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SECOND REPORT OF THE A.S.T.M. TASK GROUP STUDYING
THE WYZENBEEK PRECISION WEAR TEST METER

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FOREWORD

The Quartermaster Corps has a wide interest in the wear resistance of textiles because of its tremendous annual procurements of clothing and equipage items for men in the armed forces. One of the most difficult problems connected with the study of wear resistance is the development of reliable laboratory techniques for the prediction of fabric durability. The prerequisites for any abrasion instrument are (1) reproducibility of results, and (2) correlation of these results with field wear.

This report is concerned with the first of these two considerations, namely reproducibility, with respect to the Wyzenbeek Precision Wear Test Meter, a commercial laboratory abrader. The Quartermaster Corps has welcomed an opportunity to cooperate with the American Society for Testing Materials in an interlaboratory evaluation of this instrument. The details of the experiment are given herein, indicating the reproducibility of results obtainable by one of these instruments as well as a correlation of the results given by different models of the machine under the slightly varying local conditions of the cooperating laboratories.

It is anticipated that future reports will discuss the second important characteristic of abrasion testing instruments, namely their correlation with field wear as obtained on the Quartermaster Combat Course, Camp Lee, Virginia.

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Research Director
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Textiles, Clothing, and Footwear

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SECOND REPORT OF THE A.S.T.M. TASK GROUP STUDYING
THE WYZENBEEK PRECISION WEAR TEST METER

Seaman J. Tanenhaus* and Gerald Winston**

Abstract

A study of the Wyzenbeek Precision Wear Test Meter was made to determine its suitability for use as a standard instrument for determining the abrasion resistance of textiles. The results of two interlaboratory tests, which included consideration of end-points and abradants, indicate that the severity of abrasion among the units is too variable to permit the use of the Wyzenbeek apparatus for establishing interlaboratory standards. Individual instruments were found to be sufficiently precise for evaluating differences among fabrics. A number of suggestions for improving the technique of operation are included.

Introduction

A principal objective of the Task Committee on Abrasion Testing (under Subcommittee B-1, Section 1, of Committee D-13, A.S.T.M.) is the examination of various commercial abrading instruments to determine their suitability for use in establishing standard methods. Task groups have been formed within the Committee to study the Taber Abrader, the U. S. Testing Company's abrader and the Wyzenbeek Precision Wear Test Meter, as a letter ballot had indicated that these instruments are in widest use⁽¹⁾. The present paper discusses the work of the task group investigating the Wyzenbeek apparatus (Figure 1). This machine is manufactured by A. Wyzenbeek & Staff, Chicago, Illinois.

A search of the literature and a questioning of technicians indicated that various techniques are extant. Methods of evaluating the extent of damage fall into two classes, namely, those utilizing visual evidence of degradation, generally employed when appearance is a factor (woolen outerwear, plush, etc.) and

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FIGURE I
WYZENBEEK PRECISION WEAR TEST METER

those considering the change in some mechanical characteristic, usually breaking strength, after a given period of abrasion. The latter method is used primarily for utility fabrics (work garments, webbings, etc.). Abradants are of many types, including metal screening, abrasive cloths and papers, standard fabrics and the test cloth itself. Statistical control is used by some technicians. Some operators employ the vacuum device furnished by the manufacturer to remove the detritus, others use a brush for this purpose and the rest do neither. A choice of operating conditions insofar as load, tension and cycles of abrasion are concerned is possible by virtue of the construction of the instrument.

Because of the many possible variations in technique, it was decided first to ascertain satisfactory conditions of load and tension for performing the test on a readily available cloth and using a single machine. After standard abrading conditions for this unit were selected, a test was initiated to determine the consistency of results among a number of instruments. Two types of fabrics were used as test cloths to determine the adequacy of subjective methods for estimating endpoints. The results of this interlaboratory study exhibited a high degree of variation. As this might have been caused by a lack of precision in the subjectively determined endpoints, it was deemed advisable to conduct a second interlaboratory Wyzenbeek test, using an objective endpoint by ascertaining the discriminatory faculty of the instrument with regard to ranking a number of test fabrics.

