A STUDY ON COMPRESSIVE STRENGTH TESTS OF CONCRETE USING THE UNBONDED CAPPING SYSTEM

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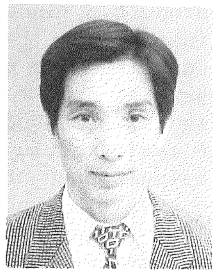
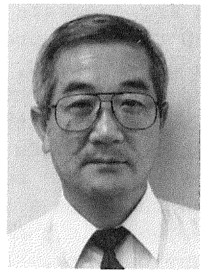

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A study is made with regard to adoption of an unbonded capping system using steel caps and rubber pads to save time and labor in work to cap specimens for compressive strength tests of concrete. Beginning with appropriate specifications for steel caps and rubber pads, methods of controlling rubber pads and the applicable scope of unbonded capping are examined through experiments. The experiments show that the results of compressive strength tests of concrete using unbonded capping are equivalent to those with neat cement paste capping or ground plane cylinder tops as specified in JIS A 1132. In addition, a rational method of testing compressive strength of concrete based on unbonded capping is proposed.

Keywords: compressive strength test, unbonded capping, steel cap, rubber pad, durometer

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1. INTRODUCTION

Production in Japan of ready-mixed concrete in 1966 amounted to 180 million cu m, and quality control was carried out on prescribed lots of this production. To elaborate, at each ready-mixed concrete plant, one set (of 3 or 6) to several sets of specimens for compressive strength tests ("specimens") are made at a rate of once daily for quality control of the manufacturing process. As for concrete delivered, 6 cylinder specimens are made at least once every 150 cu m for product inspection. Particularly, at ready-mixed concrete plants in urban areas, test specimens are made on an average of once every 30 cu m, and there are cases when the number of specimens made in a day reaches 60 to 90. Based on these figures, the quantity of specimens made at ready-mixed concrete plants may be estimated to reach roughly 11 million per year. These specimens are mostly being capped at ready-mixed plants with neat cement paste and there is a need to save time and labor in this work. Unbonded capping is designated in ASTM C 1231 [1] and AS 1012.9 [2] as a method of saving labor in capping work. Unbonded capping consists of merely placing on top of a specimen a steel cap and inserting a rubber pad between cap and specimen, only the top surface of the latter having been smoothed by trowelling to obtain a similar result as with a ground top or cement paste capping ("conventional capping"). However, particulars of steel caps and qualities and methods of controlling rubber pads are not defined in detail in ASTM C 1231 and AS 1012.9, and it is feared that accurate test results may not be obtained. Experiments were conducted in this study with the objective of prescribing detailed specifications for steel caps and rubber pads used in unbonded capping. To elaborate, inside diameters of steel caps, and dimensions, materials, and physical properties of rubber pads were examined to determine which would yield compressive strength test results similar to those of specimens having conventional capping. Furthermore, a new method of control in which the serviceable limit of reuses of rubber pads is determined with a durometer was devised, and a study was made concerning adoption of unbonded capping.

2. PRESENT STATUS OF UNBONDED CAPPING SYSTEM

In testing, the rubber pad used in the unbonded capping system deforms under load to comply with recesses on the top surface of the specimen, the result being that the load acts evenly on the specimen. As for the steel cap, it restricts deformation of the rubber pad in the circumferential direction to suppress horizontal shear forces.

The unbonded capping method was standardized in AASHTO T 22 and AS 1012.9 in 1986, and on the basis of studies such as that by Carrasquillo & Carrasquillo [3], it was specified in ASTM C 1231 in 1993. As a result of these standardizations, unbonded capping has come to be used as a normal procedure in Australia and the United States.

In Japan, research work was carried out by Noguchi, Tomosawa, et al. on concrete of comparatively high strength [4,5]. Yoshikane et al. did studies on concretes with strength levels stipulated in JIS A 5308 "Ready-mixed concrete" [7,8]. In the ready-mixed concrete industry, along with establishing ZKT-205 (National Ready-Mixed Concrete Industrial Associations Test Method), experiments were conducted comparing compressive strengths with those of specimens capped by the conventional method.

Equipment employed in unbonded capping is as shown in Photo. 1.

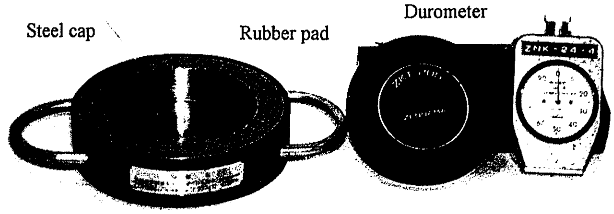


Photo.1 Test apparatus for unbonded capping

3. OUTLINE OF EXPERIMENTS

The objective of these experiments was to determine particulars regarding the following four issues.

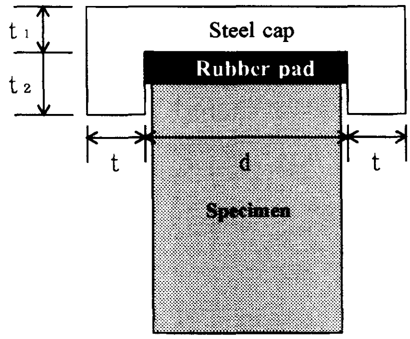
(1) Dimensions of steel cap
(2) Material, physical properties, and dimensions of rubber pad
(3) Method of controlling rubber pad
(4) Scope of application as regards compressive strength

These four issues are not unrelated, but mutually affect each other. However, to take into consideration all possible combinations would necessitate an enormous amount of experimenting, so the number of factors was narrowed down through preliminary testing. That is, tests on (1) and (2) were first carried out and their respective particulars decided. Based on these, tests regarding (3) and (4) were then performed.

The dimensions of steel caps were based on values specified in ASTM C 1231. In Japan, cylinder specimens of dimensions ϕ10 x 20 cm and ϕ12.5 x 25 cm are generally used for compressive strength tests of concrete. Accordingly, it was decided to determine the inside diameters of steel caps suitable for such specimens. Furthermore, in determining the inside diameters of steel caps, hardness of rubber pad is a major factor, while the number of reuses is also very important. Therefore, besides roughly grasping the relationship between inside diameter of steel cap and hardness of rubber pad, the types of rubber were narrowed down to chloroprene rubber and polyurethane rubber in consideration of precision and number of reuses. Notably, detailed descriptions regarding the physical properties of rubber pads are not given in overseas standards, with only ranges of hardness indicated. Impact resilience was therefore added to the quality control factors of rubber pads. Furthermore, a study was made on how to simply and quickly judge the reuse life of a rubber pad from its hardness.

