

The Chemistry and Technology of **GYPSUM**

R. A. Kuntze, editor

ASTM **STP 861**

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THE CHEMISTRY AND TECHNOLOGY OF GYPSUM

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Foreword

The symposium on The Chemistry and Technology of Gypsum and Gypsum Products was presented at Atlanta, GA, 14–15 April 1983. The symposium was sponsored by ASTM Committee C-11 on Gypsum and Related Building Materials and Systems. Richard A. Kuntze, Ontario Research Foundation, presided as chairman of the symposium and is editor of the publication.

Related ASTM Publications

Masonry: Materials, Properties, and Performance, STP 778 (1982), 04-778000-07

Extending Aggregate Resources, STP 774 (1982), 04-774000-08

Cement Standards—Evolution and Trends, STP 663 (1979), 04-663000-07

Significance of Tests and Properties of Concrete and Concrete-Making Materials, STP 169B (1978), 04-169020-07

A Note of Appreciation to Reviewers

The quality of the papers that appear in this publication reflects not only the obvious efforts of the authors but also the unheralded, though essential, work of the reviewers. On behalf of ASTM we acknowledge with appreciation their dedication to high professional standards and their sacrifice of time and effort.

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Contents

Introduction	1
Physical Testing of Gypsum Board Per ASTM C 473— ROBERT F. ACKER	3
Gypsum Analysis with the Polarizing Microscope— GEORGE W. GREEN	22
The Effect of Sorbed Water on the Determination of Phase Composition of $\text{CaSO}_4 \cdot \text{H}_2\text{O}$ Systems by Various Methods— DANICA H. TURK AND LARBI BOUNINI	48
A Simple Apparatus for Measurement of the Hydration Ratio of Plasters and Plaster Rocks— ETIENNE KARMAZSIN	57
Determination of Sulfur Trioxide in Gypsum— S. GOSWAMI AND D. CHANDRA	67
Rapid Multielement Analysis of Gypsum and Gypsum Products by X-Ray Fluorescence Spectroscopy— VLADIMIR KOCHAN	72
The Relationship Between Water Demand and Particle Size Distribution of Stucco— LYDIA M. LUCKEVICH AND RICHARD A. KUNTZE	84
Retardation of Gypsum Plasters with Citric Acid: Mechanism and Properties— THOMAS KOSLOWSKI AND UDO LUDWIG	97
Byproduct Gypsum— JEAN W. PRESSLER	105
Assessment of Environmental Impacts Associated with Phosphogypsum in Florida— ALEXANDER MAY AND JOHN W. SWEENEY	116

Evaluation of Radium and Toxic Element Leaching Characteristics of Florida Phosphogypsum Stockpiles—ALEXANDER MAY AND JOHN W. SWEENEY	140
Drying and Agglomeration of Flue Gas Gypsum—FRANZ WIRSCHING	160
Summary	173
Index	177

Introduction

Recent advances in gypsum chemistry, analytical techniques, and manufacturing technologies have raised a number of issues of concern to producers and users of gypsum products alike. For example, the analysis of gypsum and gypsum products as covered by ASTM standards is based almost entirely on wet chemical methods. However, modern instrumental methods are now used routinely in most laboratories and institutions. They are capable of determining constituents and impurities of gypsum and its dehydration products more accurately and reliably than conventional methods.

In addition, by-product gypsums are increasingly considered as raw material in the manufacture of gypsum products as partial or complete replacement of natural gypsum. Present ASTM standards do not deal with these synthetic materials, which provide a number of analytical problems because of the presence of unusual impurities not normally found in natural gypsums. For the same reason, the manufacture and application of building materials containing by-product gypsums is affected by serious difficulties.

In order to address these questions and problems, this symposium was sponsored by ASTM Committee C-11 on Gypsum and Related Building Materials and Systems. The symposium was intended to provide a forum for discussions of theories, test methods and analyses, and basic information on gypsum and its products.

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Physical Testing of Gypsum Board Per ASTM C 473

REFERENCE: Acker, R. F., "Physical Testing of Gypsum Board Per ASTM C 473," *The Chemistry and Technology of Gypsum, ASTM STP 861*, R. A. Kuntze, Ed., American Society for Testing and Materials, 1984, pp. 3–21.

ABSTRACT: This work was performed to investigate modernization of the equipment used for the physical testing of gypsum board that has not been basically changed over a period of many years and is not commercially available. A comprehensive study has been made using a commercially available machine for three strength tests, with the expectation that this type of equipment might be incorporated into ASTM methods and specifications in the future. Technical advances in the methods of evaluating gypsum board are desirable in a progressive industry.

The procedure used was to run the three major physical tests: flexural strength; core, end, and edge hardness; and nail pull resistance on a machine using constant strain rate loading and compare those results with those obtained on the commonly used ASTM specified machine that uses a constant stress rate. A TM 51008 tester made by Testing Machines, Inc. was used for the work reported in this paper. Comparative tests were made on equipment conforming to the specifications of ASTM Physical Testing of Gypsum Board Products, Gypsum Lath, Gypsum Partition Tile or Block, and Precast Reinforced Gypsum Slabs (C 473). Preliminary work was done in a research laboratory to develop the fixtures and procedures necessary to use the new equipment. The machine was then placed in a manufacturing plant and duplicate tests on all types of board products were run for a period of several months.