Preliminary Studies

Tension, Load and Cycles. The Wyzenbeek instrument permits the test specimen to be subjected to tensions ranging from one to six pounds and to compressional loads of from one to five pounds over four square inches of abraded area by means of two independent series of adjustable cantilever clamps. The specimen is forced by a rubber pad against an oscillating curved abrasive surface for the desired number of cycles. Three or four specimens may be tested simultaneously, depending upon the Wyzenbeek model used.

The apparatus used for determining satisfactory values of the parameters of tension, load and length of abrasion for a particular fabric was a four-arm machine whose drum oscillated at the

rate of 90 cycles per minute. The vacuum device had been removed for ease of operation. No. 320 Aloxite cloth was employed as the abradant and was changed after each run. Before testing, care was taken that each specimen was free of loose threads, but no attempt to remove detritus was made during the course of the runs. The fabric selected was an 8.5 ounce vat-dyed herringbone twill. The loss in warp tensile strength after warpwise abrasion was chosen as the measure of abrasion resistance. Control-chart technique was employed to determine homogeneity of results from the four test arms and statistical conformance of the operator and of the tensile tester. The specimens were abraded under several tensions and loads for various cycle stages.

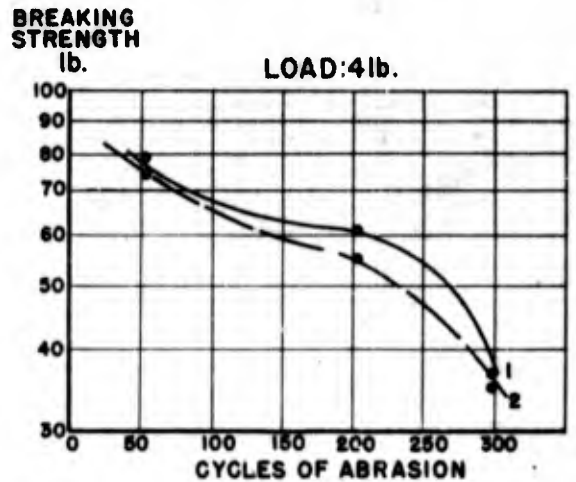
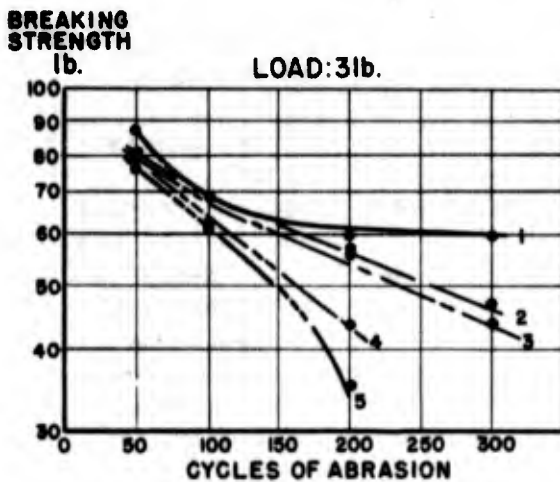
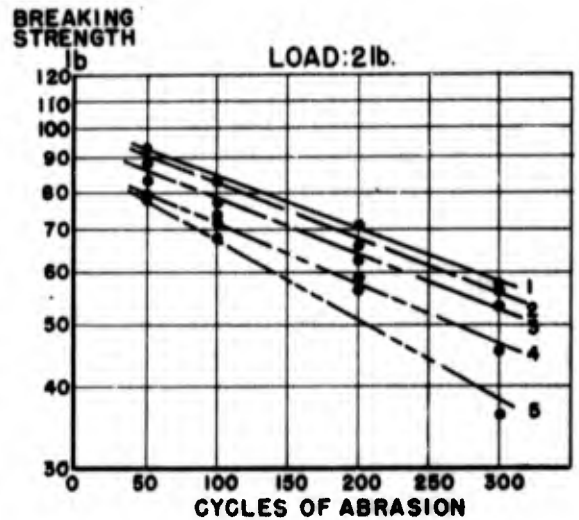
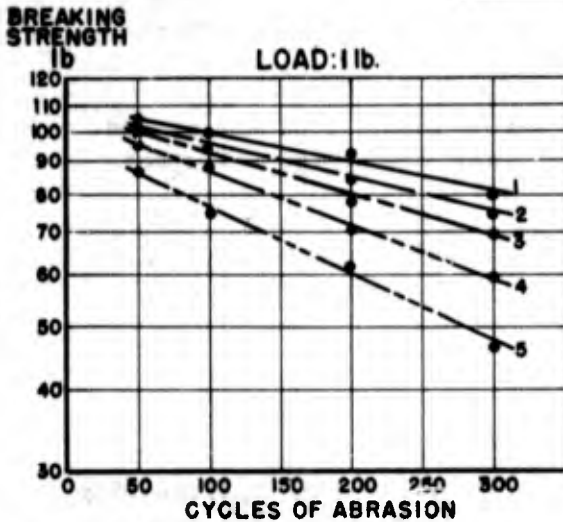
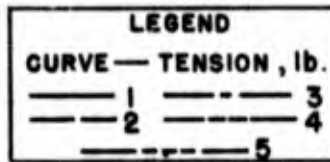
The results, presented graphically in Figure 2, indicate that, within limits, semi-logarithmic relationships exist between the amount of abrasion and the loss in breaking strength. A satisfactory endpoint may be obtained by choosing any combination of values for the parameters of load, tension and cycles of abrasion which lie within these limits.

