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7-DAY TENSILE STRENGTH OF CEMENT MORTARS USING THE RING TEST

by

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V.M. Malhotra*

SUMMARY

Results are presented of an investigation using the ring test to determine the tensile strength of cement mortars. In this study the test specimens were 6-in. diameter rings, 1 in. thick and 1 in. high (an earlier investigation had reported results using rings which were 1 1/2 in. high). The specimens were stressed to failure by applying radial hydrostatic pressure through a rubber bladder acting against the entire inside periphery of the ring. Twenty-nine standard batches of cement mortar were made; both ring specimens and companion 2-in.-cube compression specimens were cast from each batch and tested at 7-days. The test results are analysed statistically and discussed. The coefficients of variation for 7-day strengths for both the tension and compression tests are about 7 per cent, indicating that the ring test is a satisfactory means for determining the tensile strength of cement mortars.

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RESISTANCE À LA TENCION (7 JOURS) DES MORTIERS DE CIMENT, DETERMINÉE PAR L'ESSAI DE L'ANNEAU

par

V.M. Malhotra*

RÉSUMÉ

L'auteur rend compte des résultats d'un essai de l'anneau pratiqué de façon à déterminer la résistance à la tension des mortiers de ciment. Pour cette étude, les éprouvettes étaient des anneaux de 6 pouces de diamétre, 1 pouce d'épaisseur et 1 pouce de hauteur; (les résultats d'une étude précédente faisaient état d'anneaux de 1 pouce 1/2 de hauteur). Les éprouvettes ont été soumises à la rupture en appliquant une pression hydrostatique radiale au moyen d'une vessie en caoutchouc qui exerce une poussée sur toute la périphérie interne de l'anneau. Vingt-neuf gâchées ordinaires de mortier de ciment ont été préparées; les éprouvettes annulaires et les cubes de 2 pouces destinés aux essais de compression ont été coulés à partir de chaque gâchée et éprouvés au bout de 7 jours. Les résultats des essais sont analysés par statistique, puis commentés. Les coefficients de variation de résistance aprés 7 jours, à la fois pour les essais de tension et de compression, sont d'environ 7 p. 100, ce qui indique que l'essai de l'anneau est un bon moyen de déterminer la résistance à la tension des mortiers de ciment.

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INTRODUCTION

In 1965 the Mines Branch reported (1, 2, 3, 4) a new test for determination of the tensile strength of concrete and of cement mortars. In this method hydrostatic pressure is applied radially against the entire inside periphery of a 6-in.-diameter ring-test specimen. The resulting tensile stresses developed in the specimen at the moment of failure are determined from the equations for the stress analysis of thick-walled cylinders. The specimens used in the earlier investigations to determine the tensile strength of cement mortars were rings of 6-in. inside diameter, 1 in. thick and 1 1/2 in. high*. It is now considered that the non-symmetrical section used for the mortar studies can introduce stress concentrations and therefore may not be the ideal section. Theoretical considerations suggested that 6-in.-inside-diameter, 1-in.-thick and 1-in.-high specimens would probably provide for the most suitable stress distribution. Furthermore, this size would also reduce the amount of material needed to cast a set of three ring-specimens. This report, therefore, describes an investigation that was undertaken to determine the tensile strength of cement mortars using 6-in.-ring specimens having a section of 1 in. by 1 in.

STRESS DISTRIBUTION AND ASSUMPTIONS MADE

The stress distribution and the assumptions made in calculating the tensile stresses in the ring section have been described in some detail elsewhere (2-4). Here it should suffice that the tensile stresses vary from a maximum of 3.6 P_i at the inside periphery to a minimum of 2.6 P_i at the outside surface, where P_i is the applied hydrostatic pressure.

MATERIALS

Cement

A Type-1 Portland cement of Canadian manufacture was used. The physical properties and chemical analysis of the cement are shown in Table 1.