Data will be presented to show that the constant strain rate method of testing can give equally precise results with a very substantial saving in time and physical effort. For flexural strength, nail pull resistance, and core hardness there is a simple linear correlation between the results with the two machines. The constant strain rate machine can more accurately determine the maximum load causing failure than the constant stress rate machine. Correlation between the results of tests on either machine shows that the core hardness and nail pull resistance tests tend to duplicate information on core properties.

KEY WORDS: gypsum, physical tests, physical properties, gypsum board, constant stress, constant strain

About 1975 the ASTM specifications for gypsum board were changed to eliminate arbitrary weight limits and substitute performance tests. The tests added were humidified sag resistance; core, end, and edge hardness; and nail pull

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resistance. The flexure test that was already in the specifications was retained as a performance test.

With the exception of sag resistance, these tests are run by using a testing machine that can apply force to a specimen and measure the force applied. The device used was designed about 1922. It is slow and laborious to use and is not commercially available.

The test procedures are intended primarily for use by the purchaser or user. The product manufacturers voluntarily certify that their products meet the appropriate ASTM specifications. To do this, they must run sufficient tests by these procedures to determine that their products conform to the specifications. All of the tests require that specimens be conditioned for an extended period of time before testing, so the tests cannot be used for direct process control. It is desirable that the tests measure significant properties of the products so that they can be used for product evaluation.

This paper describes work done with a type of testing machine that is commercially available. It is much faster and easier to use than the presently approved type of unit, gives equal or better precision, and can furnish more information from some of the tests than the type of unit presently approved.

Testing Machines

The exact type of machine to be used is not specified in ASTM Physical Testing of Gypsum Board Products, Gypsum Lath, Gypsum Partition Tile or Block, and Precast Reinforced Gypsum Slabs (C 473). However, each procedure specifies that force be applied to a specimen at a controlled rate of 4.45 N/s (60 lb/min). A typical testing machine of the type commonly used in the industry is shown in Fig. 1. On this machine, the prescribed rate of loading is obtained by allowing lead shot to flow into a bucket through a variable size orifice.

The machine used by the United States Gypsum Company was designed in the early 1920s. Some original drawings, which are still used for basic features of the machine, are dated 1922. The method of loading by running lead shot into a bucket is simple and readily adaptable to construction in a plant shop. There is no theoretical reason for specifying constant stress rate loading. To the best of our knowledge, United States Gypsum Company built the first machine to be used for testing gypsum board, and this type of machine was specified in the ASTM procedures because it had been adopted by other manufacturers and was commonly used in the industry.

As best can be determined, other gypsum manufacturers still use similar machines including the shot-bucket method of loading, although other methods of loading are possible. The drawings in ASTM C 473 show a very similar machine, although the method of load application is not detailed.

When a test has been completed, the bucket of shot must be removed and weighed. The shot is then poured back into the supply bucket. This particular machine has a four to one lever arm ratio so the force applied to a specimen is

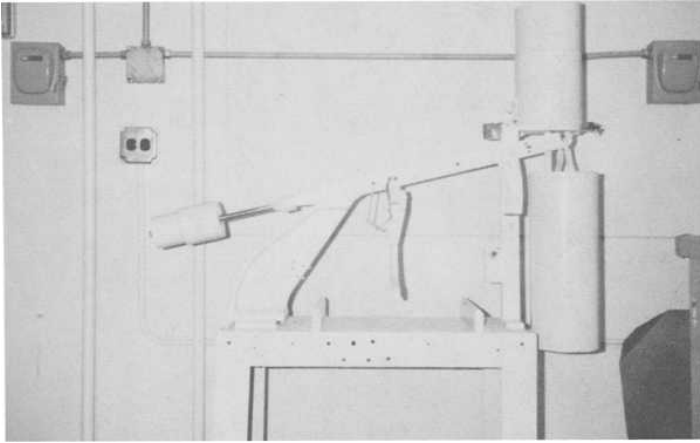


FIG. 1—Testing machine commonly used for gypsum board.

five times the mass of the shot. For 16-mm ($\frac{5}{8}$ -in.) board, the minimum breaking load for the flexural strength test broken across the fiber is 667 N (150 lbf). Actual values can be much higher, particularly for tests across the fiber.

When using this testing machine, the operator must repeatedly lift and move a bucket with a mass up to or over 13.6 kg (30 lb). This is tiring at best and can be hazardous unless the person is robust. If this manual labor were eliminated, the job would be more suitable for less robust persons, including females or the physically handicapped.

We have not been able to locate a commercially available machine that uses constant stress loading and is adaptable to the tests of ASTM C 473. Many machines in a wide range of types and capacities are available that use constant strain rate loading. Typically the force is applied to a specimen by a head moving at a constant speed, and the force applied is measured by a sensing system that supports a platform on which the specimen is placed. Testing speeds can be varied over a wide range.