4. EXPERIMENTS REGARDING SELECTION OF UNBONDED CAPPING TESTING EQUIPMENT SPECIFICATIONS

In the event of a rubber pad used in an unbonded capping system not having a suitable degree of softness, a concentrated load will act on protrusions at the top of the specimen and strength will be excessively low. In contrast, if too soft, the rubber pad will deform and squeeze into the space between the upper surface of the specimen and the inner wall of the steel cap, thus restraining the top end of the specimen and excessively high strength will be indicated. Consequently, in an unbonded capping system, it is necessary to select equipment with inside diameter of steel cap and hardness of rubber pad suited to the concrete strength. ASTM C 1231 contains specifications on steel caps, and experiments were conducted to determine appropriate values of inside diameter of caps referring to Fig. 1. As for quality of rubber pad, overseas standards do not provide details, and so experiments were carried out to determine the respective values of hardness, diameter, thickness, material, forming method, and other properties, varying them in numerous ways.



d : 102 to 107% of the diameterof specimen
t : not less than 11mm
t_1 : 0.9 times the thickness of the pad
t_2 : twice the thickness of the pad
Note) Thickness of pad in ASTM is 13±2mm

Fig.1 Steel cap

4.1 Selection of Inside Diameters of Steel Caps and Hardness of Rubber Pads

(1) Test method Quench-hardened alloy steel (SKS 3) specified in JIS G 4404 was used as the steel cap material. The cap surface to be in contact with the compression testing machine was polished to be plane to within 0.02 mm. Three cap inside diameters were used: 102 mm, 104 mm, and 106 mm. The rubber pad material used was chloroprene rubber, the pad diameter being 102 mm, the thickness 10 mm, and hardness according to JIS K 6253 (Hardness testing methods for vulcanized rubber) of A65/5, A75/5, and A90/5. As concrete specimens, fifteen $\phi 10 \times 20$ cylinders were made in accordance with JIS A 1132 for each set of testing conditions using concretes of water-cement ratios 0.44, 0.58, and 0.75. Adapting the method of JIS A 1108, compressive strengths of the test specimens with unbonded capping were compared with compressive strengths ("reference strengths") of specimens with both ends ground ("reference specimens"). The reason for grinding reference specimens at both ends was that, compared with neat cement capping, it is easier to hold planeness within the specified range and also to minimize the influence on compressive strength [8, 9, 10] of variations in planeness of the specimen bottom. In effect, the idea was to eliminate influences of differences in mix proportions of cement paste, mixing time, holding time, planeness of capping plate, and worker skill.

In evaluating the results of testing with unbonded capping, an adaption of the method of determining maximum number of reuses of rubber pads given in ASTM C 1231 was used. That is, it was decided to satisfy the requirement that the ratio of compressive strength as measured by unbonded capping to that measured by conventional capping ("strength ratio") should not be less than 0.98. Regarding this strength ratio, it has been found from the results of tests performed elsewhere that when the hardness of the rubber pad is excessively small (less than about A50/5), the ratio will rise. Consequently, it was decided to provide an upper limit (strength ratio = 1.02) as well as a lower limit in subsequent experiments to evaluate the applicability of unbonded capping. Further, in JIS K 6253, rubber hardness is expressed as A65/5, A75/5, etc., meaning that 5 seconds after the loading face of a Type A durometer has been brought into contact with the sample, the reading on the dial is 65, 75, etc.

(2) Test results The test results are shown in Table 1. In this table, test values obtained by the unbonded capping system are lower than the reference strength the larger the space between sides of the specimen and the steel cap. This is thought to be due to local failure under the influence of tensile force at the top surface of the specimen perpendicular to the loading plane and

Table 1 The influence of difference in inside diameter of steel cap and hardness of rubber pad

[Unit : N/mm^2]

W/C	Strength \ Rubber hardness	d=102mm			d=104mm			d=106mm			Reference strength
		65	75	90	65	75	90	65	75	90	
75%	Average	17.3	17.2	16.3	16.9	16.7	15.8	16.8	16.6	15.5	17.4
	Ratio	0.99	0.99	0.94	0.97	0.97	0.91	0.97	0.95	0.89	-
58%	Average	27.1	27.0	26.2	26.8	26.8	26.2	26.2	26.0	25.3	27.2
	Ratio	1.00	0.99	0.96	0.98	0.98	0.96	0.96	0.96	0.93	-
44%	Average	43.4	43.4	43.0	43.1	42.2	42.3	42.2	41.7	41.3	43.2
	Ratio	1.00	1.00	1.00	1.00	0.98	0.98	0.98	0.96	0.96	-

Note) Reference strength : result of test by JIS A 1108
Strength ratio = (unbonded capping) / (JIS A 1108)
Bold lines show range of strength ratio 1.00±0.02
d : inside diameter of steel cap

in the outward direction as the rubber pad deforms in the circumferential direction under the steel cap as loading progresses. In contrast, in case the inside diameter of the steel cap is 2 mm larger than the specimen diameter, deformation of the rubber pad is smaller and the result is good agreement with the reference strength, with strength ratios being within the range of 1.00 ± 0.02.

As for the hardness of the rubber pad, it is shown that there is better coincidence with the reference strength the softer the rubber, and it was decided that in subsequent tests rubber pads of A65/5 would be used as standard.

4.2 Selection of Rubber Pad Diameter

(1) Test method Steel caps of inside diameter 102 mm as described in 4.1 were used. Rubber pads were of thickness 10 mm and hardness A65/5, with diameters 101 mm and 102 mm. Fifteen specimens each were made from concretes of water-cement ratios 0.50, 0.60, and 0.70 for the respective test conditions. The influence of difference in pad diameter was examined based on these conditions.

(2) Test results The test results are given in Table 2. According to this table, strength ratios with a pad diameter of 101 mm were 0.94 to 0.97 regardless of water-cement ratio and were outside the specified range. Coefficients of variation were also high, at 4.67 to 5.21%. In contrast, when the diameter was 102 mm, strength ratios were 0.98 to 1.00, coefficients of variation 0.97 to 1.21%, and there was good agreement with the reference strength. Based on these results, it may be considered that 102 mm, equal to the inside diameter of the steel cap, is suitable as the diameter of the rubber pad.

