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PROGRESS REPORT ON THE DEFINITION OF ALGINATE IMPRESSION MATERIALS BY A SPECIFICATION

by

Masayoshi Ohashi, D.D.Sc.*
George C. Paffenbarger, D.D.S.**
John W. Stanford, Ph.D.**

*Research Associate, American Dental Association at the National Bureau of Standards, on leave from the faculty of the School of Dentistry, Nihon University, Tokyo, Japan.

**Research Associates, American Dental Association at the National Bureau of Standards, Washington, D. C. 20234

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NATIONAL BUREAU OF STANDARDS



The Definition of Alginate
Impression Materials by a Specification*

Abstract

The formulation of a specification for dental alginate impression materials, which will characterize them adequately, is described and much of the experimental data obtained during the development is presented.

1. Introduction

In 1956 the Specifications Committee of the Dental Materials Group of the International Association for Dental Research, which serves as the principal consultant to the American Dental Association on specification matters, suggested to the Council on Dental Research that a specification for alginate impression material was needed. The Council agreed and asked the Specifications Committee to formulate such a specification. This Committee responded by appointing the following subcommittee to undertake the task.

Ralph W. Phillips, Chairman (1956-61), Indiana University

George C. Paffenbarger, Chairman (1961-63), American Dental Association Research Division, National Bureau of Standards

E. W. Skinner, Northwestern University

A. B. Godber, The S. S. White Dental Mfg. Co.

James Cresson, The L. D. Caulk Co.

Alex Dunlop, The Kerr Mfg. Co.

R. L. Bowen, Secretary, American Dental Association Research Division,
National Bureau of Standards

The final specification draft [1], which was approved by the Specifications Committee and the Council on Dental Research appears in the Guide to Dental Materials, Second Edition, published by the American Dental Association. The Council approved the specification in July 1963 and it became effective in July 1964. This specification is patterned after the original American Dental Association Specification No. 11 for Hydrocolloidal Impression Material -- Agar Type [2] and Federal Specification U-1-498, 10 May 1953 for Impression Material, Hydrocolloidal, Alginate Type, Dental [3].

A comparison of the differences among the specifications given in references [1], [2] and [3] shows that there are several major improvements in the current specification. Among these are a classification into two types, based upon time of setting; a redesigned test for setting time; the incorporation of new tests for working time, for compatibility with gypsum, for fineness and for volume after mixing.

2. Discussion of Specification Tests and Data

Much of the testing of dental materials for determining the adequacy of the testing procedures given in a tentative specification is done in the Dental Research Section of the National Bureau of Standards. In this instance the alginate impression materials, listed alphabetically in Table 1, were subjected to the tests outlined in the specification except where modified as subsequently described. The data from these tests are presented in Tables 2 and 4. Data on the materials in these and other tables are not presented in the same sequence as in Table 1.

* Part of the information included in this report was presented previously in National Bureau of Standards Progress Report 7838. The present report includes additional data and further analysis of results.

Types (1.2.1).* The alginate impression materials were divided into fast and normal setting types (1.2.1) based upon the rate of gel formation (3.2.6, 3.2.7). Orthodontists, in particular, prefer a fast-setting type such as Materials B, G, M, P-2 and R (Table 2, Column 1). All of the others were normal-setting. Two types are given in the Federal specification but the classification is Type I, no fixing solution required, and Type II, fixing solution required. In the American Dental Association specification a manufacturer may or may not specify treatment with a fixing solution in instructions for use (3.3) but in the test for compatibility with gypsum (3.2.4 and 4.3.6) no treatment by a fixing solution is permitted.

Irritation (3.2.2). No tests or data are available on the toxicity of alginate impression materials so no test or limiting values are specified. The requirement (3.2.2) is very similar to that in the early specification for agar impression materials [2] except that the volume of ingested alginate is 10 ml instead of 30. So far there are no reports in the literature of ill effects caused by the accidental swallowing of any alginate material during the taking of an impression. Since some of the alginate impression materials contain fluorides [4] and perhaps some contain lead silicate [4] it is well to have a safeguard (3.2.2) until an appropriate toxicity test is available.

