

Comparative Study on Compressive Strength of Concrete with New Sand-Cap and Neoprene Pad

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Abstract: The most typical capping method for concrete structures is a sulfur-mortar compound capping, provided it satisfied the standard criterion set forth by ASTM C 617, but this conventional bonded-type method has many problems. It exhibits relatively the smaller unreliable value of the strength of high-strength concrete due to the differences of elasticity and strength between the cylinder and the cap, and manifests poor serviceability such as dangerous working tasks or a waste of the working time. To prevent these problems, unbonded-type capping methods have taken the place of the conventional methods in recent years. One of the popular methods is the use of synthetic rubber like a neoprene pad. Serious problems still remain in this method, which include the consideration of its chemical characteristics in consideration of the selection, the safekeeping and the economy of the pads. Moreover, the synthetic rubber pads cannot be used in concrete cylinder with strength greater than 80 MPa according to ASTM C 1231-00. New 'sand-capping method' presented in this study, can be applicable to the compressive strength evaluation of the high strength concrete in the range of 70~100 MPa. This new method has better simplicity and reliability than those of existing 'sand-box', because usual materials such as standard sand and simply-devised apparatus are used for the capping system. The statistical analysis of the test results revealed that the new sand-capping method exhibited the smallest deviation and dispersion, attesting for its much better reliability than other methods specified in ASTM C 1231/1231M.

Keywords: capping, sand-cap, neoprene pad, compressive strength, high strength concrete.

1. Introduction

Various errors in measuring compressive strength of concrete tend to be due to the test method and condition. Thus, capping at the end of concrete cylinder should satisfy the specific standards set forth in ASTM C 617¹ in order to obtain accurate test results for the compressive strength of concrete. Of a particularly important concern in the case of high strength concrete cylinder is that the reliable data on its compressive strength can be measured only by a special end-capping method. The method of cutting and grinding the end of a cylinder is employed in the compression test of high strength concrete, because the compressive strength test by conventional bonded-type methods using a cap with sulfur-mortar, high-strength mortar or high-strength gypsum has shown relatively the smaller unreliable values of the compressive strength. Unbonded capping methods such as grinding or capping with pads is not efficient in economical administration and easy administration of the test as well.

New 'sand-capping method', which is introduced in this study, uses a simpler device compared to other complicated 'sand-box' system proposed by Purington and McCormick² or Boulay and

Larrard.³ 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 unbonded method. These results are verified by the average compressive strength of concrete as compared to sand-capping, neoprene pad capping and sulfur-mortar capping methods pursuant to ASTM C 1231/1231 M.⁴

2. Experimental programs

In this study, the effect of capping method for concrete cylinder-end only is considered in the evaluation of its compressive strength. The other testing factors such as specimen size, loading method, testing-machine type etc. should follow the specifications of ASTM C 39.⁵ Such three capping methods are sulfur-mortar compound capping, neoprene pad capping and sand capping. The design strength for each concrete cylinder group is set to be 21 MPa (Group A), 34 MPa (Group B) and 70 MPa (Group C) subjected to the following mix proportions.

2.1 Test specimens

The three mix proportions as shown in Table 1 were prepared to investigate the effect of capping on the compressive strength, and cylindrical specimens of $\varnothing 100 \text{ mm} \times \text{H}200 \text{ mm}$ were cast by moulds. The test groups were composed of 20 specimens for each mix type and each capping method. Ordinary Portland cement (ASTM type I) was used for all the specimens. Crushed stone with 19 mm maximum size and river sand were used as the coarse and fine aggregate, respectively. Powdered silica-fume was used as an

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Table 1 Mix proportions of concrete cylinders.