4.3 Selection of Thickness of Rubber Pad

The thickness of the rubber pad is specified in ASTM C 1231 and AS 1012.9 as 11 to 15 mm. If the thickness could be reduced, economics and work efficiency

Table 2　Influence of rubber pad diameter

[Unit : N/mm^2]

W/C (%)	Diameter = 101mm				Diameter = 102mm				Reference strength
	Strength	σ	V (%)	Ratio	Strength	σ	V (%)	Ratio	
50	47.4	2.21	4.67	0.94	49.4	0.60	1.21	0.98	50.4
60	38.3	1.85	4.83	0.96	39.5	0.38	0.97	0.99	39.9
70	28.5	1.48	5.21	0.97	29.4	0.31	1.04	1.00	29.4

Note) Strengths in this table are average values (n = 15)
Reference strength : result of test by JIS A 1108
Strength ratio = (unbonded capping) / (JIS A 1108)
Bold lines show range of strength ratio 1.00 ± 0.02
σ : standard deviation , V : coefficient of variation

would be improved, so a study was carried out to see if the thickness could be made less than that specified in ASTM.

(1) Test method　Steel caps of inside diameter 102 mm as described in 4.1 and rubber pads of diameter 102 mm, hardness A65/5, and thickness 10 and 13 mm were used. Fifteen specimens each were made from concretes of water-cement ratios 0.50, 0.60, and 0.70 for the respective test conditions. The influence of difference in rubber pad thickness was examined in the tests.

(2) Test results　The test results are given in Table 3. According to this table, the influence of rubber pad thickness was not very great. However, the test results for pads of thickness 10 mm gave strength ratios at all strength levels in a range of 1.00 ± 0.02. Consequently, the rubber pad can be made 10-mm thick, 1 mm less than the ASTM standard value.

Table 3　Infuence of thickness of rubber pad

[Unit : N/mm^2]

W/C (%)		Thickness (mm) 6	10	13	Reference strength
40	Average	55.4	56.7	56.8	56.6
	σ	1.62	1.96	0.60	1.30
	V (%)	2.93	3.45	1.06	2.30
	Ratio	0.98	1.00	1.00	-
50	Average	44.3	45.0	44.2	45.7
	σ	2.48	0.59	1.60	1.06
	V (%)	5.60	1.31	3.63	2.31
	Ratio	0.97	0.99	0.97	-
60	Average	33.0	33.1	33.0	32.7
	σ	1.15	1.00	0.94	1.06
	V (%)	3.49	3.03	2.85	3.26
	Ratio	1.01	1.01	1.01	-

Note) Reference strength : result of test by JIS A 1108
Strength ratio = (unbonded capping) / (JIS A 1108)
Bold lines show range of strength ratio 1.00 ± 0.02
σ : standard deviation , V : coefficient of variation

4.4 Selection of Rubber Pad Material

(1) Test method　Steel caps of inside diameter 102 mm as described in 4.1 were used. The rubber pads were of diameter 102 mm, thickness 20 mm, and hardness A65/5. The materials tested were chloroprene rubber (3 kinds), natural rubber, styrene-butadience rubber, and polyurethane rubber, for a total of six varieties. Instead of making specimens to be broken at each cycle of loading, specimens of the high strength of 128 N/sq mm were provided and repeatedly applied a load corresponding to a stress of 34 N/sq mm. Meanwhile, specimens of strength 34 N/sq mm (water-cement ratio 0.52) made separately were taken and subjected to compression tests (actually loading to failure) at 1, 10, 50, 100, 150, 200, 250, and 300 cycles of loading, and the influences of differences in rubber pad materials were examined.

(2) Test results　The test results are given in Table 4. According to this table, chloroprene rubber and polyurethane rubber yielded strength ratios in

Table 4 Influence of rubber

[Unit : N/mm^2]

Rubber pad material	Items	Cycles of loading (cycle)							
		1	10	50	100	150	200	250	300
Chloroprene - T	Strength	33.9	33.8	33.9	33.7	33.8	33.8	33.9	34.1
(H=65,R=53,S=1.41)	Ratio	0.99	0.99	1.00	0.99	1.00	1.00	0.99	1.01
Chloroprene - S	Strength	34.2	33.9	33.9	34.0	33.4	33.5	3.7	32.5
(H=65,R=54,S=1.38)	Ratio	1.00	0.99	1.00	1.00	0.98	0.99	0.99	0.96
Chloroprene - D	Strength	34.0	34.0	33.9	34.6	33.7	33.9	33.2	32.7
(H=65,R=56,S=1.43)	Ratio	0.99	1.00	1.00	1.02	0.99	1.00	0.97	0.97
Natural rubber	Strength	34.2	33.8	33.4	32.0	29.3	—	—	—
(H=65,R=63,S=1.25)	Ratio	1.00	0.99	0.98	0.94	0.86	—	—	—
Styrenebutadiene rubber	Strength	34.3	34.2	34.1	33.9	32.7	32.2	32.2	31.5
(H=65,R=46,S=1.26)	Ratio	1.00	1.00	1.00	1.00	0.97	0.95	0.95	0.93
Polyurethane	Strength	34.4	34.3	34.0	33.6	33.9	33.8	33.8	33.5
(H=65,R=59,S=1.29)	Ratio	1.01	1.01	1.00	0.99	1.00	1.00	1.00	0.99
Reference strength		34.2	34.1	34.0	34.0	33.9	33.8	34.1	33.8

Note) Reference Strength : result of test with JIS A 1108
Strength ratio = (unbonded capping) / (JIS A 1108)
Bold lines show range of strength ratio 1.00 ± 0.02
H : Hardness , R : Impact resilience (%) , S : Density (g/cm^3)

the 1.00 ± 0.02 range even after repeated use more than 200 times. Thus, these materials are durable in comparison with natural rubber and styrene-butadience rubber. Based on these results, chloroprene rubber and polyurethane rubber can be recommended as materials for use in unbonded capping.