Endpoints and Abradants. Once satisfactory operating conditions for a given fabric were ascertained by use of an objective endpoint, the next step was to investigate a method employing visual endpoints. This latter method⁽⁵⁾ consists of abrading a 2-7/8 by 9 inch specimen folded in "S" fashion to 1-7/8 by 9 inches to simulate edge abrasion and 1-7/8 by 9 inch flat strips to simulate plane wear. The number of cycles required to reach the following endpoints is noted;

- A. First Wear - Any radical disturbance of surface, as fuzzing, scuffing or pilling.
- B. First Rupture of Yarn - Any rupture visible with pick glass.
- C. Threadbare - The detachment of yarn or yarns parallel to the long direction of the specimen as a result of multiple rupture of cross-wise yarns.

For this phase, a 10.5 ounce wool serge was abraded both flat and folded in the warp and filling directions using the following abradants; the fabric itself, No. 320 Aloxite, No. 400 Aloxite,

Fig. 2
EFFECT OF TENSION ON BREAKING STRENGTH AT VARIOUS LOADS
WYZENBEEK PRECISION WEAR TEST METER



NOTE: Breaking Strength of Unabraded Herringbone Twill: 121.3lb.

and No. 500 Silica cloths. A sample of 22 ounce serge was tested similarly, except that the last two abrasants were omitted. The number of cycles required to reach each endpoint and the ratios of cycles for endpoints A and B to cycles for endpoint C, expressed as percentages, are presented in Table I.

The results of this part may be summarized as follows:

1. As observation of surface disturbance is entirely subjective, wide variation in results using endpoint A may be expected.
2. The ratio of the cycles for endpoint B to the cycles for endpoint C appears to be fairly constant, regardless of specimen or abrasant.
3. For heavier textiles, the use of the test fabric as the abrasant necessitates an excessively long period of abrasion to reach a satisfactory endpoint.

First Interlaboratory Test⁽⁶⁾

Before a decision could be reached as to the applicability of the Wyzenbeek Precision Wear Test Meter to a standard procedure, it was necessary to ascertain whether instruments in different laboratories were potentially capable of yielding reproducible and consistent results. It must be noted that although several articles have been written about this apparatus^(2,4,5), no broad attack on the problem of interlaboratory correlation has been reported. A test was therefore formulated to determine (a) the internal consistency of various instruments and (b) the reproducibility of interlaboratory results. The cooperating agencies were furnished samples of 8.5 ounce cotton herringbone twill and 10.5 ounce wool serge, two commonly used abrasants (No. 320 Aloxite cloth and No. 1/0 Emery metallographic paper) and a test plan. The plan detailed the conditions of load and tension, indicated how to prepare the specimens and how often to observe the progress of the abrasion, and defined the visual endpoints. The endpoints chosen were; A. First Wear; B. First Rupture; and C. Threadbare; as described previously.

Adequate returns were received from ten laboratories. The data for the First Wear endpoint were so scattered as to show

TABLE I. NUMBER OF CYCLES TO REACH FIRST RUPTURE AND THREADBARE ENDPOINTS. PRELIMINARY PHASE.

