RP561

THE COMPRESSOMETER, AN INSTRUMENT FOR EVALUATING THE THICKNESS, COMPRESSIBILITY, AND COMPRESSIONAL RESILIENCE OF TEXTILES AND SIMILAR MATERIALS

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ABSTRACT

The instrument described in this paper provides a convenient means for measuring the thickness and the change in thickness of a textile or similar material when it is subjected to increasing or decreasing pressures. The foot of the instrument can be lowered or raised by means of a rack and pinion acting through a helical spring. The pressure applied to the specimen by the foot is indicated on a dial micrometer and the corresponding thickness of the specimen on a second dial micrometer. Readings are taken under increasing pressures and then under decreasing pressures.

Curves for the compression and recovery of several materials are shown. Definitions are proposed for the terms thickness, compressibility, and compressional resilience as applied to textiles. The results of tests on rug underlays, blankets, felts, on knit, woven, and pile fabrics, and on sheet rubber and paper are given.

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I. INTRODUCTION

The thickness of textiles and many other similar materials depends greatly upon the pressure applied to the surfaces of the specimen. It decreases as the pressure is increased. The thickness of these materials is purely a matter of definition. Many definitions of thickness and methods for measuring thickness are published. The resulting confusion is described by Emley.[1] He points out the need for general agreement on one method and proposes a specification for a standard thickness gage and a standard definition of thickness.

The purpose of this paper is to describe an instrument for measuring the thickness under a known pressure which can be increased or decreased gradually and continuously.[2] Using this instrument the thickness under a given pressure can be measured. The change in thickness under either increasing or decreasing pressure can also be

[1] W. E. Emley, Measurement of Thickness of Textiles and Similar Materials, Am. Soc. Testing Materials 1931. Preprint Report of Committee B-1 on Methods of Testing, pp. 23–27.

[2] In a paper entitled "An Instrument for Measurement of Thickness of Compressible Solids," J Sci. Instruments, vol. 6, pp, 382–385, 1929, M. C. Marsh has described an instrument suitable for measuring the thickness at a known pressure. The pressure may be varied by increments in a range between 1 mg and 100 g per square centimeter.

measured. The compressibility and compressional resilience of the material are computed from these data. These properties affect the sensations that contribute to what is usually called the softness or hardness of cloth.

Curves for the compression and recovery of several materials are shown. Definitions are proposed for the terms thickness, compressibility, and compressional resilience as applied to textiles. The results of tests on rug underlays, blankets, felts, on knit, woven, and pile fabrics, and on sheet rubber and paper are given.