4.5 Method of Forming Rubber Pad

The diametral cross section of a rubber pad formed by punching heat-treated rubber board is concave, with the depth of the depression differing according to the punching velocity. It was found in separate experiments [11] that the quality of rubber pads formed by this method will not be stable. Therefore, for comparison, rubber materials were formed in metal molds having the required dimensions, heat-treated, and tested.

(1) Test method Steel caps of inside diameter 102 mm as described in 4.1 were used. Rubber pads were of diameter 102 mm, thickness 10 mm, hardness A65/5, and made of chloroprene rubber. The rubber pads were formed by the two methods of punching and heat treating. Fifteen specimens each were made from concrete with water-cement ratios 0.44, 0.58, and 0.75 for the respective test conditions. The influence of the difference in the methods of forming rubber was examined in the tests.

(2) Test results The test results are given in Table 5. According to this table, the average specimen strength using rubber pads formed by heat treatment is close to the reference strength regardless of strength level. As strength ratios were 0.99 to 1.00 and coefficients of variation 1.6% and under, it can be seen that stable test values had been obtained. In contrast, when rubber pads formed by punching were used, the cross sections were concave, and the depths of the depressions varied within a range of 0.5 to 1.5 mm. Where variations were large, substantial horizontal displacements occurred locally in the circumferential direction accompanying load increase, and as a result, failures were seen toward the tops of the side surfaces of specimens in contact with these areas. Consequently, it may be surmised that pads formed by punching

have lower strengths than pads made by heat treatment. Therefore, consistent test values may be obtained by using rubber pads formed by heat treatment in the unbonded capping system.

Table 5 Influence of rubber pad forming method

[Unit : N/mm²]

W/C (%)		Rubber pad forming method: Punching	Rubber pad forming method: Heat forming	Reference strength
75	Strength	20.0	20.3	20.5
	σ	0.66	0.32	0.38
	V(%)	3.33	1.58	1.87
	Ratio	0.97	0.99	-
58	Strength	30.8	31.1	31.2
	σ	0.46	0.46	0.38
	V(%)	1.50	1.49	1.23
	Ratio	0.98	1.00	-
44	Strength	45.0	45.7	46.0
	σ	0.59	0.64	0.68
	V(%)	1.31	1.41	1.49
	Ratio	0.97	0.99	-

Note) Strengths in this table are average values (n = 15)
Reference strength : result of test by JIS A 1108
Strength ratio = (unbonded capping) / (JIS A 1108)
Bold lines show range of strength ratio 1.00 ± 0.02
σ : standard deviation , V : coefficient of variation

4.6 Selection of Impact Resilience and Density of Rubber Pad

Even though hardness of a rubber pad may be A65/5, its impact resilience and density will vary depending on how the rubber pad was compounded, and experiments conducted separately [11] demonstrated that this will influence compressive strength measurements. To investigate this, while holding the hardness of the rubber pad constant, compounding was varied to examine appropriate values of impact resilience and density.

(1) Test method Steel pads of inside diameter 102 mm as described in 4.1 were used. Rubber pads were of diameter 102 mm, thickness 10 mm, and hardness A65/5, and the materials were chloroprene rubber (carbon content: 4, 12, 40, and 45%) and polyurethane rubber (plasticizer content: various). The respective impact resiliences were measured according to JIS A 6255 and densities according to JIS A 6350. Specimens were mixed using a special gypsum. Six specimens each for comparison purposes were made for the respective compounding conditions from pastes of water-powder ratio 0.25. The reason for using this special gypsum was to obtain specimens of equal strength. The influences of differences in impact resilience and density were examined in the tests.

Table 6 Influence of impact resilience and density of rubber pad

Rubber pad material	Hardness	Impact resilience (%)	Density (g/cm³)	Strength(N/mm²) 1 cycle	Strength(N/mm²) 10 cycle	Carbon content (%)
Chloroprene - T	A65/5	59	1.32	35.2 (1.03)	35.0 (1.03)	45
	A65/5	53	1.41	33.9 (0.99)	33.8 (0.99)	40
	A65/5	33	1.59	30.4 (0.89)	28.6 (0.84)	12
	A66/5	29	1.71	30.1 (0.88)	25.4 (0.74)	8
Polyurethane	A66/5	66	1.21	35.8 (1.05)	35.9 (1.05)	–
	A65/5	59	1.29	34.4 (1.00)	34.3 (1.01)	–
	A65/5	50	1.41	32.6 (0.95)	32.4 (0.95)	–
	A65/5	47	1.58	30.2 (0.88)	28.6 (0.84)	–
Reference strength				34.2	34.1	–

Note) Reference strength : result of test by JIS A1108
Strength ratio = (unbonded capping) / (JIS A 1108)
Bold lines show range of strength ratio 1.00 ± 0.02

(2) Test results The test results are given in Table 6. According to this table, the impact resilience of chloroprene rubber increased in proportion to its carbon content and varied between 29 and 59%. As for density, it decreased with rising carbon content, being between 1.32 and 1.71 g/cu cm. These tests rubber pads of constant hardness and varying impact resilience and density yielded a compressive strength ratio of 0.99 in the case of an impact resilience of 53% and a density of 1.41 g/cu m. The strength ratio decreased with lower impact resilience while, conversely, it increased with higher impact resilience.

In the case of polyurethane rubber, also, impact resilience and density varied with compounding differences. Suitable impact resilience and density values for testing were 59% and 1.29 g/cu m.

As for quantity of plasticizer contained in the polyurethane rubber, this was said to be an industrial secret of the manufacturer and details are unknown.

5. METHOD PROPOSED FOR CONTROLLING RUBBER PADS

A rubber pad will suffer from fatigue as the number of reuses increases. To judge the maximum number of reuses of a rubber pad, it is stipulated in ASTM C 1231 that when the pad has been reused 100 times, test strength is to be compared with that of a specimen with conventional capping as mentioned previously. As for AS 1012.9, it is stipulated that judgment is to be made by visual inspection. This unfortunately leads to problems related to the tedium of actually counting the number of reuses and the subjectivity of visual inspection. Therefore, a method using a durometer was examined as a simple and quick way of controlling rubber pads.