Figure 2 shows a high-capacity high-cost machine of this type that typically could be found in a research laboratory or testing agency. Figure 3 shows the TM 51008 made by Testing Machines, Inc. (TMI). This is a smaller, lower cost machine suitable for use in a plant laboratory. The work to be described was done on this machine, but obviously any machine that gives constant strain loading could be used. For convenience we will refer to the machines as constant stress and constant strain machines.

The TMI machine is equipped with a device for recording a stress-strain curve for tests. Such a device is normally available for any constant strain testing machine.

Figure 4 shows the accessories used for nail pull resistance, and core, end,

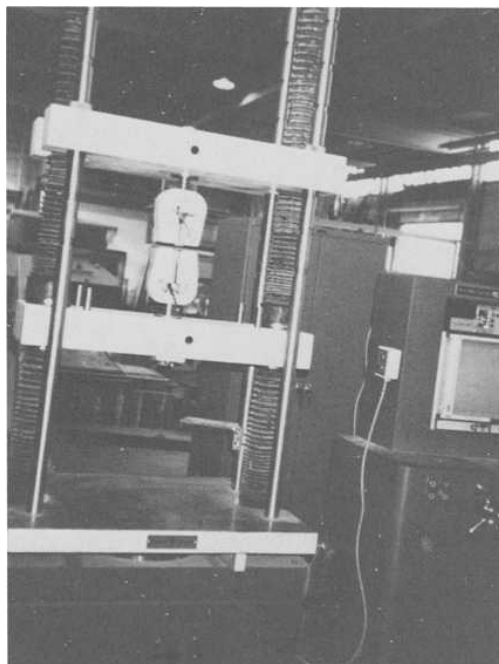


FIG. 2—Commercial constant strain type testing machine.

and edge hardness on the two machines. Since the weight of the specimen holder is included in the load measured on the TMI tester, it is convenient to have all accessories weigh the same to avoid frequent adjustment of tare load. The holes drilled in the TMI accessories were used to adjust the weight. The nail pull resistance specimen support for the TM tester has a slot cut in the face. This makes it convenient to remove the specimen by only retracting the sample head slightly and saves a good deal of time on this test.

Flexure Testing

On the TMI tester, the testing area is a little more than 305 mm (12 in.) square. For flexure testing, a 305- by 254-mm (12- by 10-in.) specimen tested on 254-mm (10-in.) centers was used. ASTM C 473 specifies that a 305- by 406-mm 12- by (16-in.) specimen tested on 356-mm (14-in.) centers be used. There is no particular significance to this specimen size other than that the predominant product made in 1922 was 406-mm (16-in.) wide, and the specimen size simplified specimen preparation.

A preliminary test of the TMI tester was run on a special run of board in which three thicknesses of board had been made with the same lots of face and

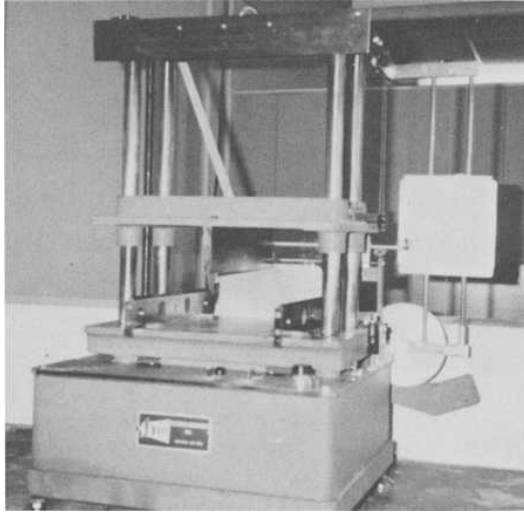


FIG. 3—*Testing Machines Inc. Model 51008 tester.*

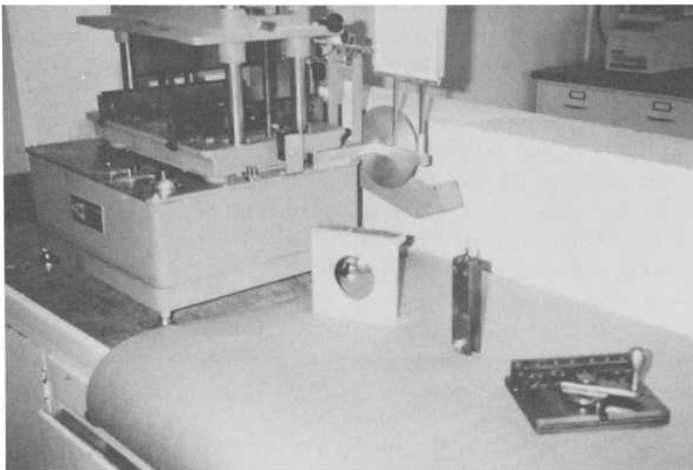


FIG. 4—*Accessories used for gypsum board testing.*

back paper. A number of specimens were run for each of the four variations of the flexure test and at two different speeds of the testing head.

Results are shown in Table 1. The main things to note are that, in the range used, the speed of the testing head had no noticeable effect and the standard deviations of the various specimens were essentially the same for both machines. The two machines have equal precision, and the variations measured are most likely in the product rather than the testing equipment.