Fineness (3.2.3 and 4.3.5). The simple sieving test eliminates coarse particles which might cause lumps or granules in the completed mix.

The powder of all of the alginate impression materials, except F, G, and H, passed completely through a No. 20 mesh sieve (Table 2, Column 2). Materials F, G and H had ten or less particles which remained in the sieves. Whether the powder was brushed gently through the sieve or passed through by vibration, comparison testing showed there was no difference in results.

Compatibility with Gypsum (3.2.4 and 4.3.6). The surface of gypsum when cast into an alginate impression is of poorer quality than when cast into other elastic impressions. Various brands of alginates affect brands of dental gypsum differently [5].

HOSODA and FUSAYAMA [6] reported that certain combinations of alginate impression and cast materials give superior surfaces to the gypsum casts. They attribute poor cast surfaces to the presence of additives in dental gypsums and recommended unmodified alpha gypsum. Using x-ray diffraction technics SMITH and FAIRHURST [7] showed that potassium sulfate when used in gypsum caused the formation of syngenite [$K_2Ca(SO_4)_2 \cdot H_2O$] on gypsum surfaces cast in alginate impressions but did not determine its effect. This work was reported as a research annotation and, as the authors state, was only a preliminary study. More work needs to be done to find the specific cause of poor surfaces on gypsum casts poured in alginate impressions.

Therefore, it was necessary to prescribe a standard unmodified gypsum for the test in 3.2.4 without using a trade name. This was resolved by adjusting, if needed, the time of setting of commercial gypsum (see 6.1) free of additives to 10 ± 3 minutes by using set gypsum (calcium sulfate dihydrate $CaSO_4 \cdot 2H_2O$) as the accelerator.

All of the alginate impression materials listed in Table 1 gave rougher surfaces on the gypsum casts than did the agar impression materials that were tested during the revision of the specification for agar impression material.

PEYTON [8] stated that his coworkers at the University of Michigan found that dusting the brass test block (Fig. 1 in the specification) with talcum and then blowing away the excess prevented the alginate and other impression materials from adhering to the brass and at the same time improved the detail reproduction of the lines (Fig. 1). The experience of the authors confirms this observation so this suggestion was incorporated into 4.3.6 of the specification.

The data in Table 2, Column 4, were obtained on gypsum casts that had remained in contact with the impression for one hour. This time was shortened to 30 minutes in the last draft of the specification (4.3.6). Although one cannot state that Materials E, H, K and O would not comply with the requirement for compatibility with gypsum as described in 4.3.6, one can say that their compatibility is poorer than that of the other alginate materials.

* Numbers in parentheses refer to sections of the specification.

Setting Time (3.2.6 and 4.3.7). BIRD of the Amalgamated Dental Company described a simple and reliable test for time of setting which had been in use in his company's laboratory since 1938 [9]. The test is very useful in defining the fast and normal setting types (1.2.1) and was incorporated into section 4.3.7 of the specification.

The temperature of the mixing water influences the time of setting [10]. In the specification the temperature test conditions are $23.0 \pm 2.0^\circ\text{C}$ with a relative humidity of 50 ± 10 percent (4.3.2) and the data in Table 2, Column 5, were obtained under these conditions. All of the materials complied with the requirements for setting time (3.2.6) except P-2.

The effect of the temperature of the mixing water on the time of setting for each of the alginate impression materials is shown in Table 3 over the range 10 to 40°C . With the exception of the mixing water, all of the materials and equipment were held at $23.0 \pm 2.0^\circ\text{C}$ and at a relative humidity of 50 ± 10 percent. The sensitivity of the various materials is expressed by the average change in setting time for each degree Celsius change in the temperature of the mixing water over the range 10 to 40°C (Table 3). This rate ranged from 2.7 to 7.0 seconds per degree Celsius. The alginate impression Materials A, I, K, L and O, having a rate of 6.0 seconds per degree Celsius or higher would be more sensitive to the temperature of the mixing water than Materials G, M and R which have a change of less than 3.0 seconds per degree Celsius. One rate reported in the previous literature [10] was 8 seconds per degree Celsius over the range 6 to 50°C which is higher than any of the values in Table 3. Perhaps a test for sensitivity to temperature changes should be considered in a future revision of the specification.