5.1 Changes in Hardness and Compressive Strength of Rubber Pad with Repeated Use

(1) Test method Compressive strength tests were performed repeatedly on specimens having various top surface configurations, and changes in compressive strength and hardness were tested. The testing was consigned to five testing facilities of the ready-mixed concrete industry throughout the country. The steel caps used in the tests were of inside diameter 102 mm as described in 4.1. Rubber pads were of diameter 102 mm, thickness 10 mm, hardness A65/5, of chloroprene rubber, and were of two types: made by punching and by heat treatment. As specimens for nondestructive testing, high-strength cylinders (specimens with strengths of about f_c = 80 to 100 N/sq mm made at the respective testing institutions) were used. The tests consisted of repeatedly applying loads corresponding to stresses of 20, 30, and 45 N/sq mm to rubber pads inserted in steel caps, and at every 50 cycles of loading, performing compressive strength tests (loading to failure) on standard specimens made of special gypsum. The results of these were compared with those of reference specimens made at the same time.

As a note, the top surface of the specimens were finished in such manner that the difference between the highest and lowest points at the surfaces would be 0, 3, and 6 mm ("inclinations" 0, 3, and 6 mm) and with the circumferences at the top surface of the specimen as the reference, finishing was done to result in a depression or protrusion at the center of 3 mm.

(2) Test results An example of the test results is shown in Fig. 2. This

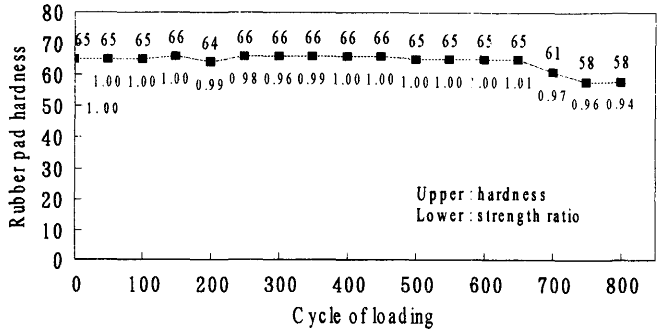


Fig.2 Changes in compressive strength and rubber pad hardness

figure shows test results for an inclination of 3 mm; the hardness of the rubber pad gradually declines as the number of reuses exceeds 650, indicating that the rubber pad deteriorates with repeated use. The compressive strength of the concrete approximated that of the reference concrete up to around 650 times, with strength ratios in the range 1.00 ± 0.02. The strength ratio gradually declined after 650 times also, becoming 0.94 at the 800th use. The relationship between hardness of rubber pad and compressive strength is shown in Fig. 3. According

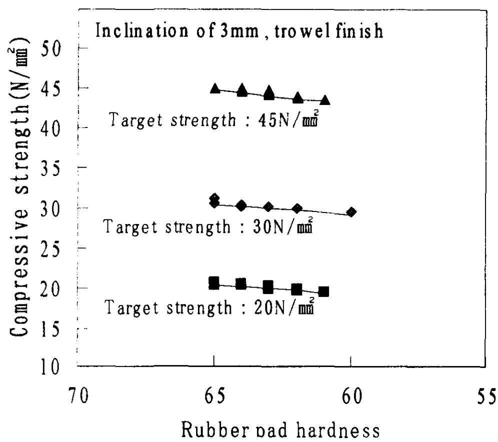


Fig.3 Relationship between rubber pad hardness and compressive strength

Table 7 Decline in hardness of rubber pad corresponding to decline in strength retio 1.00 ± 0.02

Configuration of top suface / Target strength	Inclination (mm)				Depre -ssion	Protru -sion
	0		3	6	3mm	3mm
	A*	B	B	C	D*	E*
20N/mm²	1.50	3.27	1.65	1.55	0.63	0.46
30N/mm²	4.21	3.17	2.47	4.38	2.37	6.39
45N/mm²	0.56	3.08	2.32	4.02	2.75	2.10

Note) Results of strength test of pads made by punching.
A,B,C,D,E : laboratory

to this figure, compressive strength declines as the rubber hardness falls, and the relationship can be represented by a straight line. Based on this relationship, if the reuse limit of a rubber pad is taken to be when the strength ratio in compressive strength tests declines to 0.98, the corresponding decline in rubber pad hardness is as shown in Table 7. In this table, the decline in hardness of rubber pad corresponding to this 0.02 decline in strength ratio, though differing somewhat depending on test conditions, is an average of approximately 2.5.

Based on these results, the maximum number of reuses of a rubber pad may be set at the point when the hardness of the rubber declines by 2 from the initial value.

5.2 Temperature Correction for Hardness of Rubber Pad

A rubber pad by nature becomes harder the lower the temperature. Therefore, if the maximum number of reuses of a rubber pad is to be controlled by hardness, it is necessary to make a correction for temperature.

(1) Test method Twenty-seven rubber pads of hardness A64/5 to A73/5 were left for 24 hours in constant temperature rooms at 10, 20, and 30°C and the relationship between temperature and hardness of rubber pad was sought.

Table 8 Relationship between temperature and rubber pad hardness

Temp of pad = 10℃			Temp of pad = 20℃			Temp of pad = 30℃		
Measured value	Adjusted value for 20℃	Ratio	Measured value	Adjusted value for 20℃	Ratio	Measured value	Adjusted value for 20℃	Ratio
66	64.59	1.01	64	64.03	1.00	63	63.84	1.00
66	64.59	0.99	65	64.99	1.00	64	64.81	1.00
66	64.59	0.99	65	64.99	1.00	64	64.81	1.00
66	64.59	0.99	65	64.99	1.00	64	64.81	1.00
69	67.41	1.02	66	65.95	1.00	66	66.76	1.01
68	66.47	1.01	66	65.95	1.00	66	66.76	1.01
69	67.41	1.02	66	65.95	1.00	66	66.76	1.01
69	67.41	1.01	67	66.91	1.00	66	66.76	1.00
68	66.47	0.99	67	66.91	1.00	66	66.76	1.00
69	67.41	1.01	67	66.91	1.00	66	66.76	1.00
69	67.41	1.01	67	66.91	1.00	66	66.76	1.00
70	68.35	1.02	67	66.91	1.00	66	66.76	1.00
68	66.47	0.99	67	66.91	1.00	66	66.76	1.00
69	67.41	0.99	68	67.87	1.00	68	68.70	1.01
69	67.41	0.99	68	67.87	1.00	68	68.70	1.01
68	66.47	0.98	68	67.87	1.00	67	67.73	1.00
69	67.41	0.99	68	67.87	1.00	67	67.73	1.00
70	68.35	1.01	68	67.87	1.00	67	67.73	1.00
69	67.41	0.99	68	67.87	1.00	67	67.73	1.00
69	67.41	0.99	68	67.87	1.00	67	67.73	1.00
69	67.41	0.99	68	67.87	1.00	67	67.73	1.00
70	68.35	1.01	68	67.87	1.00	67	67.73	1.00
69	67.41	0.99	68	67.87	1.00	67	67.73	1.00
69	67.41	0.98	69	68.83	1.00	68	68.70	1.00
73	71.16	1.00	71	70.74	1.00	70	70.64	0.99
74	72.09	1.00	72	71.70	1.00	71	71.61	0.99
75	73.03	1.00	73	72.65	1.00	72	72.57	0.99