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*This non-symmetrical section was used because the original test equipment had been designed to test concrete-ring specimens which had a section of 1 1/2 in. thick and 1 1/2 in. high. No reduction in the specimen height was possible because of the size of the rubber bladder used to transmit the hydrostatic pressure.

TABLE 1

Physical Properties and Chemical Analysis of Cement*

Description of Test	Unit	
Physical Test - General		
Time of Set** (Initial	hr:min	2:50
(Final	hr:min	4:50
Fineness - Blaine	cm^2/g	3010
Soundness - Autoclavé Expansion	%	0:22
Physical Tests - Mortar Strength		
Briquette tensile Strength - (3-day	psi	395
(7-day	psi	445
(28-day	psi	510
Cube compressive strength - (3-day	psi	2700
(7-day	psi	3850
(28-day	psi	5100
Chemical Analysis		
Insoluble residue	%	0.21
Silicon dioxide (SiO_2)	%	21.28
Aluminum oxide (Al_2O_3)	%	5.63
Ferric oxide (Fe_2O_3)	%	2.49
Calcium oxide, total (CaO)	%	63.44
Magnesium oxide (MgO)	%	2.87
Sulphur trioxide (SO_3)	%	2.28
Loss on Ignition	%	0.88
Total -		99.08

* Physical test results and chemical analysis supplied by the cement manufacturing company.

** Using Vicat apparatus.

Sand

For mortar studies, standard graded silica sand * from Ottawa, Illinois, was used. The grading of the sand is given in Table 2.

TABLE 2

Grading of Ottawa Silica Sand

Sieve Size	Per Cent Passing
No. 30 mesh	99.6
No. 50 mesh	24.6
No. 100 mesh	1.4

This grading is different than that for the briquette tension test, for which the ASTM specification prescribes that the sand shall be natural silica sand from Ottawa, Illinois, graded to pass a No. 20 sieve and retained on a No. 30 sieve.

MORTAR MIXES

Design of Mortar Mixes

A total of 29 standard mortar mixes were made in the laboratory between December 1965 and February 1966. All materials were mixed in a Hobart mixer in accordance with ASTM Standard C305-64T. A standard mix-design, shown in Table 3, was used throughout in this investigation. As far as possible all mixes were made under identical laboratory conditions of temperature and humidity.

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*Standard Method of Test For Compressive Strength of Hydraulic Cement Mortars (Using 2-in. Cube Specimens), ASTM Designation: C 109-64, 1965 ASTM Book of Standards, part 30, p. 70.

TABLE 3

Standard Mortar Mix Design

Constituent	Amount, gms
cement	750.0
Sand	2062.5
Water	375.0

Characteristics of Fresh Mortar

Immediately after mixing, the flow of the mortar was determined using the method given in ASTM Designation C230-61T. It varied from 80 to 110 per cent with an average value of 97 per cent. As the mix-proportions and materials used are the same as those used in an earlier investigation (4) in which the values of flow were between 100 and 110 per cent, no changes in mix-proportions were made to increase the flow.

Test Specimens

One ring (6 in. inside diameter, 1 in. thick and 1 in. high) was cast from each mix. Three 2-in.-cube specimens were also cast from each mix for compression-strength studies.

Moulding and Curing

Standard brass moulds were used for the cube specimens and these were cast by filling the moulds in approximately two equal layers. Each layer was hand-compacted, using the method outlined in ASTM Designation C109-64.

The rings were moulded in specially fabricated moulds, illustrated in Figure 1. Each ring mould consists of a split outer ring, 8 in. inside diameter and 1 in. high, machined from mild steel, with a solid aluminum centre piece of the same height and 6 in. outside diameter. The ring and the centre piece are mounted concentrically on a 1/2-in.-thick, machined base plate and secured with wing nuts. To facilitate removal of the inner