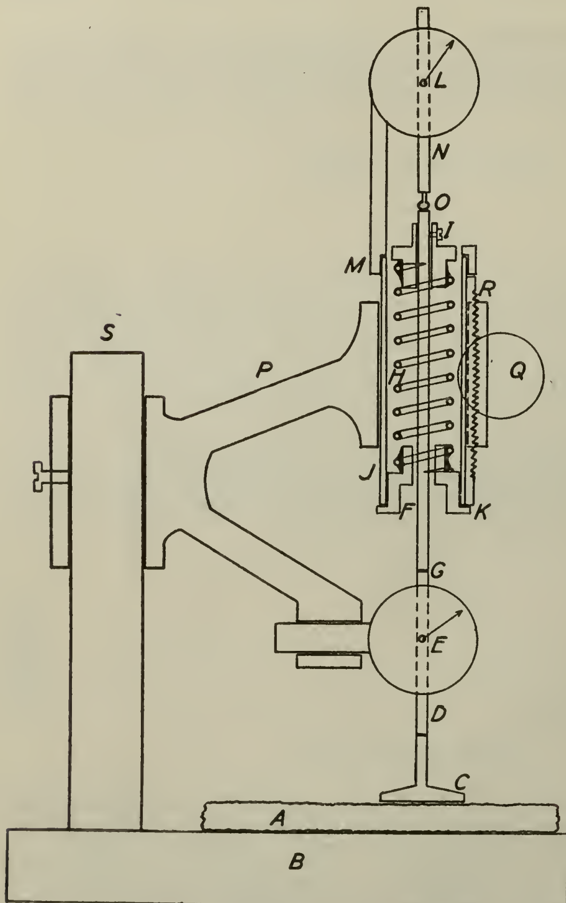

Figure 2.—*Schematic diagram of compressometer.*

II. THE INSTRUMENT

The instrument is shown in figure 1. A schematic diagram is shown in figure 2. The specimen, *A*, is placed upon the anvil, *B*. The foot, *C*, is circular in shape and 1 inch in diameter. It is fastened to the bottom of the spindle, *D*, of the lower dial micrometer, *E*. The lower surface of the foot is plane and parallel to the upper surface of the anvil. The rod, *F*, is fastened to the top of the spindle at *G* and to the top of a helical spring, *H*, at *I*. The bottom of the spring is fastened to the tube, *J*, at *K*. The upper dial micrometer, *L*, is fastened to the top of the tube at *M*. The spindle, *N*, of the upper dial micrometer rests on the top of the rod at *O*. The tube may be moved up or down relative to the frame, *P*, by turning the knob, *Q*, of the rack and pinion, *R*. By turning the knob the foot may be lowered upon the specimen. The pressure which is applied to the specimen by the foot may be ascertained from the upper dial reading and a calibration curve of the spring. The upper dial indicates the elongation of the spring. The distance between the face of the foot and the anvil; that is, the thickness of the specimen, is indicated on the lower dial. Each dial is graduated to read directly to 0.001 inch.

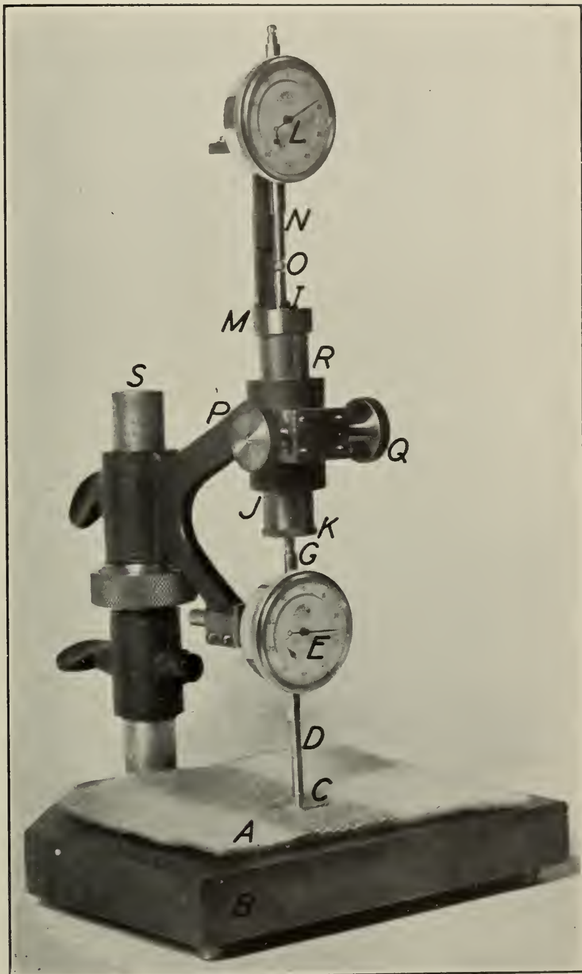

FIGURE 1.—*The compressometer.*

To calibrate the spring, the frame of the instrument is rotated through 180° about the vertical post, *S*. The foot is placed above the center of one pan of a balance. A load is placed on the other pan. The foot is lowered until the two pans are in balance and the elongation of the spring is read on the upper dial. The foot is lowered beyond the balanced position and then is raised until the two pans are again in balance. The elongation of the spring is read on the upper dial. The difference between the two upper dial readings is due to friction. Similar readings are taken for various loads. The spring elongations are plotted against the pressure; that is, the load divided by 0.7854 square inch which is the area of the foot.

The results are shown in figure 3 where curve *A* is obtained when the foot is lowered and curve *B* is obtained when the foot is raised.