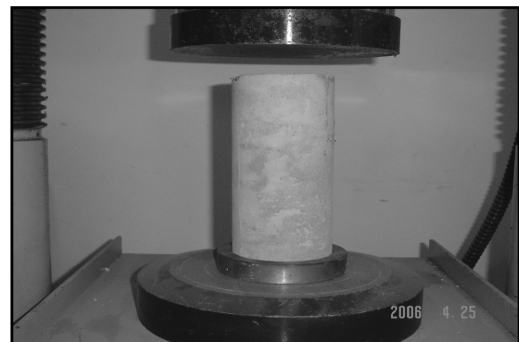
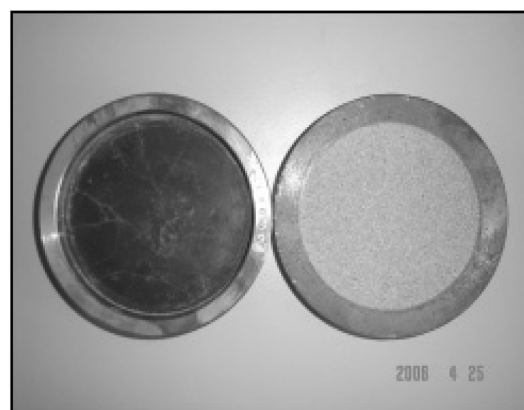
Specimen group	Batch weight		
	Group A	Group B	Group C
W/b	0.53	0.37	0.28
Cement (kg/m ³)	321	490	520
Water (kg/m ³)	171	181.3	147
Fine aggregate (kg/m ³)	905	683	634.6
Coarse aggregate (kg/m ³)	945	982	1128.4
Superplasticizer (%)	0.5	0.8	2.0
Silica-fume (%)	0	0	10
Slump (mm)	120	80	60
Compressive strength at 28 days (MPa)	21	34	70

admixture for the high strength concrete in this test. All the materials were mixed a concrete pan mixer of 80 liter capacity. The compression test of concrete cylinder was performed after the aging of 90 days passed by in consideration of the differences in the making and curing days. The curing of all specimens was performed in water until the aging of 28 days.

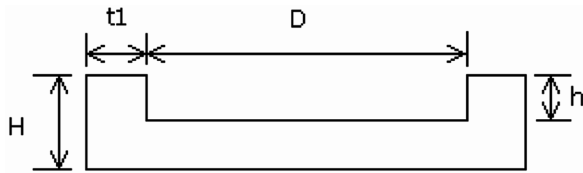
2.2 Capping methods

Three kinds of capping methods were used to compare the compressive strength of each specimen in this study. Molten sulfur-mortar compound capping was formed by a vertical capping apparatus as specified in ASTM C 617, and neoprene pad for an unbonded capping system was employed to test the hardened concrete cylinders in accordance with the capping standards as described in ASTM C 1231/ C 1231M. An elastomeric pad like neoprene pad deforms upon initial loading, conforming to the contour of the cylinder-end, and it is restrained from excessive lateral spreading by its plate and metal ring to provide a uniform distribution of the load exerting from the bearing blocks of testing machine to the end of concrete cylinder. The sand capping method as suggested in this study has the cylinder placed only on the top of sand as a simple capping device, without any other sealing process or sub-device of the existing sand-box systems. All of the dry and fine sand was passed through No.20 sieve for its use as a sand capping material.

The average thickness of the caps is summarized in Table 2 for the selection of objects of a statistical analysis. The compression test of concrete cylinders was performed for the three cylinders per each capping method in sequence in order to control for the influence of eccentricity error caused by the testing machine. The weight of sand in the device was measured at just 0.1g-precision because of the difficulty in taking an accurate measurement of the cap-thickness. Dimensions of sand-capping system and neoprene pad ring are shown in Fig. 3 and the attached table.

**Fig. 1** Sand-capping system and neoprene pad ring.**Fig. 2** Post-testing status of neoprene pad and sand cap (hardening of neoprene pad).**Table 2** Thickness of cap.