A linear correlation of the average values from the two testing machines showed excellent agreement. A calculated correlation equation is $P = 0.08N + 6.9$ ($r = 0.999$). P stands for the value on the presently approved constant stress testing machine and N for the value by the new constant strain machine, and r for the statistical correlation coefficient.

It is obvious that flexure tests should be directly proportional to specimen width. Numerous tests on both types of machines have confirmed this. The modulus of rupture (MOR) formula predicts that flexural strength should be inversely proportional to the span. Combining these relationships we can calculate that the test on the 12 by 16 specimen should be $12/10 \times 10/14 = 0.857$ times the strength of the 10 by 12 specimen. This is reasonably close to the slope of 0.8 found for the correlation equation. Gypsum wallboard is not a homogeneous material as is assumed in the calculation of MOR.

The fact that the correlation equation contains a constant can be explained by considering the action of the two testing machines. The constant strain machine records only the maximum force exerted on the specimen. For flexure tests, this is usually the point where the core first cracks. Additional resistance to breaking occurs as the paper tears and in the case of a board containing glass fiber, as the fibers pull out of the core. The force required for this second break may even exceed that for the initial core crack.

The constant strain machine will record the maximum force whenever it occurs. In a shot-bucket machine, shot will continue to flow into the bucket until the specimen completely fails, and the lever arm falls. Almost invariably there is some shot flow after the point of maximum resistance by the specimen. As will be shown later, the shot-bucket type of machine gives higher numerical values than a maximum-recording constant-strain machine. The difference between the machines is generally quite uniform and predictable. Since the constant strain machine records the true maximum force resisted by a specimen, while the shot-bucket machine usually indicates a greater force, the constant strain machine can be considered more accurate.

The next step in the evaluation was to place a TMI testing machine in a plant and run duplicate tests on all types of products for a period of several months. Results of flexural strength tests are shown in Table 2. For clarity, only the averages are shown in this table, but standard deviations were calculated for each average and were very similar for the two machines. For example, on 12.7-mm ($\frac{1}{2}$ -in.) regular wallboard where 129 sets of specimens were tested, the standard deviations were as shown in Table 3. This again shows that the two

TABLE 1.—Flexural strength tests various thicknesses.^a

Specimen	TM Tester			Board Test Unit		
	Number Tested	Average, lb	Standard Deviation	Number Tested	Average, lb	Standard Deviation
5/16 in. parallel FD	4	35.0	0 ^b	...	...	...
	6	36.2	1.5 ^c	10	34.7	0.4
5/16 in. parallel FU	2	40.0	0 ^b	...	...	...
	3	37.2	0.3 ^c	7	39.9	1.6
3/8 in. parallel FD	3	42.3	0.7 ^b	...	...	...
	13	43.6	1.5 ^c	10	42.6	1.5
3/8 in. parallel FU	3	46.2	1.0 ^b	...	...	...
	9	48.5	2.4 ^c	10	45.7	2.6
1/2 in. parallel FD	1	73.5	...	...	...	...
	6	74.6	2.4 ^c	6	66.5	2.6
1/2 in. parallel FU	1	88.6	...	...	...	...
	3	82.2	10.1 ^c	6	76.7	6.1
5/16 in. across FD	3	117.7	3.8 ^b	...	...	...
	5	122.7	1.1 ^c	11	101.2	3.8
5/16 in. across FU	3	127.3	3.8 ^b	...	...	...
	6	131.2	4.7 ^c	10	107.8	2.1
3/8 in. across FD	4	141.0	2.7 ^b	...	...	...
	11	142.5	2.6 ^c	10	118.8	2.2
3/8 in. across FU	3	149.0	6.9 ^b	...	...	...
	8	151.6	6.8 ^c	10	125.6	5.9
1/2 in. across FD	1	217.0	...	...	...	...
	5	208.8	4.3 ^c	7	177.9	5.5
1/2 in. across FU	2	224.0	1.0 ^b	...	...	...
	5	225.0	22.4 ^c	7	188.8	16.6

^a1 in. = 25.4 mm and 1 lb = 4.448 N. FU is face up and FD is face down.

^bTested at 0.5 in./min.

^cTested at 2.0 in./min.

TABLE 2—Flexural strength data averages.^a

Product, in.	Across FU, lb		Across FD, lb		Parallel FU, lb		Parallel FD, lb		Number of Tests
	Old	New	Old	New	Old	New	Old	New	
1/4	88.5	88	94	95	26.5	23.5	26.5	24.5	2
3/16	123.2	129.2	136.3	135.8	38.2	35.4	36.7	36.0	6
1/2 A	100	110	100	100	37	30	31	31	1
3/8 B	132.2	141.1	131.6	138.9	35.1	34.8	36.3	34.6	14
7/16	153	155	146	152	43	42.5	31	40.6	1
1/2 A	172	187.5	183	189	47.25	57.1	52	58.5	4
1/2 B	212.1	227.9	207.9	226.4	63.2	67.6	59.3	59.8	11
1/2 regular	175.2	184.4	174.3	183.4	49.13	49.79	49.6	48.5	129
3/4 A	247.2	280.6	243.1	279.6	75.9	82.8	76.5	84.4	9
3/4 B	252.1	280.3	246.4	272	79.4	89.4	81.5	76.6	15
3/4 X	252.4	283.0	256.0	283.0	82.5	93.2	82.0	79.1	79
3/4 C	278.8	322.2	270	305.8	96.5	126.2	94.5	95.1	4

^a 1 in. = 25.4 mm and 1 lb = 4.448 N. FU is face up and FD is face down.

