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A Comparative Study of the Tinius Olsen and Peirce Stiffness Testers

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Introduction

The hand of a fabric is that complex quality which produces a psychological impression from the stimuli obtained in the touching, squeezing, or otherwise handling of the fabric. These stimuli reflect such properties as flexibility, compressibility, extensibility, resilience, density, surface friction, surface contour, and thermal characteristics [3]. Being nonspecific in nature, hand is quite difficult to measure quantitatively, but attempts have been made. As most textile technologists agree, flexibility is perhaps the most important and the easiest of these properties to measure in the laboratory; the present study is concerned with the measurement of this property.

Not only are stiffness measurements a good index to the hand of a fabric, but they are also a means of determining the effect of finishing operations and chemical treatments on the flexural properties of a fabric. Many of the fabrics used by the Army are chemically treated to provide resistance to fire, water, weather, mildew, and shrinkage. These treatments in many cases consist of surface coatings to the fabrics which result in fiber-to-fiber bonding and give the fabric a harsher hand and an increased stiffness. To control this increase in stiffness within reasonable limits, stiffness values are included in federal specifications for many treated fabrics.

In 1951 a study was made by Abbott [1] in which the subjective evaluation of stiffness was used as the standard with which to compare the results obtained from five laboratory methods of measuring stiffness. The five methods studied were the Peirce cantilever test, the heart-loop test, the Schiefer Flexometer, the Planoflex, and the M.I.T. Drapeometer. The analysis of the results obtained indicated a significant correlation for four of the five methods, with the Peirce cantilever test yielding the best correlation of the four. It was also stated in this study that the Peirce cantilever test is the most convenient to carry out in the laboratory. However, since Abbott in his work did not include the Tinius Olsen tester, which is used extensively by the Army in its specification work and is an accepted A.S.T.M. stiffness test method [2], the present study was conducted to determine the relative merits of these two instruments.

The study was designed to compare the two machines in the following respects: (*a*) similarity or relationship between average measurements of the two instruments; (*b*) precision or reproducibility of stiffness measurements on any one fabric (a good apparatus should produce a small relative spread between the measurements on one fabric); (*c*) sensitivity or relative ability to discriminate among fabrics of varying degrees of stiffness (good sensitivity means that different degrees of stiffness are registered by a spread in the values greater than that attributable to experimental error); (*d*) influence of operator differences on the results; (*e*) ease of operation and speed of obtaining results (if the measurements obtained by both machines are equally reliable, reproducible, and discriminating, then these two factors should be used to judge between the two instruments).

Test Methods and Materials

The materials selected for testing were fifteen cotton fabrics representative of a cross section of weights, weaves, textures, yarn numbers, and other constructional factors. Ten specimens were cut in the warp direction only from each of these fabrics. To eliminate as many variables as possible, the samples were cut so that the same yarns were in both the Tinius Olsen and Peirce samples. The fabrics had been previously desized and alkali-boiled so that the additional variables due to uneven application of sizing would be eliminated.