Working Time (3.2.7 and 4.3.8). A slight modification of a plasticity test [11] in which a rod 4 mm in diameter is forced under a load of 50 g into the alginate materials (4.3.8) insures the dentist that the plasticity will be suitable at least 1 1/4 minutes (Type I -- Fast Setting) and at least 2 minutes (Type II -- Normal Setting) from the start of the mixing. As the mixing time must not exceed 1 minute (3.2.5) the dentist will have at least 15 seconds working time with fast-setting materials and at least a 1-minute working time with normal-setting materials.

The data in Table 2, Column 6, show that all of the materials complied with the specification requirements with the exceptions of M, P-2, Q heavy mix and R heavy mix. Materials M and P-2 were not labeled "Fast-Setting" but they would be so typified by the specification requirements.

Permanent Deformation (3.2.10 and 4.3.10.3). This static test in compression for permanent deformation eliminates materials having a tendency to be permanently extended after springing over an undercut surface such as presented by the contours of a tooth. The test cylinder (4.3.10.3) is compressed or shortened 12 percent for 30 seconds and then released from strain. The cylinder must return to within 3 percent of its former height 30 seconds after the strain is removed.

The data in Table 2, Column 7, show that all of the materials complied with this requirement of the specification.

In the first specification for agar impression materials [2] a fixed stress was applied to the test cylinder. Later it was pointed out that a fixed strain would be more appropriate than a fixed stress because the deformation by a fixed strain is uniform and is not dependent upon rigidities of the materials [12]. However, for comparison, the deformation caused by a fixed cycle of stressing was determined using the old test:

"The set shall not exceed 3.0 percent when stresses of 100, 1000, 0 and 100 g/cm² are applied for one-minute intervals in the foregoing sequence." [2]

The permanent deformations caused by this test are given in Table 2, Column 8. Here deformation is always higher than that caused by the fixed strain, Table 2, Column 7, but the relationship between the two values varies among the alginate materials and reflects the varying amounts of strain induced by a fixed stress on materials having different rigidities. The higher permanent deformation obtained with the fixed stress method can probably be attributed to the greater time in compression (60 rather than 30 seconds) and, for most materials, the greater strain associated with the fixed stress. Material J with the highest value of permanent deformation, 6.6 percent (Table 2, Column 8), is also the material having the highest value for strain in compression, 19.8 percent (Table 2, Column 9). An examination of the gypsum cast made in the impression of alginate J showed no distortion. The diameter of the shaft of post B, (Fig. 2, Specification) of the gypsum cast made in alginate J

impression was very near to that of the metal post B, after a dilation of 78 percent caused by passing the head of post B, which is 8 mm in diameter, through the impression of the shaft of the post, which is only 4.5 mm in diameter. Therefore, it would appear that Material J, which had the highest permanent deformation in the static test under 12 percent strain, had little or no permanent deformation when subjected to the dynamic test using the metal model (Fig. 2 Specification).

The abandonment of the test for permanent deformation based on stress does not permit compliance with the specification of impression materials that might be deformed by the weight of gypsum slurry poured into the impression; the limitation on strain in compression (3.2.12) eliminates such materials.

Compressive Strength (3.2.11 and 4.3.10.4). The compressive strengths (Table 4, Column 3) were determined on specimens 6 minutes old. In the final revision of the specification, the age of the specimen, at the time of testing, was set at 8 minutes. Therefore, the values in Table 4, Column 3, are lower than they would be if they had been determined on 8-minute-old specimens.

The specification requires a constant rate of stress of 10 ± 2 kg/min. An attempt was made to attain the stress rate by compressing the specimens in the constant rate of strain machine at an average rate of stress by noting on trial specimens the load at rupture and the time required to attain it. Values derived under such conditions may be lower than those obtained on machines operated at constant stress rates but preliminary tests on Material A showed no difference. Higher stress rates were also used. Usually a higher value for compressive strength was obtained on the high rates of loading but in many instances the differences were not significant.

There is a possibility that Materials D and E would not have sufficient strength to comply with the 3,500 g/cm² minimum strength (3.2.11).