Load; $2\frac{1}{2}$ lb.

Tension; 2 lb.

10.5 oz. Wool Serge

End-point*	Warp		Filling		Warp Folded		Filling Folded	
	Cycles	%**	Cycles	%**	Cycles	%**	Cycles	%**

Fabric as Abradant

A	9,890	7	8,750	7	7,600	7	5,570	7
B	113,100	84	110,550	83	89,800	86	62,390	84
C	135,400	100	120,700	100	103,650	100	74,600	100

No. 320 Aloxite as Abradant

A	75	50	50	38	30	43	25	42
B	130	87	110	84	60	85	50	85
C	160	100	130	100	70	100	60	100

No. 400 Aloxite as Abradant

A	80	36	65	34	40	42	30	40
B	180	82	150	79	75	79	60	80
C	220	100	190	100	95	100	75	100

No. 500 Silica as Abradant

A	120	41	90	43	55	46	50	45
B	250	86	170	81	100	83	90	82
C	290	100	210	100	120	100	110	100

22 oz. Wool Serge

Fabric as Abradant

A	16,080	6	15,040	6	14,400	6	12,890	6
B	234,160	93	232,700	95	232,080	98	201,150	90
C	251,250	100	246,100	100	236,200	100	222,650	100

No. 320 Aloxite as Abradant

A	270	53	210	55	110	58	60	40
B	390	76	300	79	150	79	100	67
C	510	100	380	100	190	100	150	100

* A = First Wear
 B = First Rupture
 C = Threadbare

** % = $100 \times \frac{\text{Cycles to Reach Given Endpoint}}{\text{Cycles to Reach Endpoint C}}$

that this endpoint is meaningless for purposes of interlaboratory comparison. The values for the other endpoints, which are shown in Table II, were of sufficient consistency to permit analysis. As the data for the cotton and the wool fabrics exhibit similar tendencies, only those of the latter fabric are shown. cursory examination of the data indicates that the number of cycles of abrasion required to reach a described visual endpoint varies widely, indicating slight agreement among laboratories. However, a closer study shows that some agencies rank consistently high whereas others rank consistently low for endpoints B and C. The data for endpoints B and C were arrayed to allow determination of the rank correlation coefficients (Spearman's ρ) for the ten laboratories with the following test variables;

- A. Directions of Abrasion
- B. Abradants
- C. Endpoints

Ranks were assigned to the number of cycles from the highest to the lowest. A value of one for ρ would indicate perfect association and zero none. The relatively high value of most of the coefficients, as seen in Table III, suggests that although the laboratories might differ among themselves, each individually is quite consistent.

To further substantiate the rankings of the laboratories, a check was made for any possible fortuitousness of the results by performing eight one-way analyses of variance of rank for each of the four directions of abrasion (warp, filling, warp folded, and filling folded) for the first rupture and threadbare endpoints for each of the two abradants. The design of the analyses is illustrated by the following outlines;

		<u>WARP*</u>										<u>FIRST RUPTURE-EMERY**</u>											
		<u>Laboratory</u>										<u>Laboratory</u>											
<u>Group</u>		<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>	<u>9</u>	<u>10</u>	<u>Group</u>		<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>	<u>9</u>	<u>10</u>
FR-E												W											
FR-A												F											
T-E												WF											
T-A												FF											

*Repeated for Filling, Warp Folded, and Filling Folded.

**Repeated for First Rupture-Aloxite, Threadbare-Emery, and Threadbare-Aloxite.

TABLE II. CYCLES TO REACH ENDPOINTS FOR 10.5 OZ. WOOL SERGE

First Rupture Endpoint

No. 1/0 Emery Paper				No. 320 Aloxite Cloth			
Warp	Filling	Warp	Filling	Warp	Filling	Warp	Filling
Lab n	Lab n	Folded	Folded*	Lab n	Lab n	Folded	Folded
Lab n	Lab n	Lab n	Lab n	Lab n	Lab n	Lab n	Lab n
H 830	H 1210	H 256	I 263	I 225	G 228	F 87	C 100
I 638	I 638	C 240	C 260	F 224	I 220	C 80	F 75
E 580	E 620	I 238	H 256	H 210	F 218	H 62	H 64
C 540	G 558	F 203	F 200	C 180	H 178	I 50	G 52
D 540	D 500	G 170	G 168	D 165	C 160	L 50	I 52
G 478	C 480	L 170	K 158	G 158	D 120	G 46	L 50
L 450	L 390	K 142	D 140	L 120	L 120	D 45	D 45
F 428	F 355	D 140	E 110	E 80	J 110	E 30	K 32
J 221	J 355	E 100	J 99	K 74	E 100	J 28	E 30
K 218	K 218	J 84		J 59	K 82	K 28	J 28