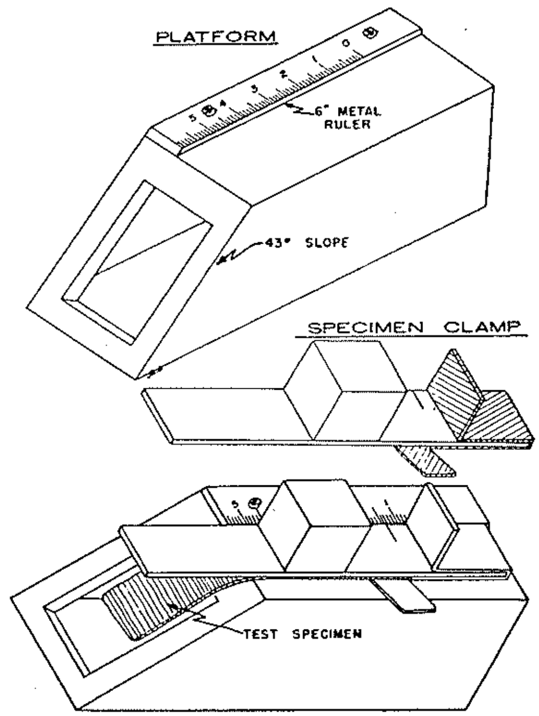

FIG. 1. *Peirce stiffness tester.*

The Peirce cantilever tests were made on a commercially available instrument [4] shown in Figure 1. In essence, this instrument allows a sample to bend under its own weight to a fixed angle when projected as a cantilever. Mechanically, the fabric sample represents a cantilever beam which is uniformly loaded by its own weight and bends downward until its end reaches a line which makes an angle of 43° with the horizontal. The longer the projected length, the stiffer the fabric. The apparatus consists of a metal stand with the front tapered off at a 43° angle and a specimen clamp with a 1-in. brass cube screwed to the top. A metal ruler calibrated in tenths of an inch is fastened to the platform at the top of the stand and is used to measure the length of the overhanging sample. A sample 6 in. by 1 in. is placed under the specimen clamp, the end of the sample co-

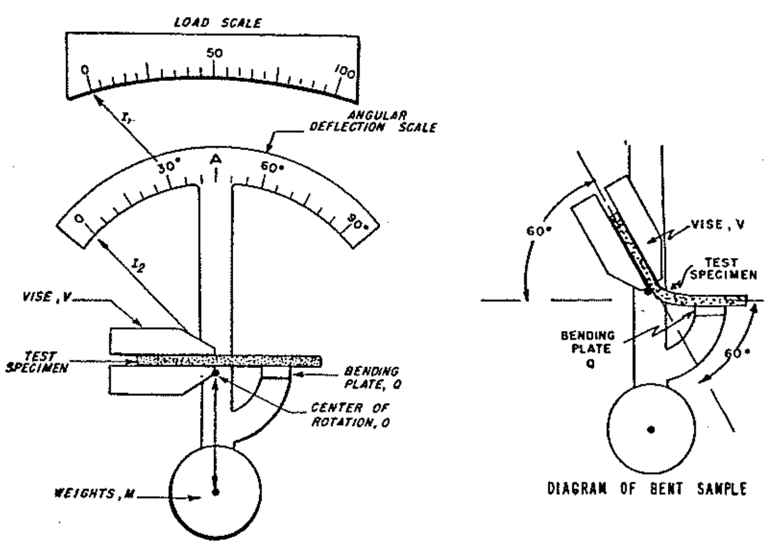

FIG. 2. *Mechanical system of Tinius Olsen stiffness tester.*

inciding with the end of the clamp. The whole assembly, including the sample, is then gradually pushed over the platform, thus allowing the specimen to project as a cantilever from the horizontal platform. Care is taken to prevent relative motion between the clamp and the sample. When the overhanging end touches the 43° line, measurement is taken from the ruler on the instrument to see how far the sample has extended beyond the edge of the platform. This quantity is the length of overhang, L. Using this value in the formula derived by Peirce [5], the bending length, C, is obtained:

$$C = Lf(\theta),$$

where

$$f(\theta) = \left(\frac{\cos \theta/2}{8 \tan \theta}\right)^{\frac{1}{3}};$$

thus

$$C = L\left(\frac{\cos \theta/2}{8 \tan \theta}\right)^{\frac{1}{3}}.$$

The selection of a 43° limiting angle was made to simplify the calculation, for in that case $C/L = f(\theta)$ = approximately $\frac{1}{2}$. Then it is only necessary to take $\frac{1}{2}$ the length of overhang, L, to obtain the bending length, C.

Peirce also defined the flexural rigidity, G, as

$$G = WC^3,$$

where W is the weight per unit area of the fabric. In order to calculate stiffness values in in.-lb. units, as was done in this study, the formula for flexural rigidity is

$$G = W \times C^3 \times 0.482 \times 10^{-4} \text{ in.-lb.},$$

where C is in inches and W is in oz./sq. yd.

The Tinius Olsen tester shown in Figure 2 is a beam-bending type of instrument which involves the bending of a fabric through an angle of 60° and recording the load applied at the bending plate to accomplish this. The fabric sample in this case represents a cantilever beam which is being bent upward by a load that is applied by the bending plate, Q, at a bending span of $\frac{1}{2}$ in. The moment applied by the plate, Q, acts against the stiffness and weight of the fabric sample to bend it. The bending mechanism is shown in the diagram of the bent sample in Figure 2.