Strain in Compression (3.2.12 and 4.3.10.5). The values in Table 2, Column 9, for strain in compression were obtained on the same specimens later used in the test for set after compression at a fixed stress, Column 8, as specified in the first American Dental Association Specification No. 11 for Hydrocolloidal Impression Material -- Agar Type [2], except that the specimens were 6 minutes old when the test began. The revised requirement in the specification now prescribes a specimen 10 minutes old that has not been subjected to any previous loading (4.3.10.5).

The values in Column 9 are, in general, much higher than those obtained on the agar base materials. Generally lower values than those reported would be obtained if the specimens were tested at 10 minutes as now prescribed (4.3.10.5) rather than at 6 minutes.

It is believed that all of the materials will comply with the current requirement of not less than 4 nor more than 20 percent.

Deterioration (3.2.13 and 4.3.10.6). Since introduction of the alginate impression materials the deterioration during storage has been a problem. Such is still true. The alginate impression materials deteriorate rapidly when stored at 65°C for one month but are stable generally when stored for 3 1/2 months at 50°C [13]. Consequently, it was decided to store the alginate in sealed containers at 60°C and 100 percent relative humidity for one week (4.3.10.6) in designing a specification test.

A comparison of the compressive strengths of the materials stored at 60°C with the compressive strengths of the unaged, as-received materials (Table 4, Columns 3 and 8) shows that in every instance the compressive strength on the aged material was reduced. Sometimes the reduction amounted to as much as 94 percent (Material P-1) or to as little as 11 percent (Material S) on the values obtained at the lower rates of loading.

A value of 2,600 g/cm² was set as the minimum compressive strength after aging (3.2.13). From the data in Column 8 in Table 4, one could hazard an opinion that Materials A, B, D, E, F and P will be likely not to comply with the minimum strength of 2,600 g/cm².

The compressive strengths of the materials (at various rates of stress) as received, after two years of storage at $23 \pm 2^\circ\text{C}$ and when heated at $60 \pm 1^\circ\text{C}$ and stored at 100 percent relative humidity for one week (4.3.10.6), are given in Table 4. The ratios (Column 6) obtained by dividing the strength after storage at a constant room temperature of $23 \pm 2^\circ\text{C}$ for two years (Column 5) by the compressive strength in the

as-received condition (Column 3), show a range from no deterioration in strength, 1.0, to almost 0.4, or 60 percent loss in strength (Column 6).

The ratios (Column 9) between the strengths of the materials heated to $60 \pm 1^\circ\text{C}$ for one week (Column 8) and the original strength (Column 3) show a greater loss than when the strength after two years of aging at room temperature was compared with the original strength (Column 6). Thus, the test for deterioration, as given in the specification (3.2.13 and 4.3.10.6), is more severe than the loss caused by storage at room temperature for two years. A numerical comparison of the relative effect is shown by the ratios (Column 10) obtained by dividing the strength after deterioration of one week at $60 \pm 1^\circ\text{C}$ (Column 8) by the strength after two years of storage at $23 \pm 2^\circ\text{C}$ (Column 5). In every instance the aging test in the specification produced in one week a greater loss in strength than did aging at room temperature for two years. In some instances the lowering was negligible -- Material G with ratios 0.92 and 0.94. In other materials the loss of strength was very severe -- Material P-1 with ratios 0.08 and 0.09.

Other workers showed that the deterioration was caused by depolymerization of the alginate constituent of the impression material [13]. Why some of the materials show marked loss in strength on aging and others do not, cannot be determined unless one has the composition and additional characteristics which could not be determined at this time.