Threadbare Endpoint

No. 1/0 Emery Paper				No. 320 Aloxite Cloth			
Warp	Filling	Warp	Filling	Warp	Filling	Warp	Filling
Lab n	Lab n	Folded	Folded	Lab n	Lab n	Folded	Folded
Lab n	Lab n	Lab n	Lab n	Lab n	Lab n	Lab n	Lab n
I 1200	H 1844	I 538	C 720	F 314	I 305	F 124	C 140
H 1184	I 1200	C 520	I 388	H 298	C 280	C 120	I 105
C 1080	C 1100	H 306	H 280	C 280	F 276	I 95	F 102
D 900	L 800	L 280	F 278	I 250	G 270	G 92	H 92
L 890	D 780	F 279	G 272	D 235	H 250	H 90	G 90
E 700	E 700	G 266	L 260	G 194	D 195	L 70	L 70
G 604	G 696	D 220	D 240	L 150	L 170	D 60	D 60
F 596	F 506	E 170	K 186	E 140	J 168	J 56	J 54
J 413	J 474	K 166	E 170	J 102	E 140	E 50	E 50
K 218	K 218	J 136	J 136	K 76	K 82	K 36	K 36

*Laboratory L value not received.

TABLE III. RANK CORRELATION COEFFICIENTS* FOR
TEN INSTRUMENTS. FIRST INTERLABORATORY TEST

A. Between Directions of Abrasion**

Abradant	First Rupture Endpoint vs. Threadbare Endpoint							
	W vs. F		WF vs. FF		W vs. F		WF vs. FF	
	Serge	HBT	Serge	HBT	Serge	HBT	Serge	HBT
Emery	0.96	0.79	0.95	0.82	0.98	0.93	0.94	0.60
Aloxite	0.77	0.25	0.94	0.92	0.82	0.67	0.95	0.74

B. Between Abradants

Fabric	No. 1/0 Emery vs. No. 320 Aloxite							
	First Rupture Endpoint				Threadbare Endpoint			
	W	F	WF	FF	W	F	WF	FF
Serge	0.58	0.47	0.85	0.88	0.59	0.56	0.77	0.94
HBT	0.49	0.28	0.90	0.92	0.38	0.55	0.52	0.88

C. Between Endpoints

Fabric	First Rupture vs. Threadbare							
	Warp		Filling		Warp Folded		Filling Folded	
	Emery	Alox.	Emery	Alox.	Emery	Alox.	Emery	Alox.
Serge	0.89	0.92	0.78	0.88	0.89	0.90	0.98	0.90
HBT	0.93	0.47	0.92	0.76	0.55	0.72	0.83	0.85

*Spearman's rank correlation coefficient, ρ , is expressed by the following formula:

$$\rho = 1 - \frac{6 \sum d^2}{N(N^2 - 1)}$$

where d = difference in rank between paired items in two series,
N = number of ranks.

**W, F, WF, FF designate Warp, Filling, Warp Folded and Filling Folded, respectively.

Thus for each of the eight sets there are four rows and ten columns. Following the method suggested by Friedman⁽³⁾ the statistical test is set up to determine whether the different columns, which show the rankings of each laboratory, came from the same population and therefore would indicate whether the ranks would be due to chance and, consequently, the laboratories are inconsistent.

The statistic χ_r^2 was computed* which has the χ^2 (Chi-Square) distribution when the ranking is random. The results of these analyses indicate that the probability that the rankings were due to chance alone in each of the eight sets for both the serge and the herringbone twill was less than one in a thousand, and illustrate the marked consistency of the ten laboratories in evaluating the abrasion resistance under eight different conditions.