The angular deflection, scale A, the pointer indicator, I_1, the bending plate, Q, and the weights, M, are rigidly attached to form a pendulum system pivoted for nearly frictionless rotation about the point O. The fixed load scale measures the deflection of the pendulum system when pressure is applied at Q.

Also rotating about the point O, at the rate of 60° arc/min., is the specimen vise, V, to which is attached the angular deflection pointer, I_2. This vise holds one end of the specimen, while the other end rests on the bending plate, Q, of the pendulum system. As the vise turns in a clockwise direction, the free end of the specimen presses down on Q, thus causing a deflection of the pendulum system, which, as has already been stated, is measured on the fixed load scale by the pointer I_1. The load scale is calibrated to read directly 100 ($L \sin \theta$), where L is the distance between the center of rotation, O, and the center of the applied load, M. Thus, M times the load scale reading divided by 100 gives the bending moment:

$$\text{B.M. (in.-lb.)} = \frac{\text{moment weight} \times \text{load scale reading}}{100}.$$

This calculation is simplified, for each moment weight is stamped with the bending moment it applies when the pendulum is at the maximum angle of swing.

In operation, a 2 in. by 1 in. sample is firmly clamped in the vise. By turning a hand crank, sufficient load is applied to the specimen to show a 1% load reading, and the angular deflection pointer is set to indicate zero angle. The motor is engaged and the load scale is read when the angular deflection scale indicates 60°. The load reading is then reduced by 1%. The stiffness is calculated in terms of bending moment, as shown in the above formula.

Results and Discussion

Table I lists the results of the tests as averages of the ten stiffness measurements obtained by the two testers on each of the fifteen fabrics and a number of statistical analyses. The values obtained by the Tinius Olsen tester are approximately three times as large as, and are closely related to, those obtained by the Peirce tester. This is quantitatively illustrated by the correlation coefficient between the stiffness measurements obtained by the testers—*viz.*, $r = +0.93$; thus the average Peirce stiffness values (in.-lb. $\times 10^{-4}$) can be converted to Tinius Olsen values by the following formula:

$$\text{T.O.} = 3.4 + 3.1P.$$

Figure 3 shows this relationship graphically. Note,

TABLE I. EVALUATION OF AVERAGE WARP STIFFNESS MEASUREMENTS OBTAINED ON THE TINIUS OLSEN AND PEIRCE MACHINES (10 SPECIMENS OF EACH OF 15 FABRICS)

Fabric No.	Fabric weight (oz./sq. yd.) Amount	Fabric weight Rank	Stiffness (in.-lb.×10⁻⁴) Tinius Olsen Amount	Tinius Olsen Rank	Peirce Amount	Peirce Rank	σ_w Precision (in.-lb.×10⁻⁴) T.O.	Precision Peirce	Relative precision $100\left(\frac{\sigma_w}{\text{ave.}}\right) = V\%$ T.O.	Relative precision Peirce
22	5.8	1	19.6	4	6.4	9	2.9	.8	15	12
30	6.6	2	17.8	2	5.2	4.5	1.4	.7	8	13
23	7.3	3	22.4	8	7.0	11	2.4	1.1	11	15
106	7.8	4	17.1	1	4.2	1	1.2	.2	7	5
109	8.1	5.5	22.5	9	6.1	7.5	1.7	.5	7	8
31	8.1	5.5	21.0	6	6.6	10	1.1	.6	5	10
100	8.4	7	22.0	7	6.1	7.5	5.2	1.0	15	17
103	8.6	8	22.8	10	5.2	4.5	1.3	.6	6	12
104	8.7	9	18.6	3	5.1	3	1.1	.4	6	8
112	9.1	10	20.4	5	5.0	2	3.5	1.3	17	25
98	9.3	11	25.5	12	7.1	12	3.7	1.5	14	21
101	9.5	12	27.2	13	9.5	14	1.2	.9	4	10
110	9.6	13	25.3	11	5.8	6	5.6	1.7	22	29
25	10.8	14	38.7	14	9.0	13	3.6	1.3	9	14
33	11.7	15	49.3	15	14.6	15	4.4	2.2	9	15
		Average	24.7		6.8		2.9	1.1	10	14
Spread among ave. fabric stiffness values, σ_a			8.6		2.6					
Relative spread, $\frac{\sigma_a}{\text{ave.}}$ (100)			.35		.38					
Discrimination Sensitivity Index, $\frac{\sigma_a^2}{\bar{\sigma}_w^2}$			9		6					

Relationships

Rank correlation with weight: T.O., .82; P, .52
Equation relating stiffness measurements on the two testers: T.O. = 3.4 + 3.1 P
Correlation (r) between T.O. and Peirce = .93

however, that the Tinius Olsen values are more closely related to the weight of the fabric than are the Peirce values. This is shown by the rank correlation coefficient between Tinius Olsen stiffness values and weight—namely, 0.82 as against 0.52 for the Peirce.