3. References

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Table 1
Alginate Impression Materials Tested

Brand	Date received	Batch number	Manufacturer or distributor
A.I.C.	4-6-64	14663278	The S. S. White Dental Mfg. Co.
A.I.C. (Fast set)	4-6-64	17264065	The S. S. White Dental Mfg. Co.
Coe Alginate	3-29-62	03042	Coe Laboratories, Inc.
Coe Alginate (Fast setting)	3-29-62	AA4	Coe Laboratories, Inc.
Coe Loid	3-29-62	03062	Coe Laboratories, Inc.
Easy-Mix	5-14-62	112121	Baker Dental Division Engelhard Industries, Inc.
Elastic Impression Cream	3-29-62	4787	Dental Perfection Company
Formula 55	4-3-62	36.2B	The William Getz Corporation
Identica	11-20-63	DH54	The Amalgamated Dental Company, Ltd.
Jeltrate	4-23-62	59623	The L. D. Caulk Company
Jeltrate (Fast set)	4-23-62	59620	The L. D. Caulk Company
Jeltrate (Heavy body)	4-23-62	74623	The L. D. Caulk Company
Jeltrate (Inlay)	4-23-62	10062	The L. D. Caulk Company
Kalginate	4-3-62	36.2D	Lee Smith Company
Key to Alginates	3-29-62	216	Dental Perfection Company
Kromopan	4-2-62	53	F. H. Wright Dental Company
Technicol	7-11-62 3-5-63	SX7 XB18	The G. C. Chemical Mfg. Company
Whip-Mix Alginate	3-27-62	4901201	Whip-Mix Corporation
Zelex	4-23-62	9H613	The L. D. Caulk Company

Table 2

Data on Specification Tests on Alginate Impression Materials

1	2	3 4		5	6	7 8		9
Material	Fineness 3.2.3 4.3.5	Compatibility with gypsum		Setting time 3.2.6 4.3.7	Working time 3.2.7 4.3.8	Permanent deformation		Strain in compression 3.2.12 4.3.10.5 ^e
		3.2.4 4.3.6				3.2.10; 4.3.10.3	Fixed strain	
		Line ⁴	Line ⁵	Min. Sec.	mm ⁷	%	%	%
A	S ²	D	C	3:00	0.10	2.1	4.6	15.5
B ¹	S	D	A	2:00	0.10	2.0	2.9	13.7
C	S	D	C	3:10	0.13	1.9	3.0	14.1
D	S	D	A	4:20	0.08	2.6	4.3	15.2
E	S	E	D ⁶	2:30	0.05	1.7	4.8	17.3
F	US ³	C	A	2:40	0.05	2.3	3.8	13.3
G ¹	US	C	B	1:10	0.05	2.3	3.9	12.1
H	US	E	D ⁶	3:20	0.05	2.4	3.8	11.3
I	S	C	C	3:00	0.05	2.0	3.2	17.6
J	S	D	B	2:20	0.05	2.8	6.6	19.8
K	S	D	D	3:10	0.08	1.5	4.3	17.7
L	S	C	C	3:00	0.05	1.9	4.3	17.9
M ¹	S	D	C	2:00	3.69 ⁸	1.5	3.6	15.9
N	S	C	C	2:00	0.10	2.9	3.8	11.2
O	S	D	D	3:00	0.13	1.8	3.3	14.3
P-1	S	C	C	3:00	0.13	2.2	3.7	14.3
P-2 ¹	S	-	B	2:20	5.41 ⁸	2.1	2.7	11.3
Q r ¹⁰	S	-	B	2:30	0.13	2.3	3.4	13.1
R ¹ h ¹¹	S	-	-	2:20	0.38	2.0	2.8	11.3
R ¹ r ¹⁰	S	-	C	1:30	0.15	2.2	3.0	11.9
R ¹ h ¹¹	S	-	-	1:20	2.87	2.0	2.4	10.7
S	S	-	C	2:30	0.13	2.0	3.7	13.8
Requirement in A.D.A. Specification No. 18	All powder shall pass a No. 20 sieve	-	Line O (Fig. 1) 0.075mm wide	Min.-Max. Seconds Type I 60-120 Type II 120-270	Not more than 0.25 mm	Maximum 3%	-	% 4.0-20.0

¹ Type I - Fast-Setting

² S = Satisfactory

³ US = Unsatisfactory

⁴ Impression was blotted with absorbent paper to remove surface exudate prior to pouring cast without vibrating the gypsum slurry.

⁵ Impression was shaken to remove surface exudate prior to pouring the cast with vibrating of the gypsum slurry.

⁶ Line A is discernible when the impression is soaked for 10 minutes (Material E) and for 1½ minutes (Material H) in fixing solutions furnished by their respective manufacturers.