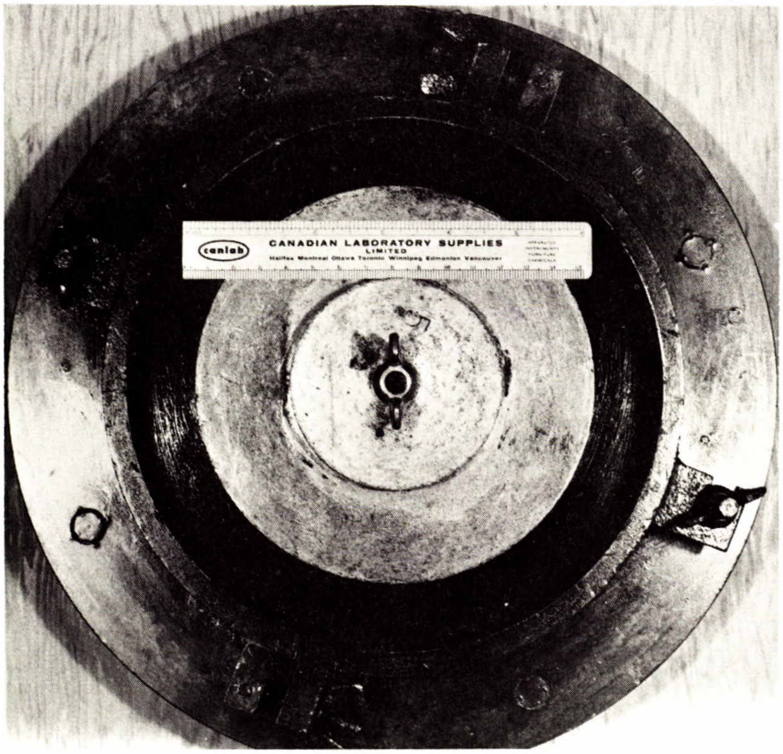

Figure 1. Ring Mould.

centre piece during demoulding, the centre piece is tapered over its full height so that the upper end is 0.003 in. less in diameter than the lower end.

The test rings were cast by filling the steel mould and vibrating it on a vibrating table for 30 sec. The time elapsed between mixing and moulding of the specimens was 4 min.

After casting, all moulds were covered with wet burlap, which was kept moist during the following 24 hr. The specimens were then removed from the moulds and were transferred to the moist curing room (73.4±3.0°F and 100 per cent relative humidity) for the next 6 days. At the end of the curing period, the specimens were taken out of the curing room and prepared for testing.

TESTING OF MORTAR SPECIMENS

Compression Test

All 2-in.-cube specimens were tested in a moist condition in a 60,000-lb-capacity Tinius-Olsen testing machine, with pressure applied in a direction at right angles to that of casting. The rate of loading was 400 lb/sec.

Tensile Test

The ring-tensile-test specimens were tested in a moist condition in a specially fabricated jig (2). The radial pressure was applied hydrostatically from the inside through a specially moulded rubber bladder. The rate of loading was 8 to 10 psi/sec. Figure 2 shows the ring-testing jig just after assembly. Immediately before testing, the rings were weighed and any cavities in the inside surface of the rings were filled with wet cement paste to prevent damage to the rubber bladder.

TEST RESULTS AND THEIR ANALYSIS

A summary of the test results is given in Table 4. Also included in the table is the ratio of ring-tensile strength to compressive strength.

The "within-batch" and "between-batches" coefficients of variation for the test results are given in Tables 5 and 6. The frequency distribution of the test results is given in the histogram of Figure 3.