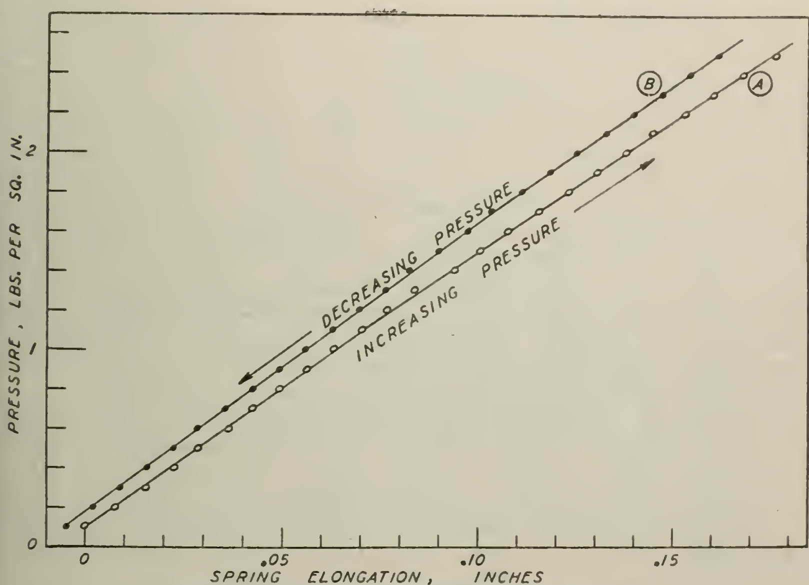

FIGURE 3.—*Calibration curves of helical spring.*

Curves *A* and *B* differ from each other because of friction in the moving parts of the dial micrometer. The friction gradually increases from the equivalent of about 0.1 lb./in.^{2} at low pressures to about 0.2 lb./in.^{2} at high pressures. It is probably high in the present instrument and could be reduced by changes in the design. For the present instrument where the friction in the moving parts is appreciable, curve *A* is used when the pressure on the specimen is increased, while curve *B* is used when the pressure is decreased.

The small helical spring of the lower dial micrometer was removed because it would alter the calibration curves when specimens of various thicknesses are measured.

The lower dial micrometer was calibrated for periodic and hysteresis errors. In the calibration a load of 1 pound was placed upon the spindle. The periodic error was less than 0.0005 inch. The hysteresis error was less than 0.0001 inch.

The periodic and hysteresis errors of the lower dial micrometer were also determined under the conditions in which the instrument is used. The periodic error was practically the same as that determined on the dial alone. The hysteresis error, however, increased from 0.0001 inch at a pressure of 0.1 lb./in.^{2} to 0.0003 inch at a pressure of 2 lb./in.^{2}.

The elastic deformation of the frame of the instrument when the pressure exerted by the foot is increased or decreased 1 lb./in.^{2} is about 0.0002 inch. The maximum departure from parallelism of the foot from the anvil is about 0.0003 inch.

These errors are negligible and were neglected in reporting the results.

III. TEST PROCEDURE

The data for the loading and unloading of a specimen are obtained as follows. The specimen is placed on the anvil without tension. The foot is lowered upon the specimen by means of the rack and pinion and the pressure is gradually increased. When the pressure reaches 0.1 lb./in.^{2}; that is, when the upper dial indicates the spring elongation given by curve *A* at the pressure of 0.1 lb./in.^{2}, the thickness; that is, the lower dial reading, is recorded, the ten thousandth place being estimated. Similar simultaneous observations are made at seven other pressures up to 2.0 lb./in.^{2}. The pressure is then gradually reduced and observations are made at the same pressures during unloading, the upper dial indicating the spring elongations given by curve *B* at the various pressures. The observations are made in rapid succession. With a little practice an observation can be made in about 10 seconds. The time required to obtain the data for the compression and recovery cycle of a specimen is approximately 3 minutes.

Curves of the compression and recovery cycle of several materials are shown in figure 4. The curves are drawn through the average of the values obtained at three or more places on each specimen. It is evident that the variations of the observed values of any material are mainly attributable to differences in thickness of the specimens at the places measured. The curves of different materials show great differences.

IV. DISCUSSION AND APPLICATION

In order to evaluate the thickness of fabrics and similar materials and to evaluate the properties of compressibility and compressional resilience, it is necessary to define each in terms of measurable properties. The definitions must of necessity specify the size and shape of the foot and the pressure exerted by the foot. The pressure of 1 pound per square inch proposed by Emley [3] is used in the tentative definition of standard thickness. The definition for compressional resilience of textiles requires the selection of a standard pressure range. The range from 0.1 to 2.0 lb./in.^{2} is suggested. The definitions which follow are for textile fabrics, but may be applicable to other materials.

It is assumed that unless otherwise specified tests made with the compressometer will be carried out on specimens that are in equilibrium with an atmosphere of 65 percent relative humidity at a temperature of 70° F., the standard conditions for textile testing.

[3] See footnote 1, p. 705.