⁷ Depth of material under indenter at one minute and 25 seconds for Type I and at 2 minutes and 10 seconds for Type II.

⁸ Material M and Material P-2 were not labeled fast-setting but complied with Type I, Fast Setting, and did not comply with Type II, Normal Setting. When tested as a Type I, Fast Setting material, the readings were 0.18 mm and 0.13 mm, respectively.

⁹ The values for strain in compression were on 6- not 10-minute-old specimens as the specification requires; hence, the values given should be higher than those values derived on specimens 10 minutes old.

¹⁰ Regular body mix.

¹¹ Heavy body mix.

Table 3

Effect of Temperature of the Mixing Water Upon Time of Setting

Material	Temperature of the Mixing Water				Change in Setting Time† Sec./°C
	10°C Min.Sec.	20°C Min.Sec.	30°C Min.Sec.	40°C Min.Sec.	
A	4:00	3:00	2:00	1:00	6.0
B	2:40	2:00	1:20	40	4.0
C	4:10	3:10	2:10	1:20	5.7
D‡	--	--	--	--	--
E‡	--	--	--	--	--
F	4:00	3:00	2:10	1:20	5.3
G	1:40	1:10	40	20	2.7
H	4:20	3:20	2:20	1:30	5.7
I	4:20	3:00	1:40	50	7.0
J	3:20	2:20	1:30	1:00	4.7
K	4:30	3:20	2:20	1:30	6.0
L	4:20	3:20	2:20	1:20	6.0
M	2:40	2:10	1:40	1:20	2.7
N	2:40	2:00	1:20	40	4.0
O	4:10	3:00	2:00	1:00	6.3
P-1	3:40	3:00	2:20	1:50	3.7
P-2	3:20	2:20	1:40	1:20	4.0
Q Regular Mix	3:20	2:30	1:40	1:00	4.7
Heavy Mix	3:00	2:20	1:30	50	4.3
R Regular Mix	2:00	1:30	1:00	40	2.7
Heavy Mix	1:50	1:20	50	30	2.7
S	3:10	2:30	1:50	1:10	4.0

† Average value for the same range 10°C to 40°C.

‡ No material of the same lot was available.

Table 4
Changes in Compressive Strength Caused by Aging

1	2	Compressive Strength†								9	10	
		(3.2.11 and 4.3.10.4)				B/A	(3.2.13 and 4.3.10.6)		C/A			C/B
		0 Year		After 2 years			Deterioration					
		kg/min	A g/cm ²	kg/min	B g/cm ²	kg/min	C g/cm ²					
A	8.5 17.4 20.5	5,300 5,470 5,410	8.2 19.3 --	4,960 5,210 --	0.94 0.95 --	5.2 13.5 --	1,920 2,080 --	0.36 0.38 --	0.39 0.40 --			
B	8.8 24.9	5,510 5,650	8.8 17.9	4,180 4,380	0.76 0.78	6.3 15.2	2,350 2,450	0.43 0.43	0.56 0.56			
C	9.8 25.4	6,370 6,340	8.4 19.6	4,180 4,750	0.66 0.75	6.4 17.1	2,690 2,930	0.42 0.46	0.64 0.62			
D	6.2 14.3	2,580 2,710	-- 11.1	-- 2,320	-- 0.86	4.4 9.3	1,530 1,550	0.59 0.57	-- 0.67			
E	6.5 15.8	2,720 2,970	-- --	-- --	-- --	5.3 13.6	2,010 2,440	0.74 0.82	-- --			
F	-- 12.1 30.8	-- 6,620 6,750	7.1 14.1 16.6	3,150 3,120 3,320	-- 0.47 0.49	2.6 6.3 --	830 840 --	-- 0.13 --	-- 0.27 --			
G	-- 12.4 29.8	-- 6,740 7,430	6.1 12.8 --	2,740 2,900 --	-- 0.43 --	6.3 17.4 --	2,560 2,650 --	-- 0.39 --	0.94 0.92 --			
H	-- 13.8 33.0	-- 6,160 6,720	6.0 15.6 --	5,950 6,160 --	-- 1.00 --	-- 14.1 30.4	-- 5,290 4,790	-- 0.86 0.72	-- 0.86 --			
I	-- 14.5 34.6	-- 9,430 9,840	5.6 14.4 --	8,490 8,540 --	-- 0.91 --	-- 10.7 26.5	-- 6,180 6,370	-- 0.66 0.65	-- 0.72 --			
J	9.1 22.8	6,540 8,300	7.7 17.3	4,800 5,520	0.73 0.67	5.6 14.5	3,070 3,420	0.47 0.41	0.64 0.62			
K	-- 15.9 44.2	-- 10,930 12,900	4.4 12.0 --	6,670 6,830 --	-- 0.62 --	8.5 21.6 --	4,330 5,200 --	-- 0.48 --	-- 0.76 --			