Reproducibility

Both the standard deviation, σ_w, and the coefficient of variation, V, of the ten stiffness measurements for each fabric were used as the basis for evaluating the precision or reproducibility of each machine. On the average, the standard deviation, σ_w, of the Tinius Olsen measurements is almost three times as large as for the Peirce measurements, but the coefficients of variation are approximately equal. This shows that there is little difference between the two testers in their relative precision or spread (in percent) of the readings for each fabric about its average stiffness value.

Sensitivity

An analogous situation exists in the spread of the average stiffness values of the fifteen fabrics. The standard deviation of the Tinius Olsen average stiffness values is approximately three times that of the Peirce, but the relative spread of the two machines—spread in relation to the average of the fifteen values—is about the same.

Sensitivity Index

The sensitivity index takes cognizance of the spread of the average stiffness values of the fifteen fabrics as evaluated by the standard deviation of their averages, σ_a; and the reproducibility among the specimen stiffness values for any one fabric as shown by their over-all average standard deviation, $\bar{\sigma}_w$. The ratio $\sigma^2_a/\bar{\sigma}^2_w$ is the sensitivity index; the higher the value, the better the discrimination. The indices of 9 and 6,

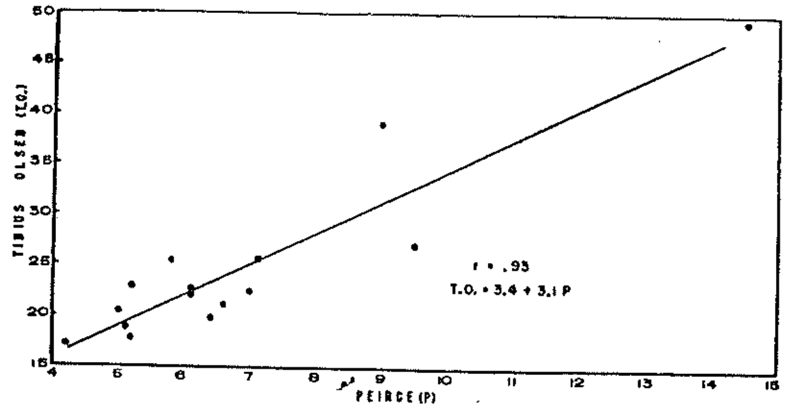

Fig. 3. *Relationship between stiffness values (in.= lb. × 10⁻⁴) obtained on the Tinius Olsen and Peirce stiffness testers.*

TABLE II. Stiffness Values (10^{-4} in.-lb.) Obtained on the Tinius Olsen and Peirce Stiffness Testers by 3 Operators (5 Specimens of Each of 4 Fabrics)

	Tinius Olsen operators						Peirce operators					
	I		*II*		*III*		*I*		*II*		*III*	
Material	Amount	Rank	Amount	Rank	Amount	Rank	Amount	Rank	Amount	Rank	Amount	Rank
33	54	4	60	4	59	4	14.6	4	16.1	4	13.2	4
25	39	3	42	3	40	3	8.3	2	8.0	3	7.4	2
101	28	2	29	2	29	2	8.7	3	7.7	2	8.1	3
31	23	1	24	1	24	1	5.5	1	5.5	1	5.2	1
Operator ave.	36.0		38.8		38.0		9.3		9.3		8.5	
Inherent reproducibility (operator's ave. of 5 specimens)			10%						14%			
Over-all reproducibility (95% probability) (estimated max. % difference of any one operator average (5 specimens) from over-all fabric average)			13%						15%			

respectively, for the Tinius Olsen and Peirce machines, not being statistically different, indicate that both machines discriminate equally well among fabrics of differing stiffness.