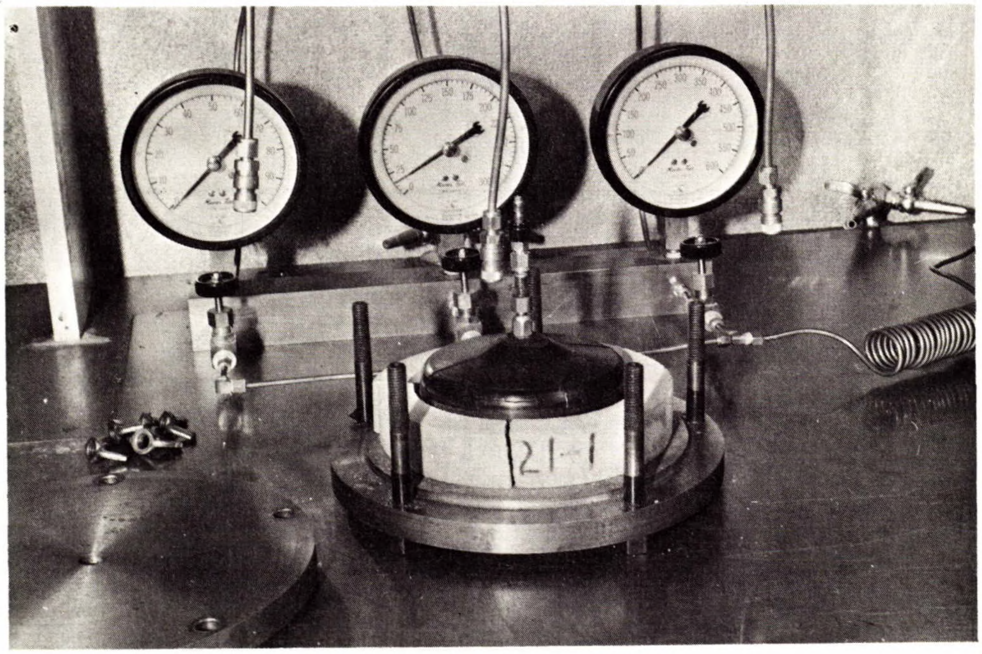

Figure 2. Ring-Testing Jig Just After Test.