TABLE 3—Standard deviations for 12.7-mm (1/2-in.) regular wallboard.

Test ^a	Standard Deviation	
	Old Tester	New Tester
Parallel FU	4.0	4.3
Parallel FD	3.9	3.7
Across FU	10.1	9.7
Across FD	10.1	9.6

^aFU is face up and FD is face down.

machines have the same precision and that the variations measured are in the products.

Figure 5 is a graph of these results showing that there is obviously a very good correlation between the two machines. A calculated correlation equation using all the individual test results, except for a few to be discussed later, gave the equation $P = 0.88N + 7.07$ ($r = 0.99$). This is an excellent correlation, and the slope 0.88 is very close to the theoretical value of 0.857 calculated as explained earlier. This curve is shown as a solid line in Fig. 5. Theoretically, the relationship between the two testers should be a straight line. Experiments show that a slightly better correlation can be achieved by using the exponential formula for a curvilinear correlation.

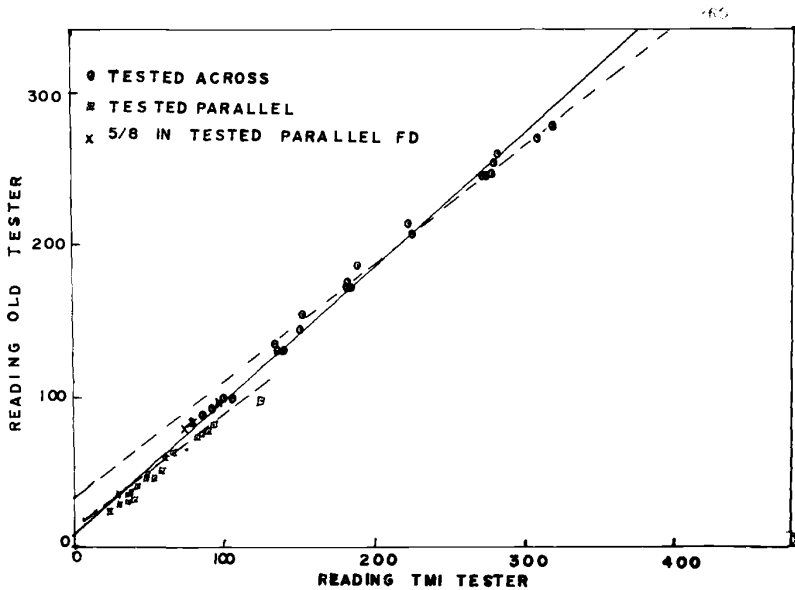


FIG. 5—Flexure test—TMI tester versus old tester.

Inspection of the graph suggests that the across the fiber and parallel to the fiber tests may fall on different curves. Calculating separate correlations for the two sets of data, we get the equations

$$P = 0.79N + 28.67 \quad (r = 0.97) \text{ tests across}$$

$$P = 0.69N + 15.55 \quad (r = 0.91) \text{ tests parallel}$$

These are still excellent correlations, but the parallel tests are not quite as consistent. These curves are shown as dotted lines in Fig. 5.

Inspection of the data in Table 2 shows some unusual results in the data for a 15.88-mm ($\frac{5}{8}$ -in.) board tested parallel. On 15.88-mm ($\frac{5}{8}$ -in.) Type X, where 79 sets of specimens were tested, the face-up and face-down tests have the same average when tested by the present tester. However, the face-up tests average higher and the face-down tests slightly lower on the new tester. The same trend is noticeable on the other types of 15.88-mm ($\frac{5}{8}$ -in.) board tested, although there is more variation because of the smaller number of specimens tested. The face-down data do not fit the correlation curves and were omitted in calculating the correlation equations.

All of the 15.88-mm ($\frac{5}{8}$ -in.) board tested in this study contained glass fibers. As mentioned previously, board containing glass fiber behaves differently in a flexure test than board containing only paper fiber. One of the advantages of the constant strain machine is that a stress-strain curve can be recorded. Figure 6 shows the stress-strain curves for several flexure tests. It is particularly obvious in the case of 15.88-mm ($\frac{5}{8}$ -in.) Type X that the face-up and face-down curves are quite different. It may be that the action of the constant strain machine is revealing a difference that is not shown by the more violent action of the shot-bucket machine. A tentative explanation is that glass fiber distribution is not perfectly uniform through the thickness of the board. Additional data will be needed to clarify this point.

The stress-strain diagram gives considerably more information about the product tested than the single-value result, which is all that can be obtained from the present unit:

1. The test will show the actual value at which the board first cracks. The primary purpose of a flexural strength specification is to ensure that the board has enough strength to withstand normal handling. The force required to crack the core is probably a more practical measure of board utility than the force required to pull it apart after it is cracked.