Note) Figures 65 and 66 (measured value and adjusted value) indicate A65/5 and A66/5

Ratio : (adjusted value) / (hardness of rubber pad at 20℃)

(2) Test results The test results are given in Table 8. According to this table, the hardness of a rubber pad at 10°C is higher by approximately 1 as compared with the value measured at 20°C. At 30°C, there is a corresponding reduction of approximately 1. These changes are due to the molecular structure of rubber [12], and the physical properties and quantity of plasticizer added.

The following equation is obtained by constant determination using the method of least squares based on these test results:

$$K_{20} = 1.08 \cdot T^{0.03} \cdot Ki^{0.96} \qquad (1)$$

where, K_{20}: adjusted hardness of rubber pad at temperature of 20°C
T: temperature of rubber pad at time of measurement (°C)
Ki: hardness of rubber pad at temperature T°C

To verify Eq. (1), adjusted values of hardness at 20°C were determined from measurements at various temperatures. Results are shown, along with the ratios between measured values at 20° and adjusted values, in Table 8. These ratios fall in the range of 1.00 ± 0.02 in almost all cases and it is seen that Eq. (1) can be used to make corrections for temperature.

5.3 Proposal for Method of Controlling Rubber Pads

For a method of controlling the reuse limit of rubber pads employing a durometer, the results of tests described in 5.1 and 5.2, JIS K 6253, and the instructions for use of the Type A durometer are referred to, and the procedure would be as follows:

(i) Measurement frequency Determine the frequency of measurements on rubber pads as suited making measurements once in about 100 to 150 uses according to the number of times compressive strength tests are performed daily on average.

(ii) Method of measuring hardness (1) Measure hardness at a point approximately 15 mm from the perimeter of the rubber pad toward the center. Three measurements should be taken, with the locations equally spaced apart. (The measurement locations and number of measuring points are selected in this way because when measurements were made at 19 points on the surface of each of 200 rubber pads, differences could not be recognized between maximum, minimum, and average values.)
(2) Maintaining the durometer perpendicular, bring it into contact with the loading plane at a constant rate in such manner that the plunger is perpendicular to the rubber pad.
(3) After bringing the durometer into contact with the rubber pad, wait 5 seconds and then read the dial. The dial indicates the maximum value at the moment the loading plane comes into full contact with the rubber pad, although even when this position is maintained, the reading gradually falls. Because of this, the value 5 seconds after contact should be read, as this is a reasonably short time and comparatively stable test values can be obtained. In JIS K 6253, it is stipulated that the force made to act after the durometer contacts the rubber pad until hardness is read is to be 10 N, but similar measurement values are obtained even when the force is in a range of 8 to 10 N. Therefore, the plunging force should be made about 8 to 10 N.
(4) Take as the test result the average of three measurements. Furthermore, record room temperature at the time of testing.

(iii) Calculation of results The hardness and temperature (or when it cannot be measured directly, the ambient temperature) of the rubber pad are to be substituted into Eq. (1) for conversion to values at 20°C.

(iv) Maximum number of rubber pad uses In the event that the converted rubber hardness is lower by 2 or more than the value initially used, discontinue use of the pad and exchange it for a new one.

6. SCOPE OF APPLICATION OF UNBONDED CAPPING SYSTEM

The applicable scope of the unbonded capping system was examined varying planeness of top surface of specimen, specimen dimensions, and type and strength of concrete.

6.1 Planeness of Top Surface of Specimen

(1) Test method Steel caps of inside diameter 102 mm as described in 4.1 were used. Rubber pads were of diameter 102 mm, thickness 10 mm, and hardness A65/5, and were made of chloroprene rubber. Fifteen specimens each were made from concretes with water-cement ratios of 0.44, 0.58, and 0.75 for the respective test conditions. Furthermore, the number of passes with a trowel in finishing specimen tops when casting was varied to examine tolerance with regard to planeness.

(2) Test results The test results are shown in Fig. 4. In this figure,

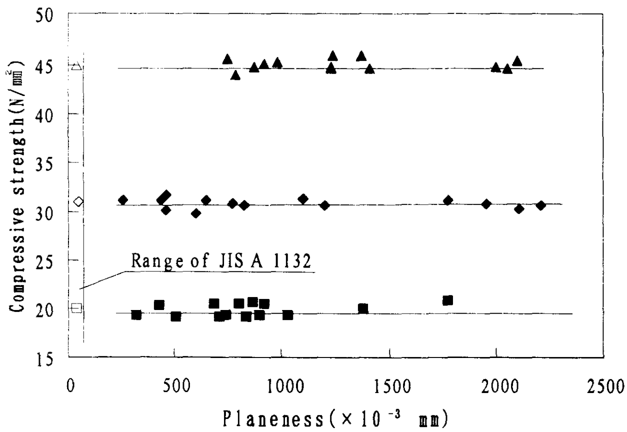


Fig.4 Relationship between planeness of trowel finishing and compressive strength

planeness of specimen tops were from 0.25 to 2.25 mm. These compressive strength test results with the unbonded capping system, regardless of difference in strength levels, agree well with test values obtained with conventional capping according to JIS A 1132, which are also shown in this figure. In experiments regarding planeness performed elsewhere [13], proper test values were at times obtained even with poor planenesses of 3 to 4 mm. However, it is conceivable that in such cases local deterioration of the rubber pads might go undetected, and it is considered appropriate for the tolerence to be within 2 mm.