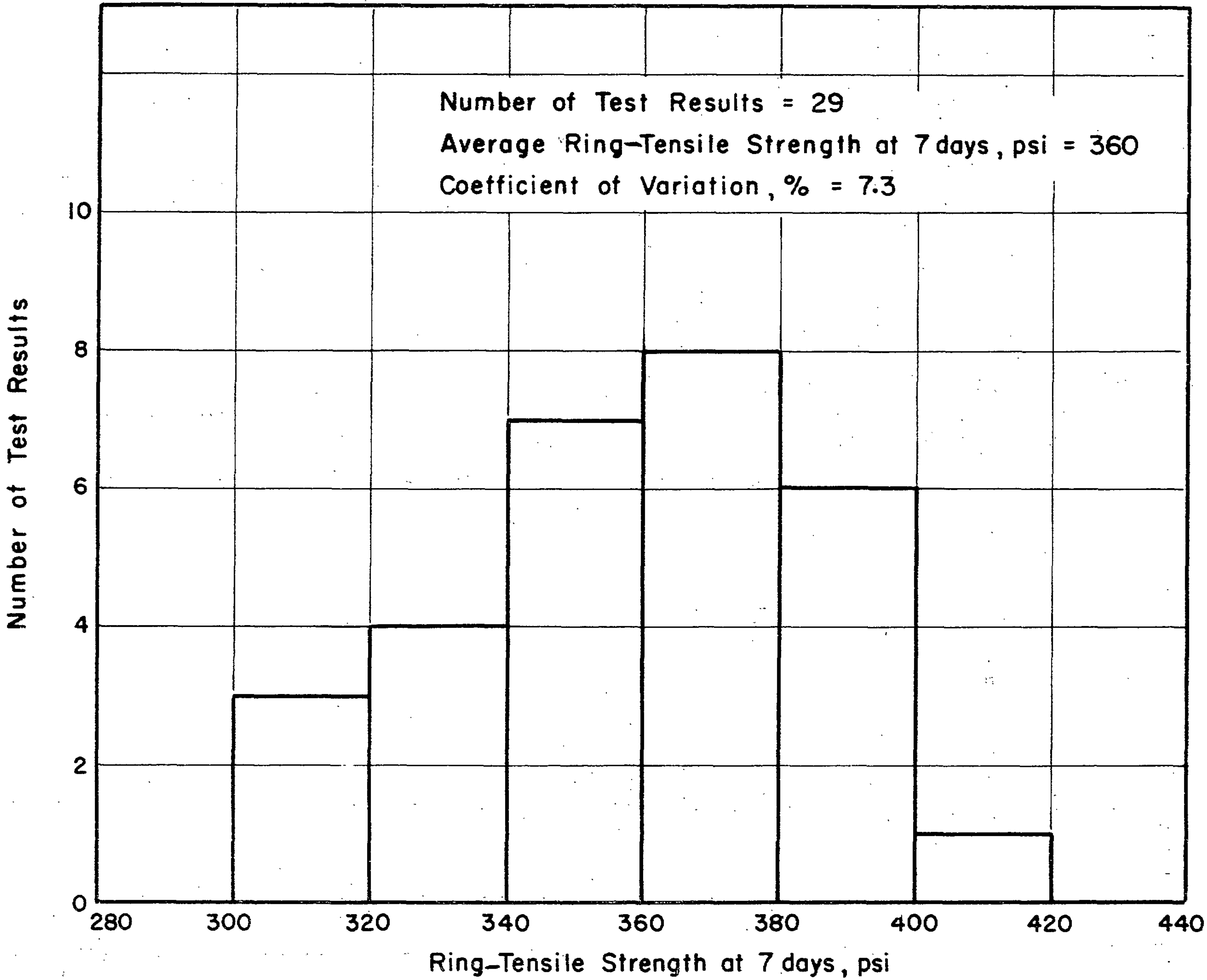

FIGURE 3. Frequency Distribution of Ring-Tensile Strengths.

TABLE 4

Summary of Test Results

Mix No.	Tensile Strength, psi 1-in.-thick rings	Compressive Strength, psi 2-in. cubes	Tensile Strength/ Compressive Strength, per cent
1	400	3575	11.2
2	395	3790	10.4
3	345	3365	10.2
4	345	3295	10.5
5	320	3655	8.8
6	390	3795	10.3
7	365	3800	9.6
8	380	3840	9.9
9	330	3530	9.3
10	335	3515	9.5
11	360	3595	10.0
12	380	3875	9.8
13	335	3770	8.9
14	320	4005	8.0
15	360	3725	9.7
16	360	3690	9.8
17	340	3785	9.0
18	400	4190	9.5
19	310	3380	9.2
20	390	4040	9.7
21	395	3970	10.0
22	370	4110	9.0
23	365	3935	9.3
24	405	4010	10.1
25	360	4095	8.8
26	365	4060	9.0
27	365	4255	8.6
28	345	4185	8.2
29	370	4230	8.7
			Average = 9.5

TABLE 5

Within-Batch Variation in Test Results

Type of Specimen	No. of Batches	No. of Test Specimens per Batch	Within-Batch Variation		
			Average Strength, psi	Average Standard Deviation, psi	Average Coefficient of Variation, per cent
1-in.-thick ring	29	1	360	--	--
2-in. cube	29	3	3830	82.3	2.2

TABLE 6

Between-Batches Variation in Test Results

Type of Specimen	No. of Batches	Between-Batches Variation		
		Average Strength, psi	Standard Deviation, psi	Coefficient of Variation, per cent
1-in.-thick ring	29	360	26.3	7.3
2-in. cube	29	3830	269	7.0

DISCUSSION OF TEST RESULTS

Reproducibility of Tensile-Strength Results

The ring-tensile strength results show a high degree of reproducibility, with a "between-batches" coefficient of variation of only 7.3 per cent. Considering the simplicity of the equipment and the fact that only one specimen was tested per batch, this is a relatively low value and is comparable to the results reported by Ramesh and Chopra (5), O'Clery and Byrne (6) and Kaplan (7). It is believed that if the number of specimens per batch in the ring test is increased from one to three, the "between-batches" reproducibility of the test results would be superior to those obtained in the other existing tests.