2. The slope of the first part of the stress-strain curve is a measure of the flexibility of a board. Numerous attempts have been made to measure this property by measuring load versus deflection on the constant stress type of tester, but it is not practical on this type of machine. The area under the curve measures the total work required to break the board or the toughness of the board.

The stress-strain curve gives an accurate measure of these properties; and with

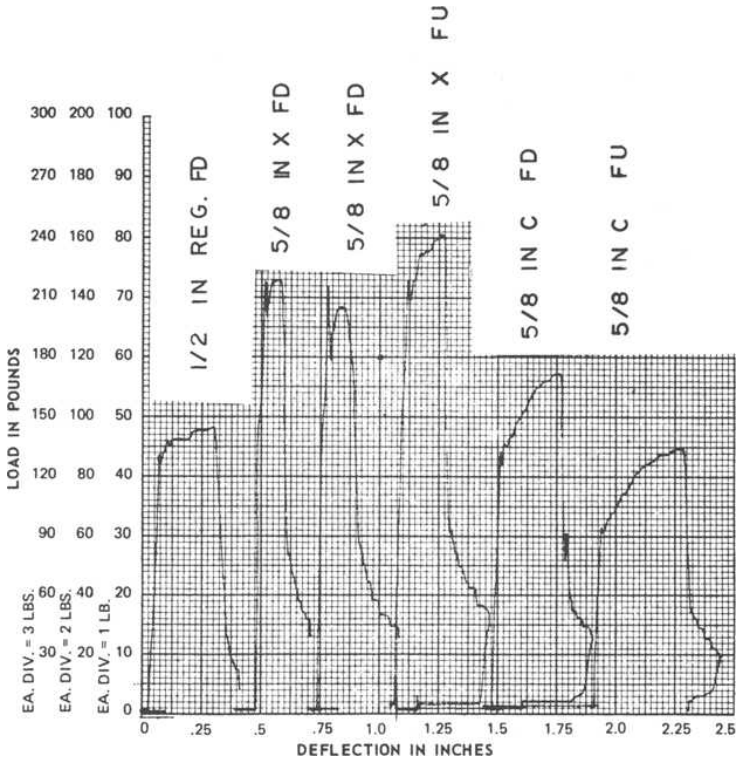


FIG. 6—Flexure test—stress-strain curves.

a good evaluation, it may be possible to learn to control them better and set meaningful specifications for them.

3. The complete stress-strain curve gives additional information about core properties. As noted previously, it may show something about fiber distribution, and additional knowledge about core properties may give us a chance to improve them.

The timesaving from running flexure tests on a constant strain machine is substantial. For 15.88-mm ($\frac{5}{8}$ -in.) wallboard, the specifications are 667 N (150 lb) across and 222 N (50 lb) parallel. For a full sample of four specimens, the minimum load application time is $6\frac{2}{3}$ min, and it can be substantially greater. On the constant strain machine, the total testing time is only a minute or two per sample regardless of the load required.

In view of the good correlation between the two types of machines, we do not believe that any plant or testing agency would have any difficulty in devel-

oping a correlation that would permit them to test on a constant strain machine and certify that the products would meet the appropriate specifications when tested according to ASTM C 473.

In view of the increased accuracy and the additional information that can be obtained by using the constant strain machine, we would recommend that ASTM Committee C-11 on Gypsum and Related Building Materials and Systems consider adopting it as a standard device for conducting strength tests on gypsum board. Some additional testing on various types of board from different plants would be required to determine the best values for specifications for tests run on the new machine.

Nail Pull Resistance Test

The constant strain machine can be readily adapted for running the nail pull resistance test. No change in sample size is required. The only change made in the equipment was the slot in the sample holder referred to previously. This makes inserting and removing a sample quicker and more convenient but is not absolutely necessary.

Table 4 shows comparative data obtained from plant tests on various types of board. Note that the standard deviations are very similar on the two machines. Possibly the constant strain tester is slightly more precise, but it is apparent that most of the variation is in the products.

The correlation equation for this data is $P = 0.98N + 6.3$ ($r = 0.93$). The correlations for any one type of board are not as good. For example, on 12.7-mm (1/2-in.) regular wallboard, the correlation coefficient is only 0.48. This is enough to show a significant relationship but not enough for prediction. The explanation is that this product is reasonably uniform, and most of the variations in each set of test results are random variations around an average. These variations will not necessarily correlate. When several types of board are included, there is a wider range of values and the averages for the various types of board do correlate well.

The slope of the correlation curve is very close to unity indicating that differences in results are the same on both machines. The absolute values differ slightly, and there is a constant term in the correlation equation because the shot-bucket machine always tends to overshoot the maximum value as explained previously. The maximum force occurs just as the paper starts to tear, but there is a noticeable delay in the fall of the lever arm on the shot-bucket machine before the sample fails completely.

The minimum values that should be specified for a constant strain testing machine to be equivalent to the ASTM C 473 specifications are shown in Table 5.

It would probably make little practical difference if specifications by a constant strain machine were rounded off at 20 N (4.5 lb) below the present specifications.