If the top surface of the specimen is concave and the depth of the depression is more than about 2 mm, the outer perimeter of the specimen top will fail while the load is still quite low, and proper testing cannot be done. In such a case, by using very fine sand with particles of about 0.15 mm or under to level up the concave part of the specimen, it is possible to use the unbonded capping system.

6.2 Specimen Dimensions

(1) Test method Steel caps of inside diameter 102 mm, 2 mm larger than specimen diameter, 127 mm, and 156 mm were used. Rubber pads were of thickness 10 mm and hardness A65/5, and were made of chloroprene rubber. Pad diameters were the same as the inside diameters of respective steel caps. Fifteen specimens each were made from concretes of water-cement ratios 0.58 and 0.75 for the respective combinations of test conditions. The applicable scope of testing as regards specimen dimensions was examined.

(2) Test results The test results are shown in Fig. 5. This shows that irrespective of concrete strength and specimen dimensions, test results with unbonded capping are in agreement with reference strengths.

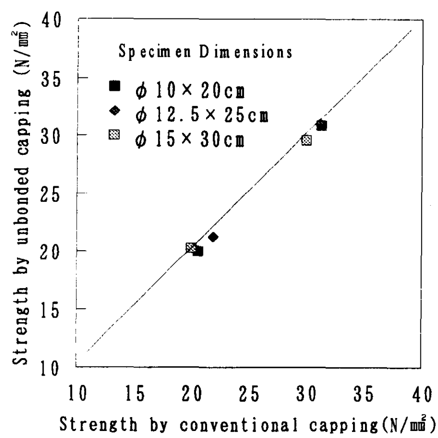


Fig.5 Relationship between strength by conventional capping and by unbonded capping

6.3 Scopes of Application of Kind and Strength of Concrete

(1) Test method Steel caps of inside diameters 102 mm and 127 mm as described in 6.2 were used. Rubber pads were of thickness 10 mm and hardness A65/5, with diameters equal to the inside diameters of the steel caps, and they were made of chloroprene rubber. The concretes used were mainly those normally delivered from ready-mixed concrete plants and consisted of lightweight concretes (Class 1 and Class 2), dry-mixed concrete (concrete for the slipforming method: SFC), and extra dry-mixed concrete (RCCP concrete). The applicabilities of types and strengths of concrete were examined in the tests.

(2) Test results The test results are shown in Figs. 6 and 7. Figure 6 gives the results for specimens of dimensions φ10 x 20 cm, and although measurements were fewer for concretes other than ordinary concrete, it can be seen that compressive strength test results using unbonded capping agreed well with those obtained with conventional capping.

Figure 7 gives the results for φ12.5 x 25-cm specimens, and as with the φ10 x 20-cm specimens, there was good agreement between strengths as obtained using the two methods of capping.

The scopes of application as regards the strengths of these φ10 x 20-cm and φ12.5 x 25-cm specimens are 10 to 65 N/sq mm for the former and 10 to 60 N/sq mm for the latter.

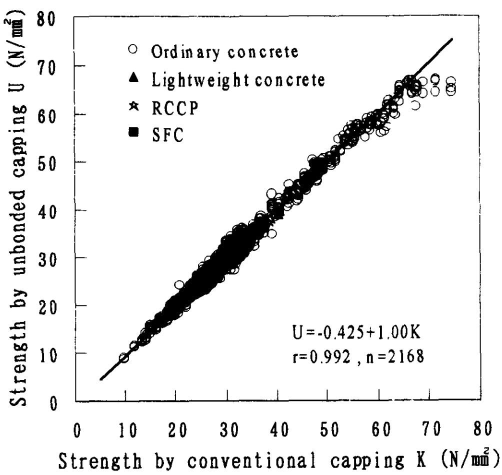


Fig.6 Relationship between strength by conventional capping and by unbonded capping (ϕ 10×20cm)

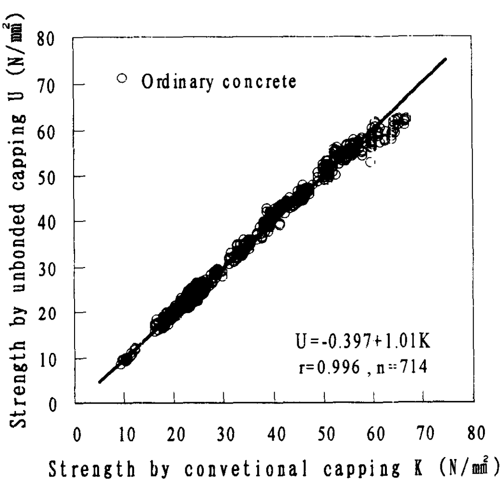


Fig.7 Relationship between strength by conventional capping and by unbonded capping (ϕ 12.5×25cm)

7. METHOD OF TEST FOR COMPRESSIVE STRENGTH OF CONCRETE WITH UNBONDED CAPPING (PROPOSED)

I. Scope of Application This method shall apply to compressive strength tests on concretes of strength about 10 to 60 N/sq mm using steel caps to restrain rubber pads and deformations of rubber pads.

II. Test Apparatus

II.1 Steel Cap Quench-hardened SKS steel shall be used and the surface coming into contact with the compression testing machine shall have a planeness within 0.02 mm. Thicknesses of the steel cap shells shall be as given in Table 9 according to the specimen dimensions on referring to Fig. 1.

II.2 Rubber Pad Rubber pads shall have diameters equal to the inside diameters of steel caps given in Table 9 and a thickness of 10 mm. The qualities of the rubber pads shall be according to Table 10.

II.3 Rubber Hardness Tester The rubber hardness tester shall be a Type A durometer as specified in JIS K 6253.

III. Test Method (1) Follow JIS A 1132 and finish in a manner such that coarse aggregate is not exposed at the top surface of the concrete specimen.

(2) Wipe moisture from the surface of the concrete specimen at the specified age and check to see that no foreign matter adheres to the surface. Following this, place the steel cap on top of the specimen in such manner that the cast surface of the specimen is in contact with the rubber pad.