*The χ^2 distribution = $\frac{Ns^2}{\chi^2}$, where

	<u>General Case</u>	<u>For Ranked Data</u>
Degrees of Freedom for Means	N	p - 1
Mean	$\frac{1}{2}(p + 1)$	$\frac{1}{2}(p + 1)$
Sample Variance	s^2	$\sum_{j=1}^p \frac{1}{p} (\bar{r}_j - \frac{1}{2}(p + 1))^2$
Population Variance of Means	$\frac{\sigma^2}{N}$	$\frac{p^2 - 1}{12n}$

Thus, for ranked data

$$\chi_r^2 = \frac{12n}{p(p + 1)} \times \sum_{j=1}^p (\bar{r}_j - \frac{1}{2}(p + 1))^2$$

where \bar{r}_j = average of jth column

n = number of rows = 4

p = number of columns or ranks = 10

For small values of n and large values of p, the significance of χ_r^2 is tested by considering

$$\frac{\chi_r^2 - (p - 1)}{\left[\frac{2}{n} (n - 1)(p - 1) \right]^{1/2}}$$

as a normally distributed variate with zero mean and unit variance.

Having determined that the laboratories were consistent as to their relative standings in the number of cycles necessary to reach a given visual endpoint, exclusive of the first wear endpoint, under various experimental conditions, the analysis then considered the internal consistency within each laboratory. The assumption was made that there should be a similarity of ratios of the number of cycles to abrade each fabric fillingwise, warpwise folded and fillingwise folded, respectively, to the warp, which was considered to be 100. This similarity should occur for the first rupture and the threadbare endpoints for each type of abradant. A χ^2 test was performed involving four rows (warp, filling, warp folded, filling folded), two columns (first rupture and threadbare endpoints) and three degrees of freedom. A laboratory was deemed to be inconsistent when the χ^2 computed could have occurred by chance less than one time in a hundred. The results of this analysis are shown in Table IV.

TABLE IV. CONSISTENCY OF LABORATORIES

A. Herringbone Twill Fabric

Abradant	Laboratory									
	C	D	E	F	G	H	I	J	K	L
Emery	G	G	G	G	G	G	G	P	P	P
Aloxite	G	G	P	G	P	G	G	P	G	P

B. Serge Fabric

Abradant	Laboratory									
	C	D	E	F	G	H	I	J	K	L
Emery	G	G	G	G	G	G	G	G	G	G
Aloxite	G	G	G	G	G	G	G	G	G	G

Note: G - Good consistency
P - Poor consistency

Parenthetically it may be stated that several laboratories which exhibited poor internal consistency later indicated that operators had been changed during the test or that the decision as to the proper visual endpoint had been modified.

In a separate attempt to illustrate consistency, the percentages of cycles to reach the first rupture endpoint to the cycles to reach the threadbare endpoint were calculated. When these data are plotted as in Figure 3, the evidence of internal consistency of the laboratories is perhaps more easily observed. For example, all 16 percentages for Laboratory F lie between 70 and 79. Similarly, 13 of the 16 percentages for Laboratory D lie between 60 and 76. For Company J, on the other hand, the values vary from 10 to 81 percent. A vivid illustration of the differences in visual endpoints as judged by the various agencies is furnished in Figure 4.

Conclusions from the First Interlaboratory Test. Using the Wyzenbeek Precision Wear Test Meter as an interlaboratory test instrument for abrading 8.5 ounce cotton herringbone twill and 10.5 ounce wool serge shows that;








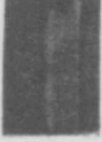










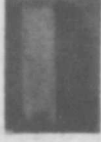























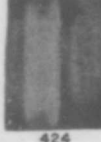

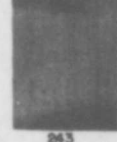



1. There is a high consistency among the laboratories insofar as ranking is concerned.
2. There is a low consistency among the laboratories insofar as actual numerical values are concerned.
3. There is a high association between the first rupture endpoint and the threadbare endpoint, indicating the lack of necessity for abrading to the latter stage.
4. Certain laboratories exhibit decidedly higher internal consistency than others.