The timesaving on this test is also substantial. A minimum test of 355 N (80

TABLE 4—Nail pull resistance tests.^a

Product, in.	Number of Tests	Old, lb		New, lb		Correlation Coefficient
		Average	Standard Deviation	Average	Standard Deviation	
1/2 regular	40	89.6	4.7	85.4	4.4	0.48
1/2 other	12	108.2	8.0	103.1	7.6	0.47
3/8 Type X	24	105.8	5.2	102.5	5.3	0.89
3/8 other	12	110.1	17.0	103.7	16.0	0.70
Less than 1/2	12	87.9	11.6	84.4	9.3	0.97

^a1 in. = 25.4 mm and 1 lb = 4.448 N.

TABLE 5—Minimum values that should be specified for a constant strain testing machine to be equivalent to ASTM C 473 specifications.

Board Thickness		ASTM Specification		TM Specification	
mm	in.	N	lb	N	lb
6.4	¼	178	40	153.1	34.4
8	⅜	222	50	198.5	44.6
9.5	⅜	267	60	243.4	54.7
13	½	356	80	335.1	75.3
16	⅝	400	90	380.5	85.5

lb) on 12.7-mm (½-in.) wallboard requires a minimum of 6⅔-min shot flow time, for the five specimens in a sample, on the shot-bucket machine. On the constant strain tester, the time is only 1 or 2 min regardless of the load required.

The use of the stress-strain curve recorder does not give much additional information with this test. However, the timesaving that is possible would recommend the adoption of the constant strain type of tester by manufacturing plants, testing agencies, and ASTM.

Core, End, and Edge Hardness Tests

These tests can also be readily run on the constant strain machine. Equipment and technique are essentially the same.

Table 6 shows the results of comparative tests in a plant on various types of boards. Since this test does not vary with thickness, there is no need to separate the data by thickness. The correlation equation is $P = 1.03N + 3.6$ ($r = 0.92$).

The standard deviations are similar with possibly a little better uniformity on the constant strain machine. The slope of the correlation curve is close to unity, again indicating that differences in results are equal on the two machines. The constant term shows a small difference in absolute values with the constant stress machine giving a larger numerical value for the same reasons as explained previously.

The reason for the higher reading is also clearly shown on a stress-strain diagram. Figure 7 shows a number of curves for this test. In most cases, the force required for penetration rises rapidly at first and then levels off. However, on the constant stress machine the load applied would continue to increase until the 12.7-mm (½-in.) penetration was achieved. The constant strain machine gives a more accurate or more realistic value.

The stress-strain curves also show that there can be numerous small-scale variations in core hardness. Most likely these represent small voids or lumps in the core. We believe that these local variations can cause some of the extreme variation between specimens that can occur in the nail pull resistance test. While these variations can affect the shape of the curve, in most cases the final value is quite consistent.

TABLE 6—Core, end, and edge hardness tests.^a

Test	Number of Tests	Machine Reading				Correlation Coefficient
		Old		New		
		Average, lb	Standard Deviation	Average, lb	Standard Deviation	
Core hardness	87	29.8	5.8	25.5	4.6	0.80
End hardness	74	28.6	7.2	23.0	6.1	0.86
Edge hardness	77	44.7	17.4	39.9	15.0	0.90

^a1 lb = 4.448 N.

The use of the stress-strain recorder provides a method for measuring the penetration of the pin with greater accuracy than is possible on the constant stress machine. However, the shape of the curve indicates that there would be no great loss in accuracy if the penetration was judged by observing a mark on the pin as is common practice with the constant stress machine.

An exception to the uniformity of this test was noted on an unusually hard Sample H (Fig. 7). On this sample the readings did not level off until about 19.05-mm ($\frac{3}{4}$ -in.) penetration was achieved. This sample had small-scale variations in hardness and would have been judged quite variable when tested at 12.7-mm ($\frac{1}{2}$ -in.) penetration. At 19.05-mm ($\frac{3}{4}$ -in.) penetration, the results were quite uniform. The stress-strain curve could provide considerably more information about a sample than the one-point test of the constant stress machine.

The timesaving on this test is not as great as on the other two. A minimum specification test takes about 15 s per specimen on the constant stress machine. On the constant strain machine, the test is conveniently run at 51 mm/min (2 in./min), which gives a 15-s testing time per specimen for any load.

In Fig. 7 Sample I shows a test of edge hardness. It is common in this industry to use some procedure to increase the hardness of board core at the edges. This particular sample shows considerable variation, particularly when penetration is increased beyond 12.7 mm ($\frac{1}{2}$ -in.). It is quite possible that plants could do a good deal to evaluate the operation of their edge hardness device by using this test and the stress-strain recorder.

The probability of greater accuracy and the additional information available from a stress-strain curve would indicate the advantage of using a constant strain rather than a constant stress testing machine for this test.

In practice we believe that the test is not used very widely because a sample that meets the nail pull resistance specification will substantially exceed the core and end hardness specification. Further study and development of this test is warranted particularly if it is done on a constant strain machine.

Comparison of Nail Pull Resistance and Core Hardness Tests

Consideration of what is done to the core when conducting the two tests indicates that they are somewhat similar. True, the pin used for the nail pull resistance test has a larger diameter and must tear through the paper before it crushes the core, but the basic action is to crush the core by pushing a pin into it.