Types of cap	Average thickness	Retainer ring	Mixture of cap materials
Unbonded neoprene & natural pads	12.8 mm	102 mm × 254 mm	Neoprene & natural rubbers/ steel & aluminum alloys
Sulfur-mortar compound cap	2.4 mm	-	Sulfur compound
Sand cap	38 gr	101.1 mm × 10 mm	Fine sand/ steel & aluminum alloys



	Specimen (mm)	D	H	t1	h
Neoprene pad ring	Ø100 × 200	105 ± 1	35.4 ± 1	11 ± 1	25.4 ± 1
Sand-capping system	Ø100 × 200	101.1 ± 0.5	22 ± 1	15 ± 1	10 ± 1

Fig. 3 Dimensions of sand-capping system and neoprene pad ring.

3. Results and discussion

3.1 Verification of test results

The test results were sampled to investigate the compressive strength of the test cylinders except for underrated (outlier) data due to excessive cap-thickness, imperfect capping, or failure caused by eccentric loading. The statistical confidence level of 95% was set so that the results are to be statistically acceptable at $\alpha = 0.05$. The average compressive strength obtained by unbonded capping should not be less than 98% of that obtained by bonded capping or grinding methods pursuant to ASTM C 1231.

The calculation process for verifying the unbonded capping system involved the following. For every strength group, the difference in strengths of each pair of cylinders ('sulfur-mortar capped cylinders vs. neoprene pad capped cylinders' or 'sulfur-mortar capped cylinders vs. sand capped cylinders') was computed. Next, it was verified that the average strengths of the two kinds of unbonded capping cylinders were over 98% of those of sulfur-mortar capping cylinders.

$$d_i = x_{pi} - x_{si}$$

$$x_s = (x_{s1} + x_{s2} + x_{s3} \cdots x_{sn}) / n$$

$$x_p = (x_{p1} + x_{p2} + x_{p3} \cdots x_{pn}) / n$$

where,

- d_i : Difference in strength of a pair of cylinders according to ASTM C 617.
- x_{pi} : Cylinder strength using unbonded capping.
- x_{si} : Cylinder strength using Practice for ASTM C 617.
- n : Number of the combination of the cylinder pairs tested for the strength comparison.
- x_s : Average strength of cylinders for each Group according to practice for ASTM C 617.
- x_p : Average strength of the unbonded capping cylinders for each Group.

$$\text{average difference, } d = (d_1 + d_2 + d_3 \cdots d_n) / n$$

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

In order to comply with the Practice for ASTM C 617, the following relationship must be satisfied,

$$x_p \geq 0.98x_s + (t \cdot S_d) / (n)^{1/2}$$

where, t is the value of 'student's t -test' for $(n - 1)$ pairs at significance level of $\alpha = 0.05$ as shown in the following table:

($n-1$)	$t(\alpha = 0.05)^*$
9	1.833
14	1.761
19	1.729
100	1.662

*Use linear interpolation for other values of $(n-1)$ or refer to appropriate statistical tables.

The calculation process and results are shown in Table 3 for the verification of the test result. All the compressive strengths of cylinders by unbonded capping methods exhibited greater than 98% of the reference values for all Group A, B and C.

3.2 Analysis of test results

In the statistical analysis of test results, the compressive strengths of cylinders by neoprene-pad capping manifested the

Table 3 Verification process of test results.

Capping types	Calculations (MPa)	Group A	Group B	Group C
Neoprene pad vs. Sulfur-mortar capping	① x_p	21.75	35.42	79.02
	x_s	21.6	35.12	76.91
	d	0.15	0.305	2.115
	s_d	0.6977	1.6599	3.6881
	② $0.98x_s + (t \cdot s_d) / (n)^{1/2}$	21.44	35.07	76.83
	System qualifies ① \geq ②	O.K	O.K	O.K
Sand capping vs. Sulfur-mortar capping	① x_p	22.28	36.8	81.09
	x_s	21.6	35.12	76.91
	d	0.68	1.685	4.185
	s_d	0.7516	1.6769	2.3640
	② $0.98x_s + (t \cdot s_d) / (n)^{1/2}$	21.47	35.08	76.30
	System qualifies ① \geq ②?	O.K	O.K	O.K
Common details	$n = 20, t = 1.729$			

smallest values of deviation and dispersion for normal strength concrete, but those by sand-capping method exhibited the least deviation and dispersion for high strength concrete. The average strengths of cylinders by sand-capping method are shown as the highest values of all Groups in Table 4.