Second Interlaboratory Test

The previous phases of this study have shown that the conditions of test must be selected with regard to the test fabric and that there is good indication that a high consistency can exist in the rank evaluation of materials by the individual laboratories using certain visual endpoints. In spite of this consistency in ranking by the cooperating agencies, there is no similarity in the actual values.

Replies to a questionnaire circulated after the first test showed that the age of the instruments used varied from a few months to sixteen years and that many machines had not been calibrated since leaving the manufacturer. Therefore, before the second test was begun the cooperating laboratories were requested to return their instruments

Fig. 4
COTTON, HERRINGBONE TWILL, 8.5 OZ.

O EMERY				COMPANY	320 ALOXITE				
WARP	FILLING	WARP FOLDED	FILLING FOLDED		WARP	FILLING	WARP FOLDED	FILLING FOLDED	
				B					
960	650	90	310		180	80	15	60	
					C				
2180	3560	740	1400			440	220	140	140
				D					
1760	1420	500	420			232	182	62	62
					E				
4360	3660	220	360			250	190	30	40
				F					
2356	1790	452	373			315	250	64	52
					K				
1098	1140	424	268			243	106	60	48

NUMBERS DENOTE CYCLES TO THREADBARE STAGE

to the maker for overhauling and calibrating. Upon completion of these arrangements the machines presumably were in first class condition.

The purpose of this second interlaboratory test was to compare the similarity of the machines in regard to the amount of abrasion occurring in a number of fabrics. A second objective was to ascertain the reproducibility and consistency of the results from each laboratory for the purpose of obtaining an indication of the causes contributing to the variability of the values both within and among the laboratories.

In order to get conclusive results concerning the efficacy of the Wyzenbeek apparatus as an interlaboratory instrument, the test specimens were pre-cut and the breaking strengths of the abraded specimens were determined on a single tensile tester by a single operator, both being in statistical control. By indicating which specimens were to be abraded on a given arm, the experiment permitted the assignment of a large portion of the total variation to specific causes. Each cooperating member received randomized specimens of five fabrics, two abradants and a test directive which read as follows:

ABRASION TEST METHOD

Scope: To determine the reproducibility of the characteristics of the Wyzenbeek Precision Wear Test Meter among laboratories in terms of a selected endpoint of abrasion. For this study, the endpoint is the percent loss in breaking strength. The abraded specimens will be evaluated at the Philadelphia Quartermaster Depot with a single Scott Vertical Tensile Tester, Statistical control techniques will be utilized.

Machine: Wyzenbeek Precision Wear Test Meter

Number of arms: 3 or 4

Rate of oscillation: approximately 90
cycles (double rubs) per minute.

Atmospheric Conditions: Temperature: 70 ± 2 F.

Relative humidity: 65 ± 2 %.

Design of Experiment:

<u>Fabric (Cottons)</u>	No. of Specimens Abraded									
	Arm:	Aloxite				Arm:	Emery			
		<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>		<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>
Herringbone Twill		7	7	7	7		7	7	7	7
Poplin		7	7	7	7		7	7	7	7
*Sateen		7	7	7	7		7	7	7	7
*Sateen (Filling)**		7	7	7	7		7	7	7	7
<u>2</u> Twill		7	7	7	7		7	7	7	7

*Filling flush.

**The specimens of all fabrics except this one were cut warpwise.

Procedure:

1. For each fabric, abrade seven of the eight sets of four specimens. The extra set has been included in case of error or necessity for recheck.
2. Abrade specimens marked '1' on Arm 1, '2' on Arm 2, etc. For three-armed models, disregard specimens marked '4'.
3. Use a new sheet of abradant for each set of specimens.
4. Specimens are to be inserted into arm clamps so that the side of the fabric marked in red will rest against the abradant.
5. Employ the following test conditions;
 - a. 2-pound load.
 - b. 2-pound tension.
 - c. 250 continuous cycles.
6. Identify and keep in chronological order each set of specimens by tagging the strips together and marking Run 1, Run 2, , Run 7.
7. Return sets of abraded specimens and unused fabric strips to Philadelphia.

The fabrics were abraded warpwise and broken warpwise except for one of the groups of sateen which was abraded and broken fillingwise. The two groups of sateen, basically the same fabric, were included to determine whether warpwise abrasion affects the breaking strength of the protected yarns. It was noted that regardless of direction of abrasion of filling-flush sateen, the filling yarns bore the brunt of the degradation. As the loss in warp breaking strength after 250 cycles was negligible, data for the warpwise-out sateen were not included in the following analysis.

