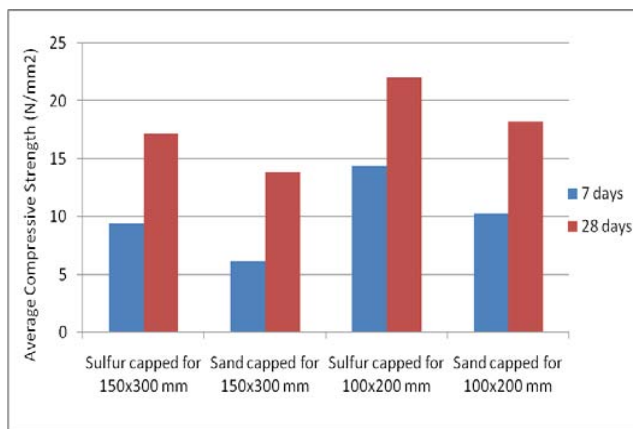


Figure 4 : Average Compressive Strength (N/mm²)

From the test results by using individual frequency distribution the standard deviation of Sand capping vs. sulfur capping for 7 days and 28 days were calculated and analyzed in the Table 2 and Table 3. From figure 1, the value of k_s is more consistent for 28 days of 150 x 300 mm cylinders and it also gives more consistence results then the 100 x 200 mm cylinders. Figure 2 shows the normal distributions for the two types of cylinders. For 100 x 200 mm cylinder normal distributions was plotted on the horizontal axis and for 150 x 300 mm cylinder on the vertical axis. Lines representing the mean of each distribution extend outward until they intersect with the mean line of the opposite cylinder size for the same strength range. This was done to plot the intersections of the means of each distribution against a 45° line of equality. It was seen that the mean compressive strengths for each strength range increased with age. The intersection of the means is an indicator of the magnitude of k_s . If the intersection is below the line of equality, then the strength is in favor of the 100 x 200 mm cylinders and k_s is greater than 1.0. If the intersection is on the line of equality, then the strengths are equal and k_s is equal to 1.0. If the intersection is above the line of equality, then the strength is in favor of the 150 x 300 mm. cylinders and k_s is less than 1.0. From figure 2, k_s is greater than 1 for each type cases. Figure 3 represent the strength conversion factor k_s which is the ratio of 100 x 200 mm to the 150 x 300 mm concrete cylinders. From the test results the sulfur capped specimen's was given higher strength for 28 days and in average the compressive strength of 100 x 200 mm cylinder is 39% to 48% higher than 150 x 300 mm cylinders.

IV. VERIFICATION OF TEST RESULT

The test results from figure 4 were sampled to investigate the average compressive strength of the test cylinders except underrated (outlier) data to excessive cap-thickness, imperfect capping or failure caused by electric loading. The statistical confidence level of 95% was set so that the results are to be statistically acceptable at $\alpha=0.050$. The average compressive

strength obtained by bonded capping should not be less than 98% of that obtained by unbonded capping methods. The calculation process for verifying the unbonded capping system involved the following. For every strength group, the difference in strength of cylinders (sulfur capped vs. sand capped cylinders) was computed. Next, it was verified that the average strengths of the two kinds of bonded capping cylinders were over 98% of those unbonded capping cylinders.

$$d_i = X_{\text{sulfur } i} - X_{\text{sand } i}$$

$$X_{\text{sulfur}} = (X_{s1} + X_{s2} + X_{s3} + X_{s4} + \dots + X_{sn})/n$$

$$X_{\text{sand}} = (X_{s1} + X_{s2} + X_{s3} + X_{s4} + \dots + X_{sn})/n$$

where,

d_i = Difference in strength of cylinders

$X_{\text{sulfur } i}$ = Cylinder strength using sulfur capping

$X_{\text{sand } i}$ = Cylinder strength using unbonded capping

n = Number of combination of cylinder

X_{sulfur} = Average strength of sulfur capped cylinders.

X_{sand} = Average strength of sand capped cylinders

Average difference, $d = (d_1 + d_2 + d_3 + \dots + d_n)/n$

Standard deviation, $S_d = [\sum(d_i - d)^2 / (n-1)]^{1/2}$

In order to comply the practice for ASTM C 617^[11], the following relationship must be satisfied,

$$X_{\text{sulfur}} \geq 0.98 X_{\text{sand}} + (t.S_d)/(n)^{1/2} \text{ for 7 days}$$

$$X_{\text{sulfur}} \geq 0.98 X_{\text{sand}} + (t.S_d)/(n)^{1/2} \text{ for 28 days}$$

Where, t is the value of 'student's t -test for $(n-1)$ pairs at significant level of $\alpha=0.050$ as shown in the Table 1.

Use linear interpolation for other values of $(n-1)$ or refer to appropriate statistical tables. The calculation process and results was shown in table below for the verification of test results. All the compressive strength of cylinders by bonded capping methods exhibit greater than 98% of the reference values of all specimens.

Table 1 : The value of t

(n-1)	t ($\alpha=.050$)
9	1.83
14	1.76
19	1.72
100	1.66

Table 2 : Statistical analyses of test results for 150 x 300 mm cylinders

Capping types	Calculation (N/mm²)	Values
Sand capping vs. sulfur capping For 7 days	(1) X_{sulfur}	9.41
	X_{sand}	6.18
	d	3.25
	S_d	0.83
	(2) $0.98 X_{\text{sand}} + (t S_d)/(n)^{1/2}$	6.4
	System qualifies (1) > (2)	ok

Sand capping vs. sulfur capping For 28 days	(1) X_{sulfur}	17.17
	X_{sand}	13.89
	d	3.3
	S_d	0.55
	$(2)0.98X_{\text{sand}} + (t S_d)/(n)^{1/2}$	13.84
	System qualifies (1) > (2)	ok
	n=18, t=1.7418	

Table 3 : Statistical analyses of test results for 100 x 200 mm cylinders

Capping types	Calculation (N/mm ²)	Values
Sand capping vs. sulfur capping For 7 days	(1) X_{sulfur}	14.4
	X_{sand}	10.28
	D	4.12
	S_d	1.63
	$(2)0.98X_{\text{sand}} + (t S_d)/(n)^{1/2}$	10.74
	System qualifies (1) > (2)	ok
Sand capping vs. sulfur capping For 28 days	(1) X_{sulfur}	22.01
	X_{sand}	18.24
	D	3.77
	S_d	0.78
	$(2)0.98X_{\text{sand}} + (t S_d)/(n)^{1/2}$	18.12
	System qualifies (1) > (2)	ok
	n=18, t=1.7418	

V. CONCLUSIONS

Strength of concrete cylinder was obviously affected by capping method. Strength variation due to various methods exhibited a different tendency for normal and high strength level. The standard deviation of sand capped was less than sulfur capped cylinders. The comparison of compressive strength of cylinders prepared by sand capping and sulfur capping reveals a little difference in the strength level. In the 150 x 300 mm sulfur capped cylinders the difference in strength was 19% higher than those prepared by sand capping for 28 days and 34% higher than those prepared by sand capping for 7 days, and for 100 x 200 mm cylinders these values were 17% and 29% higher respectively. The 100 x 200 mm cylinder was given 38% to 48% higher strength than 150 x 300 mm cylinder. It was found that each strength range had its own range of ksi values and that ksi decreased with increasing compressive strength ranges.

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