† The values for compressive strength were on 6- not 8-minute-old specimens as the specification requires; hence the values given should be lower than those values derived on specimens 8 minutes old. Average rate of loading is given.

Table 4
Changes in Compressive Strength Caused by Aging (Con't.)

Material	Compressive Strength†									
	(3.2.11 and 4.3.10.4)				B/A	(3.2.13 and 4.3.10.6)			C/A	C/B
	0 Year		After 2 years			Deterioration				
	kg/min	A g/cm ²	kg/min	B g/cm ²	kg/min	C g/cm ²				
L	-- 13.6 40.1	-- 10,030 11,580	4.5 12.3 --	6,800 7,410 --	-- 0.74 --	-- 9.6 24.9	-- 5,550 6,220	-- 0.55 0.53	-- 0.75 --	
M	-- 11.9 32.9	-- 7,160 7,770	4.7 12.1 --	7,060 7,350 --	-- 1.03 --	-- 8.1 18.7	-- 3,790 3,990	-- 0.53 0.51	-- 0.52 --	
N	-- 13.0 33.9	-- 6,250 6,690	5.6 13.6 --	6,260 6,250 --	-- 1.00 --	-- 10.7 29.7	-- 4,010 4,280	-- 0.64 0.64	-- 0.64 --	
O	-- 11.6 28.4	-- 5,860 5,940	4.3 11.2 --	5,460 5,550 --	-- 0.95 --	-- 9.1 22.4	-- 3,500 3,710	-- 0.60 0.62	-- 0.63 --	
P-1	9.2 23.9	4,520 4,810	9.1 17.8	3,110 3,110	0.69 0.65	1.3 3.0	270 260	0.06 0.05	0.09 0.08	
P-2	7.8 20.1	9,810 10,180	-- --	-- --	-- --	6.8 14.9	1,940 1,960	0.20 0.19	-- --	
Q Regular	2.5	7,440	--	--	--	--	--	--	--	
Mix	5.0	7,490	--	--	--	4.3	5,770	0.77	--	
	13.4	7,830	--	--	--	11.6	6,030	0.79	--	
	27.8	7,820	--	--	--	--	--	--	--	
	31.9	8,030	--	--	--	--	--	--	--	
	57.8	8,390	--	--	--	--	--	--	--	
Heavy	5.7	8,210	--	--	--	5.2	7,030	0.86	--	
Mix	15.2	8,730	--	--	--	13.5	7,190	0.83	--	
	--	--	--	--	--	28.4	7,320	--	--	
R Regular	4.9	7,640	--	--	--	4.9	6,460	0.85	--	
Mix	14.5	7,850	--	--	--	13.1	6,570	0.84	--	
Heavy	6.1	8,610	--	--	--	5.4	7,180	0.83	--	
Mix	16.0	8,880	--	--	--	13.9	7,270	0.82	--	
S	10.4 23.1	5,360 5,590	-- --	-- --	-- --	11.2 24.0	4,790 4,920	0.89 0.88	-- --	
Requirement in A.D.A. Specification No. 18	kg/min 10 ± 2	g/cm ² mini- mum 3,500	--	--	--	kg/min 10 ± 2	g/cm ² mini- mum 2,600	--	--	

† The values for compressive strength were on 6- not 8-minute-old specimens as the specification requires; hence the values given should be lower than those values derived on specimens 8 minutes old. Average rate of loading is given.

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