The compressive strengths of the test specimens prepared by sulfur-mortar capping, neoprene pad capping and sand capping for Groups A, B and C in the range of 20 MPa~80 MPa are shown in (a), (b), (c) of Fig. 4. A point on the graph indicates the compressive strength for one cylinder. The variation of average

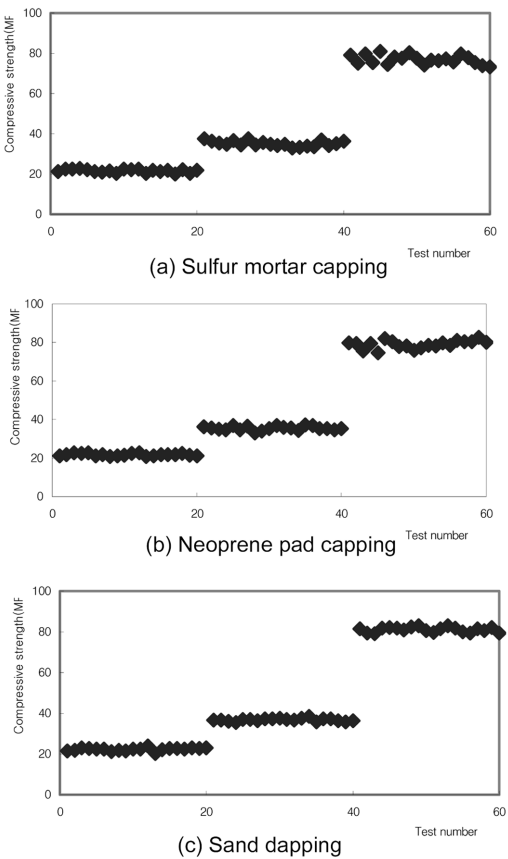


Fig. 4 Compressive strengths of cylinders prepared by three capping methods.

compressive strengths for each capping method is shown in Fig. 5(a).

In Fig. 5(a), the comparison of compressive strengths of cylinders prepared by neoprene pad capping and sulfur mortar capping reveals a little difference in the lower strength level, Group A and B, but the difference in the strengths of 27% is observed in Group C. As the concrete strength gets higher, the more difference in the strength by the capping methods is observed. The compressive strengths of concrete prepared by sand capping method are 3~5.4% higher than those prepared by sulfur mortar capping, and the difference in the strengths of the concrete increases more in the concrete of higher strength level. When the compressive strength of cylinder prepared by sulfur mortar capping is set to 1 as a reference value, the relative values of the strength of the concrete prepared by unbonded capping methods are shown as a ratio relative to it in Fig. 5(b). The standard deviations and the dispersions of the compressive strengths in Fig. 5(c) and 5(d) are greater for the higher strength level, Group C. The smallest value of deviation and dispersion is observed in the test specimens prepared by sand capping method.

The test for the compressive strength of concrete cylinder specimens revealed that the relatively higher strength concrete did not exhibit a proper strength value for a concrete cylinder, instead it was rather overestimated. Thus, a proper estimation of the compressive strength of a concrete cylinder can only be proven by reliable test results as for the case of smaller deviation and dispersion.

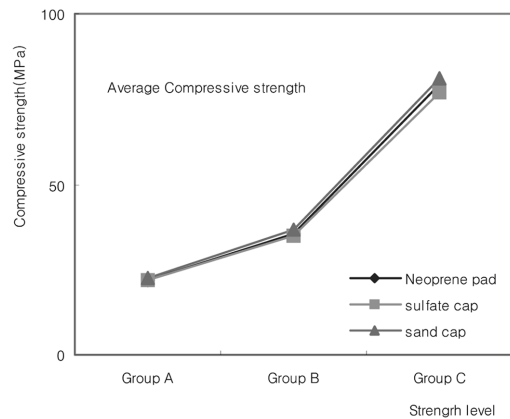
4. Conclusions

This study found that the strength of a concrete cylinder was obviously affected by different capping methods, and the effect increased significantly as the strength level of the concrete cylinder was higher. Strength variation due to various capping methods exhibited a different tendency for normal and high strength concrete cylinders.