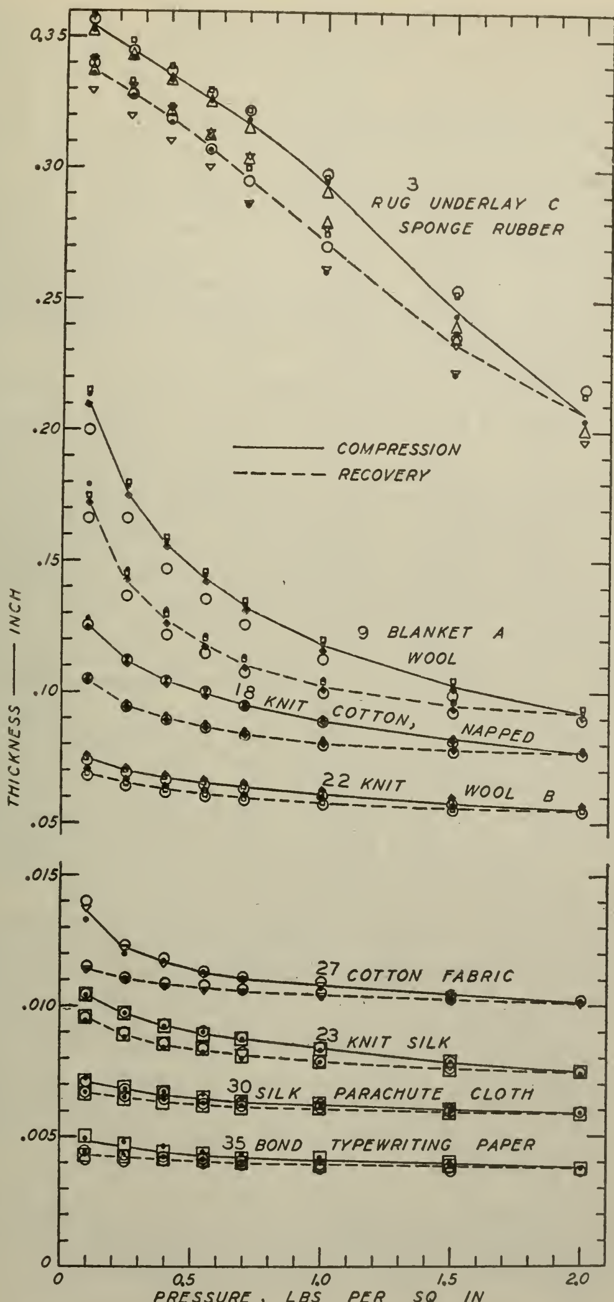

FIGURE 4.—*Typical curves of compression and recovery.*

The following conditions of test are specified. (1) The specimen shall be placed without tension upon a horizontal plane surface, the anvil; (2) a circular foot, 1 inch in diameter whose surface is plane and parallel to that of the anvil shall be brought to bear upon the specimen with gradually increasing pressures up to 2.0 lb./in.^{2} and then gradually decreasing pressures; (3) readings shall be taken at pressures 0.1, 0.2, 0.35, 0.5, 0.75, 1.0, 1.5, and 2.0 lb./in.^{2}; and (4) the time interval between two consecutive observations of points on the curve of compression or recovery shall be not less than 10 nor more than 15 seconds. Then:

The thickness of the specimen is the distance between the foot and the anvil when the pressure has been increased to a stated amount.

The standard thickness of the specimen is the thickness when the pressure is increased to 1 lb./in.^{2}.

The compressibility of the specimen is the ratio of the rate of decrease in thickness at a pressure of 1 lb./in.^{2} to the standard thickness.

The compressional resilience of the specimen is the amount of work recovered from the specimen when the pressure is decreased from 2.0 to 0.1 lb./in.^{2} expressed as a percentage of the work done on the specimen when the pressure is increased from 0.1 to 2.0 lb./in.^{2}.

The data for the numerical expression of these properties can be readily obtained with the instrument described. The area under the curve of compression bounded by horizontal lines at the initial and final thickness is equal to the work done on the specimen during compression. If simultaneous readings of thickness and pressure are taken at pressures 0.1, 0.2, 0.35, 0.5, 0.75, 1.0, 1.5, and 2.0 lb./in.^{2} then the work done can be computed by means of the formula $W = 0.025\ (6A+5B+6C+8D+10E+15F+20G-70H)$, where A, B, C, D, E, F, G, and H are the thicknesses in inches at the above pressures, respectively. This formula is based upon the assumption that the segments of the curve between two consecutive pressures are straight lines. The same formula gives the work recovered when the thicknesses from the curve of recovery are substituted.