Influence of Operators

Another problem is to determine whether there are any significant differences in stiffness values when different operators use each machine. Three operators evaluated five specimens of each of four fabrics, representing a wide range in stiffness and weight, on both the Tinius Olsen and Peirce stiffness testers. The results are shown in Table II. All four materials are ranked similarly by each operator on the Tinius Olsen, while there is a reversal of fabrics 25 and 101 by operators *I* and *II* on the Peirce tester. However, there is not a significant difference between the stiffness values of these two as measured by the Peirce apparatus.

Table II also shows the reproducibility on each tester of an average fabric stiffness value obtained by any one operator. It reveals the operator's precision and his ability to reproduce his own results. Any operator can be expected to come within 10% of his over-all fabric average 95% of the time when using the Tinius Olsen tester, and 14% on the Peirce tester.

The over-all reproducibility of the two testers is also shown in Table II. This is actually the measure of the dependability of the test method. It includes the two major sources of variability—inherent operator variability and differences between operators—and tells how much an operator's average of five specimens may deviate from the over-all fabric average 95% of the time. The Peirce averages can be expected to differ at most by 15%, and the Tinius Olsen averages by 13%.

Other Factors

Considering further advantages and disadvantages of the two machines, we find that the Tinius Olsen can measure a wider range of stiffnesses in fabrics than the Peirce tester in its present form. The

TABLE III. MINUTES REQUIRED TO OBTAIN STIFFNESS MEASUREMENTS ON TINIUS OLSEN AND PEIRCE INSTRUMENTS

Sample	Tinius Olsen	Peirce
11	1.68	0.33
25	1.87	0.32
33	1.60	0.30
31	1.65	0.28
101	1.68	0.30
	$\bar{X}$ 1.70	$\bar{X}$ 0.31

Peirce tester is limited to those fabrics which can bend under their weight to an angle of 43°. Therefore, a fabric rigid enough to support its own weight when projected as a cantilever for 6 in. could not be measured on the Peirce tester, while it could be bent on the Tinius Olsen to a moment weight up to 1 lb.

A disadvantage of the Tinius Olsen is that it is susceptible to mechanical failure or misfunction, unlike the far simpler Peirce instrument. Cases in the laboratory are on record where friction between the pendulum and the outside case of the instrument have influenced and invalidated stiffness measurements. A check of the machine must be made before each sample is tested; and repairs are likely to be needed from time to time.

Furthermore, the Peirce tester is much easier to operate and is much faster than the Tinius Olsen tester. Table III shows the results of a time study on the two instruments, using five of the fabrics previously tested.

The time recorded included the time necessary to place the sample in the apparatus, test it, and remove it from the instrument. The average results of all five samples showed that a sample can be measured on the Peirce tester in roughly $\frac{1}{6}$th the time it takes on the Tinius Olsen instrument.

Summary

1. Stiffness values obtained on the Peirce stiffness tester are highly correlated ($r = 0.93$) with those of the Tinius Olsen tester, and are equally reliable.

2. Tinius Olsen stiffness values can be estimated from the Peirce values by the relationship $T.O. = 3.4 + 3.1\ P$.

3. Both machines should discriminate equally well among fabrics of differing stiffness.

4. Any one operator's average stiffness value (of five specimens) should not deviate by more than 15% from the over-all average stiffness value (95% probability) obtained on either the Tinius Olsen or Peirce stiffness testers.

5. The Peirce is roughly six times as fast as the Tinius Olsen apparatus.

6. While the Peirce is a simpler machine and is easier to operate, its usefulness is limited by the fact that it cannot measure the wide range of stiffnesses of military fabrics.

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Literature Cited

1. Abbott, N. J., The Measurement of Stiffness in Textile Fabrics, TEXTILE RESEARCH JOURNAL 21, 435 (1951).
2. A.S.T.M. Standards on Textile Materials, D-747-43T.
3. Dreby, E. C., Physical Methods for Evaluating the Hand of Fabrics and for Determining the Effects of Certain Textile Finishing Processes, *A. Dyestuff Reptr.* 31, 497 (1942).
4. Federal Specification, CCC-T-191b, Textile Test Methods, May 1951.
5. Peirce, F. T., The Handle of Cloth as a Measurable Quantity, *J. Textile Inst.* 21, T377 (1930).

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