Relative Reproducibility of Ring Tension and Cube Compression Tests

The "between-Batches" coefficients of variation for the results of the two types of tests under discussion are of the same order, 7.3 per cent for the ring test and 7.0 per cent for the cube test. This slight difference is probably due to the fact that in the compression test three 2-in. cubes were cast and tested for each batch and the mean of the three results was used to compute the "between-batches" coefficient of variation, whereas in the ring test only one ring was cast and tested per batch.

Tensile/Compressive Strength Ratio

The ratio* of the ring tensile strength to the 2-in.-cube compressive strength varied from 8.0 to 11.2 per cent with an average value of 9.5 per cent. The briquette tension and 2-in.-cube compression tests carried out by the cement manufacturer's laboratory on the same batch of cement used in this investigation gave a ratio of 11.5 per cent**. For the same water/cement ratio that was used in this investigation, but for cements from other sources, Zoldners and Malhotra (8) report values varying from 9.6 to 12.8 per cent for the ratio between the briquette-tensile strength and the cube-compressive strength. It is, however,

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* All ratios are based upon strengths at 7-days.

** This ratio is based upon one set of test results only.

emphasized that no direct correlations should be made between the results of this investigation and those of others because experimental conditions, test materials and methods are basically different.

Advantages of the Ring Test

It is considered that the proposed form of the test specimen has the following advantages over the existing test methods:

(a) The geometry of the specimen and the nature of the load application are such that gripping and misalignment stresses are eliminated altogether -- a condition very difficult to achieve in briquette tension tests.

(b) The entire volume of the ring specimen is subjected to tensile stresses, with the uniformly distributed maximum stress occurring along the entire internal periphery of the ring. This is not the case in flexural beam tests.

CONCLUSIONS

The ring test discussed in this report is a satisfactory method for determining the tensile strength of cement mortars. The equipment is simple and portable, and yields test results of excellent reproducibility. It is considered that a ring specimen having dimensions of 6-in. inside diameter, 1 in. thick by 1 in. high should be adopted as standard for this test.

ACKNOWLEDGEMENT

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VMM:rlm

REFERENCES

1. V.M. Malhotra, Discussion of a Paper by H. Roper and J.G. Bryden, "A New Approach to the Determination of the Tensile Strength of Cement Paste by Centrifugal Force" Magazine of Concrete Research, Vol. 17, No. 52, September 1965, pp. 158-160.

2. V.M. Malhotra, N.G. Zoldners and H.M. Woodrooffe, "Ring Test for Tensile Strength of Concrete" ASTM Materials Research and Standards, Vol. 6, No. 1, January 1966, pp. 1-7. Discussion pp. 7-12.

3. V.M. Malhotra and N.G. Zoldners, "Correlation Between Ring Tensile and Compressive, Flexural and Splitting Tensile Strengths" ASTM Journal of Materials, Vol. 2, No. 1, January-March 1967, pp. 160-184. Discussion pp. 184-199.

4. V.M. Malhotra and H.M. Woodrooffe, "Ring Testing -- A New Approach to Determining the Tensile Strength of Cement Mortars" Canada Mines Branch Internal Report MPI 66-8, February 1966, 29 pp.

5. C.K. Ramesh and S.K. Chopra, "Determination of Tensile Strength of Concrete and Mortar by the Split Test" Indian Concrete Journal, Vol. 34, No. 9, September 1960, pp. 354-357.

6. D.P. O'Clery and J.G. Byrne, "Testing Concrete and Mortar in Tension" Engineering (London), March 18, 1960, pp. 384-385.

7. M.F. Kaplan, "The Reproducibility of Flexure and Compression Tests for Determining the Strength of Cement" Proceedings, ASTM, Vol. 60 (1960), pp. 1006-1017.

8. N.G. Zoldners and V.M. Malhotra, "CSA Cement Testing Programme Phase I" Canada Mines Branch Investigation Report IR 62-102, December 28, 1962, 30 pp.