The numerical values of the properties defined above appear to be useful criteria of the "handle" or "feel" of fabrics when they are squeezed between the fingers. Together with the coefficient of friction and the flexural work and flexural resilience, for which methods of evaluation have been described elsewhere,[4] they offer a means for describing the tactile and kinaesthetic characteristics of farbrics quantitatively. However, pending further consideration of the relation between the physical stimuli and the sensory responses,[5] it will suffice simply to tabulate the values which were obtained. They are given in table 1.

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[4] A. A. Mercier, Coefficient of Friction of Fabrics. B.S. Jour. Reserach, vol. 5 (RP196), pp. 243–246, 1930. H. F. Schiefer, The Flexometer, An Instrument for Evaluating the Flexural Properties of Cloth and Similar Materials. B.S. Jour. Research, vol. 10 (RP555), pp. 647–657, May 1933.

[5] Wm. D. Appel and the author are attempting to enumerate and define what may be called the kinaesthetic and tactile characteristics of cloth and the related physical properties.

TABLE 1.—*Results of tests* [1]

No.	Description of specimen	Total compression pressure range of 0.1 to 2.0 lb./in.[2]	Standard thickness	Compressibility	Compressional resilience	
						Average deviation
		Inch	*Inch*	*In.²/lb.*	*Percent*	*Percent*
1	Rug underlay A, cotton and paper	[2] 0.290	[2] 0.357	[3] 0.32	[4] 35	[4] 2
2	Rug underlay B, jute	.058	.268	.10	31	1
3	Rug underlay C, sponge rubber	.146	.292	.28	81	4
4	Rug underlay D, sponge rubber	.0075	.1635	.02	74	1
5	Sheet rubber A, pure gum	.003	.1915	.006	86	4
6	Sheet rubber B, packing	.0015	.153	.003	74	1
7	Felt A	.038	.1395	.09	35	1
8	Felt B	.0195	.075	.09	37	1
9	Blanket A, wool	.118	.117	.38	54	1
10	Blanket B, wool	.077	.116	.27	48	1
11	Blanket B after 1 washing	.097	.134	.27	42	1
12	Blanket B after 3 washings	.105	.145	.28	36	1
13	Blanket B after 5 washings	.103	.144	.27	36	1
14	Blanket C, cotton warp, wool filling	.081	.123	.25	45	1
15	Blanket C after 1 washing	.101	.145	.27	39	1
16	Blanket C after 3 washings	.101	.148	.26	36	2
17	Blanket C after 5 washings	.096	.144	.26	36	1
18	Knit cotton, napped	.0485	.089	.21	43	1
19	Knit cotton	.0115	.0415	.10	39	2
20	Knit cotton and wool	.0195	.0475	.14	45	1
21	Knit wool A	.0345	.0825	.16	53	1
22	Knit wool B	.020	.061	.13	55	1
23	Knit silk	.003	.0085	.14	56	1
24	Knit rayon	.002	.014	.06	56	4
25	Wool pile fabric	.025	.137	.06	42	2
26	Mohair pile fabric	.0105	.149	.02	48	2
27	Cotton fabric	.0035	.011	.08	41	2
28	Cotton balloon cloth	.0045	.0065	.15	28	5
29	Wool fabric	.003	.015	.07	66	4
30	Silk parachute cloth	.0015	.006	.06	67	5
31	Rayon fabric	.0015	.0095	.05	51	2
32	Weighted silk fabric	.002	.0125	.07	47	2
33	Weighted silk fabric, weighting removed chemically	.002	.011	.06	55	2
34	Filter paper	.002	.0085	.07	53	3
35	Bond typewriting paper	.001	.004	.06	56	9

[1] The results in the table are the average of 3 determinations except for specimens nos. 3, 4, and 9, which are the average of 7, 4, and 4 determinations, respectively.
[2] The total compression and standard thickness are reported to nearest 0.001 inch for those materials having a total compression greater than 0.05 inch and to nearest 0.0005 inch for those materials having a total compression equal to or less than 0.05 inch.
[3] The compressibility is reported to nearest 0.01 inch[2] per pound except specimens nos. 5 and 6, which are reported to nearest 0.001.
[4] The compressional resilience and average deviation are reported to the nearest percent.