Two variable correlations were calculated for the various types of products where both tests had been run on samples from one board. Results are shown in Table 7. On individual products little correlation was shown. As explained previously this is because a single product is reasonably uniform and the variations in test results are random variations around an average which has no reason to be correlated.

Where a wider range of products was used, particularly the 12.7-mm ($\frac{1}{2}$ -in.)

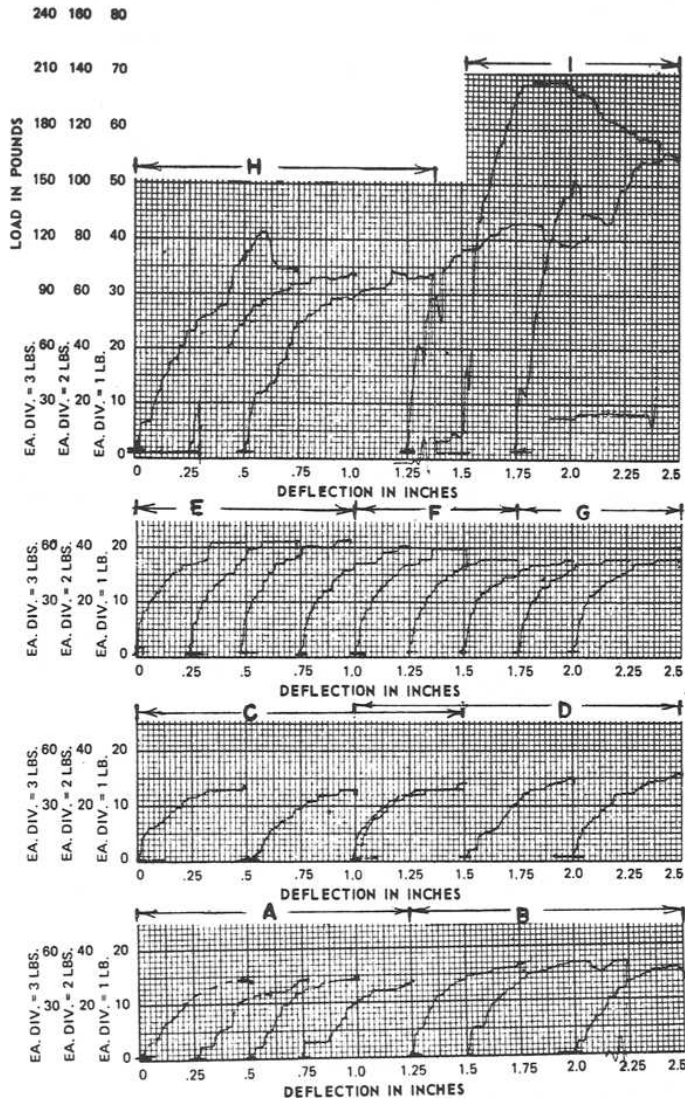


FIG. 7—Core hardness stress-strain curves.

TABLE 7—Two-variable correlations nail pull and core hardness.^a

Type Board, in.	Correlation Coefficient
½ regular	0.35
½ other	0.87
¾ Type X	0.18
¾ other	0.59
Less than ½	0.36
All	0.65

^a1 in. = 25.4 mm.

types, better correlation was obtained. However, when all the data were combined, poorer correlation was obtained than on 12.7-mm (½-in.) types alone. This is because the nail pull resistance test also varies with thickness, and another variable is introduced.

An additional evaluation was made by running a three-variable correlation using nail pull resistance as the dependent variable and core hardness and flexural strength as independent variables. The correlation coefficients are shown in Table 8.

Flexural strength varies primarily with thickness. It also varies with the tensile strength of the paper on the side tested, but the paper used on any one product is reasonably uniform. The correlation coefficients on individual products show slight increases indicating that there may be some correlation with the variations in paper strength, but the changes are hardly significant.

The combined correlation coefficient does increase significantly showing that nail pull resistance can be predicted reasonably well from core hardness and flexural strength. Since the major component of flexural strength variation is thickness, the correlation is really with core hardness and thickness. There may be a small effect of paper strength, but it is confounded with the effect of thickness.

A logical conclusion is that the core hardness and nail pull resistance tests give essentially duplicate information. The core hardness test has the potential

TABLE 8—Three-variable correlations nail pull versus core hardness and transverse strength.^a

Type Board, in.	Correlation Coefficient
½ regular	0.45
½ other	0.88
¾ Type X	0.33
¾ other	0.66
Less than ½	0.68
All	0.84

^a1 in. = 25.4 mm.

of giving more information about the product if run on a constant strain machine and is less time consuming to run on the present testing machine.

Conclusions

The testing machine commonly used on gypsum board is specified because it is something that was easy to build in the early days of the industry. It is now out-moded, very slow, laborious, and possibly dangerous to use. Now that more sophisticated machines are commercially available they should be considered for use in gypsum board. The use of a stress-strain recorder with a constant strain type of machine could give more information from the test procedures than the presently approved machine.

Consideration should also be given to what the tests tell a user about the utility of a product. The nail pull resistance and core hardness tests give very similar information. Possibly other types of tests should be devised to measure other properties of gypsum board.