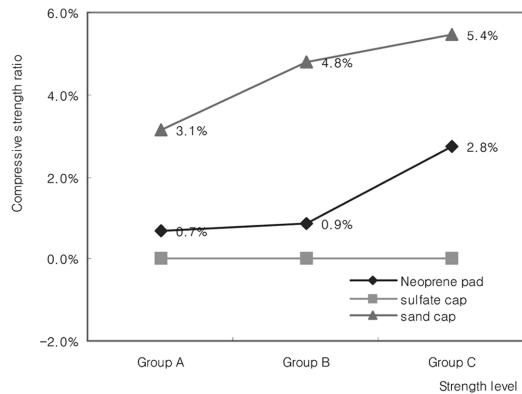
The standard deviation and the dispersion of strength for sand-capped cylinders were less than those of sulfur-mortar or neoprene pad capped cylinders. Thus, sand-capping method was the most reliable in consideration of the standard deviation and dispersion

Table 4 Statistical analysis of test results.

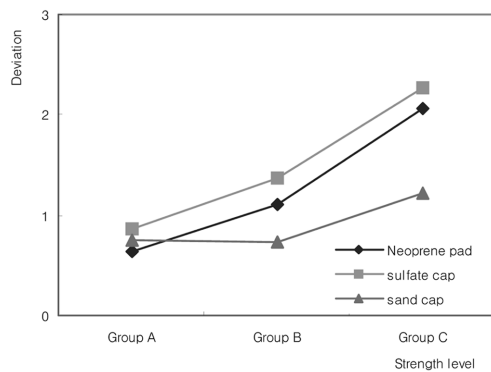
Capping types	Analysis of results	Group A	Group B	Group C
Sulfur-mortar capping	Average strength (MPa)	21.6	35.1	76.9
	Standard deviation	0.86	1.37	2.27
	Dispersion	0.75	1.87	5.14
	No. of specimens	20	20	20
Unbonded neoprene pad capping	Average strength (MPa)	21.75	35.4	79.2
	Standard deviation	0.63	1.11	2.06
	Dispersion	0.4	1.23	4.23
	No. of specimens	20	20	20
Sand capping	Average strength (MPa)	22.28	36.8	81.1
	Standard deviation	0.75	0.73	1.23
	Dispersion	0.56	0.53	1.49
	No. of specimens	20	20	20



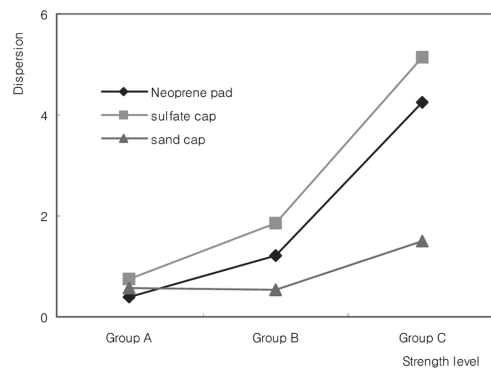
(a) Average compressive strength of concrete



(b) Ratio of compressive strength



(c) Standard deviation



(d) Dispersion

Fig. 5 Statistical analysis of test analysis.

of strength when every capping methods were analyzed statistically.

Thus, conventional bonded-capping methods might be improper for the compressive test of high strength concrete. Additionally, unbonded neoprene pad capping was not satisfactory in estimating the compressive strengths of high strength concrete, for it was not competitive to sand capping system in terms of the economy and the simplicity of the test.

Consequently, the general use of new sand capping system is proposed in this study to estimate the compressive strengths of both normal and high strength concrete cylinder more reliably and accurately.

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