Table 9 Dimensions of steel caps

Specimen of dimensions	Dimensions of shell (mm)			
	Inside dimension	Thickness		Depth
	d	t	t_1	t_2
ϕ 10 × 20cm	102.0 ± 0.1	18 ± 2	11 ± 2	25 ± 1
ϕ 12.5 × 25cm	127.0 ± 0.1			

Table 10 Quality of rubber pad

Item	Material of rubber pad	
	Chloroprene	Polyurethane
Hardness ※1)	A65/5 ~ A70/5	
Impact resilience (%) ※2)	53 ± 3	60 ± 3
Density (g/cm^3) ※3)	1.40 ± 0.03	1.30 ± 0.03

※ 1) JIS K 6253 (Hardness testing methods for rubber, vulcanized or thermoplastic)
※ 2) JIS K 6255 (Testing methods of rebound resilience for rubber, vulcanized or thermoplastic)
※ 3) JIS K 6350 (Method of analysis for rubber pad)

(3) Align the steel cap in such manner that the side surface of the specimen does not come into contact with the cap and perform compressive strength testing according to JIS A 1108.

(4) Before or after the compressive strength test, as suited, measure the hardness of the rubber pad and check to see that it is within the specified range. Replace the rubber pad in the event that hardness has declined by 2 from the value measured initially.

Caution 1) When a new rubber pad is introduced, after inserting it into the steel cap, apply load of about 150 kN two or three times in order to expel air trapped between the steel cap and rubber pad.

Caution 2) A rubber pad stored for a long period will deteriorate. Chloroprene rubber, of which the main ingredient is butadiane, becomes hard and its impact resilience declines as shown in Fig. 8 when exposed to ultra-violet rays over a long period of time. In the case of polyurethane rubber, there is a risk that hardness and impact resilience will decline due to hydrolysis. Accordingly, the precautions to be followed when storing rubber pads are as follows:

. Do not expose to ultra-violet rays for long periods of time.
. Do not allow contact with oil of any type.
. In case of polyurethane, store under dry conditions.

8. CONCLUSIONS

A detailed examination of test conditions for the unbonded capping system has been carried out with the objective of introducing it to save time and labor in capping work for compressive strength tests of concrete. The results obtained in this study were as follows:

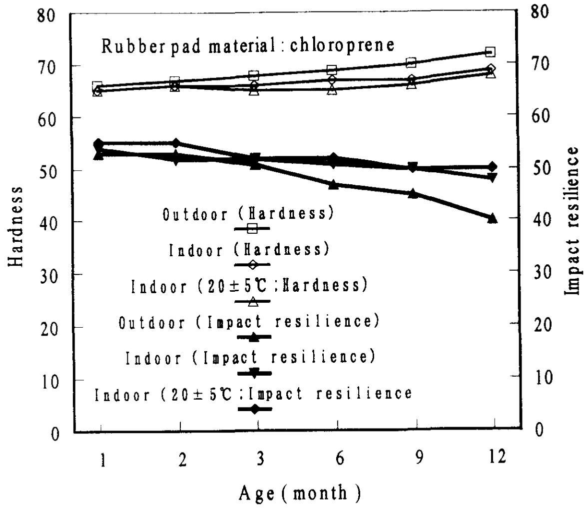


Fig.8 Changes in hardness and impact resilience of rubber pads

(1) The inside diameter of the steel cap used in unbonded capping should be 2 mm larger than the diameter of the specimen. With hardness of rubber pad A65/5, test values were equal to strengths as measured with neat cement paste capping and ground cylinder tops.

(2) Rubber pads used should be of thickness 10 mm and diameters equal to the inside diameters of the steel caps.

If chloroprene or polyurethane is used for the rubber pads, it will be possible for reuses to be made more than 200 times.

(3) The diametral cross sections of rubber pads made punched out from sheet material are concave and quality is unstable, so that the required strengths cannot be obtained; the coefficients of variation of test values are comparatively high. In comparison, if raw materials are put in metal molds of the specified dimensions and pads are formed by heat treatment, there is good agreement with the reference strength, and the coefficient of variation is comparatively low.

(4) The impact resilience and density of rubber pads will vary depending on compounding conditions even though hardness may be constant. Proper testing may be done using rubber pads of impact resilience and density of 53% and 1.41 g/cu cm, respectively, in case of chloroprene rubber, and 59% and 1.29% g/cu cm, respectively, in case of polyurethane rubber.

(5) The maximum number of reuses of rubber pads can be judged as the time when the value measured with a durometer declines by 2 from that at initial use.

(6) The measured value of hardness of a rubber pad will vary with temperature. Because of this, corrections for temperature are needed when controlling the maximum number of reuses of a rubber pad using a durometer. For this purpose, test values of hardness at all temperatures can be converted to values at 20°C

using the following equation:

$$K_{20} = 1.08 \cdot T^{0.03} \cdot Ki^{0.96}$$

where, K_{20}: adjusted value of hardness of rubber pad at temperature of 20°C
T: temperature of rubber pad at time of measurement (°C)
Ki: hardness of rubber pad measured at temperature of T°C

(7) The hardness of a rubber pad should be checked according to JIS K 6253 every 100 to 150 uses. Measurements of hardness are to be made at 3 points approximately 15 mm in from the perimeter of the rubber pad, the points being equally spaced apart. Measurement is carried out by maintaining the plunger of the durometer perpendicular to the rubber pad and bringing it into contact with the loading plane at a constant rate with a force of 8 to 10 N. The dial should be read after 5 seconds of contact.

(8) Unbonded capping may be used for compressive strength tests on concrete specimens of dimensions ϕ10 x 20 cm, ϕ12.5 x 25 cm, and ϕ15 x 30 cm where the planenesses of cast surfaces are within a tolerence of 2 mm. It may be applied to the standard products specified in JIS A 5308, concrete for the slipforming method, and RCCP. The applicable range of failure strength is 10 to 60 N/mm^2.

(9) Taking variations during the manufacturing process into consideration, the rubber pad should have a hardness of A65/5 to A70/5, with an impact resilience 53 ± 3% in case of chloroprene rubber, and 60 ± 3% in case of polyurethane rubber. Density should be 1.40 ± 0.03 g/cu cm for the former and 1.30 ± 0.03 g/cu cm for the latter.

(10) A precaution to be observed in testing is that when a new rubber pad has been inserted into a steel cap, a load of about 150 kN needs to be applied two or three times to expel air trapped between the cap and the pad. Further, in storing rubber pads, they should not be exposed to ultra-violet rays for long periods of time, nor must they be allowed to come into contact with oils. In the case of polyurethane rubber, pads must be kept under dry conditions.

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