The total compression in the pressure range of 0.1 to 2.0 lb./in.^{2} and standard thickness are reported to nearest 0.001 inch for those specimens which have a total compression greater than 0.05 inch and to nearest 0.0005 inch for those specimens which have a total compression equal to or less than 0.05 inch. The compressibility is reported to nearest 0.01 inch^2 per pound except specimens nos. 5 and 6, which are reported to nearest 0.001. The compressional resilience is reported to the nearest percent. The average deviation of the compressional resilience is also given in the table. It is 1 percent for 18 specimens, 2 percent for 9 specimens, and greater than 2 percent for the remaining 8 specimens. The average deviation is large, 9 percent for bond typewriting paper, for specimens which have a small total compression. Rug underlay *C* of sponge rubber appears to be an exception. For it the average deviation of 4 percent is probably attributable to the nonuniformity of the underlay. (See fig. 4.)

The following observations are of interest. The compressibility of the blanket is roughly six times that of the silk parachute cloth and the bond typewriting paper. The order of increasing compressional resilience is different from that of compressibility. For the specimens measured, it ranges from 28 to 86 percent. As was to be expected, the rubber specimens have the highest compressional resilience. The silk, wool, rayon, cotton, and jute specimens come next in order. The increase in thickness and total compression and the decrease in compressional resilience of the blankets after washing is marked. The difference between a weighted silk and the same silk after removal of the weighting is also marked.

The compressional resilience of the specimens of pure gum sheet rubber and of sheet rubber packing are lower than might be expected. Applying corrections for the instrumental errors to the results for these specimens decreases the compressional resilience a few percent. The explanation for the low compressional resilience of these rubber specimens therefore must be sought elsewhere. The conditions of the surfaces of the rubber specimens, whether clean, dirty, or lubricated affect the curves of compression and recovery. The total compression and the compressional resilience for the pressure range of 0.1 to 2.0 lb./in.^{2} were found to be lower for specimens with clean surfaces than for the same specimens with the surfaces lubricated with graphite. The total compression and the compressional resilience for the above pressure range were found to increase with the thickness of the specimen. The total compression for the second compression cycle was found to be smaller and the compressional resilience was found to be greater than for the first cycle when the second cycle was obtained without removing the specimen from the instrument. The results of tests are given in table 2 for two specimens of pure gum sheet rubber.

TABLE 2.—*Results showing effect of thickness and condition of surface of pure gum sheet rubber on total compression and compressional resilience*

Specimen No.	Condition of surface	Standard thickness	Total compression pressure range of 0.1 to 2.0 lb./in.^{2}	Compressional resilience
		Inch	*Inch*	*Percent*
1	Clean, first cycle	0.389	0.0018	64
1	Clean, second cycle	.389	.0013	79
1	Lubricated with graphite	.389	.0032	77
2	Clean, first cycle	1.08	.0195	90
2	Clean, second cycle	1.08	.0175	95
2	Lubricated with graphite	1.08	.0210	92

The shape and size of the foot and the dimensions of the rubber specimen relative to them probably affect the magnitude of the compressional resilience. The manner in which these affect the compressional resilience is beyond the scope of this paper.

The present instrument was designed primarily for the measurement of relatively thick textiles, such as blankets and napped underwear. The results shown in tables 1 and 2 and figure 4 indicate that it can be used satisfactorily for measuring thin fabrics, paper, and rubber. However, measurements of such materials should be significant to the fourth decimal place and an instrument accurate to 0.0001 inch should therefore be used. Moreover, to measure to this degree of precision, the following precautions must be observed: (1) The instrument must be constructed with greater rigidity to reduce the elastic deformation of the frame to less than 0.0001 inch; (2) tolerances consistent with this degree of precision must be set for the parallelism and planeness of the surfaces of the anvil and foot; and (3) the periodic and hysteresis errors of the lower dial micrometer must be determined and corrections consistent with this degree of precision must be applied.

The results given indicate what may be expected from the use of the instrument. From the data available it would seem that the compressibility depends mainly upon the structure of the specimen whereas the compressional resilience depends upon the kind of material and the structure of the specimen.

Note.—Drawings of the instrument showing the details of construction may be obtained from the textile section of the Bureau of Standards.

Washington, March 16, 1933.