Comparison of Amount of Abrasion. Considering one fabric abraded by one medium on a four-arm apparatus (the model used by all but one laboratory), it is seen that this experiment yielded 28 individual values for the residual breaking strength per laboratory. Table V compares the average amount of abrasion of the 15 instruments studied for the four fabrics using emery and aloxite abrasants. The values show a dissimilarity in the performance of the various machines, for the average range of the per cent loss in strength after abrasion is approximately 23 per cent when emery is used and 33 per cent when aloxite is the abrasant. Despite these wide ranges, with emery abrasive there are but two different rankings of the four fabrics. Twelve of the 14 laboratories ranked the materials identically while the remaining two only reversed the third and fourth fabrics. Use of the aloxite resulted in five different rankings, showing the greater consistency of the emery.

The significance of the differences in the amount of abrasion of each of the four fabrics by the various companies may be illustrated by control charts. The data for the charts are shown in Table VI and a typical example is presented as Figure 5. Values falling outside the control limits differ significantly from the overall average, as the probability is less than one in twenty that they do so by chance.

The consistency of the individual Wyzenbeek machines is illustrated by Figure 6, which indicates the linear relationship between the average residual breaking strength of all four fabrics from each laboratory using emery and aloxite abrasants. The data show, in short, that the differences in the average residual breaking-strength values of the 14 laboratories would be caused primarily by differences among the machines rather than by differences within the fabrics or to variations within any given apparatus.

TABLE V. AMOUNT OF ABRASION OF 14 INSTRUMENTS ON 4 FABRICS

Lab.	A. Emery Abradant											
	HBT			Poplin			Sateen			2/1 Twill		
	RBS* X, lb.	Dev. from X, %	B. S. Loss, %	RBS* X, lb.	Dev. from X, %	B. S. Loss, %	RBS* X, lb.	Dev. from X, %	B. S. Loss, %	RBS* X, lb.	Dev. from X, %	B. S. Loss, %
1	93	0.3	19	96	1.7	29	67	1.1	43	65	5.9	43
2	82	12.1	28	85	10.0	37	58	12.5	51	59	14.6	48
3	94	0.8	18	102	8.0	24	65	2.0	45	72	4.2	36
4	97	4.0	15	109	15.5	19	75	13.1	37	70	1.3	38
5	93	0.3	19	85	10.0	37	58	12.5	51	69	0.1	39
6	99	6.1	13	89	5.7	34	64	3.5	46	69	0.1	39
7	94	0.8	18	105	11.2	22	74	11.6	38	74	7.1	35
8	83	11.0	27	81	14.2	40	43	35.1	64	66	4.5	42
9	99	6.1	13	101	7.0	25	82	23.7	31	74	7.1	35
10	87	6.8	24	84	11.0	38	59	11.0	50	61	11.7	46
11	104	11.5	9	114	20.8	15	87	31.2	27	84	21.6	26
12	94	0.8	18	87	7.8	36	63	5.0	47	65	5.9	43
13	90	3.5	21	91	3.6	33	62	6.5	48	68	1.6	40
14	97	4.0	15	93	1.5	31	71	7.1	40	72	4.2	36
Ave.	93.3	4.9	18.3	94.4	9.1	30.0	66.3	12.6	44.1	69.1	6.4	39.0
Min.	82	0.3	9	81	1.5	15	43	1.1	27	59	0.1	26
Max.	104	12.1	28	114	20.8	40	87	35.1	51	84	21.6	48
Range	22	11.8	19	33	19.3	25	44	34.0	24	25	21.5	22

* Residual Breaking Strength (Average 28 values).

TABLE V. AMOUNT OF ABRASION OF 14 INSTRUMENTS ON 4 FABRICS

Lab.	B. Aloxite Abradant											
	HBT			Poolin			Sateen			2/1 Twill		
	RBS* \bar{X} lb.	Dev. from \bar{X} , %	B. S. Loss, %	RBS* \bar{X} lb.	Dev. from \bar{X} , %	B. S. Loss, %	RBS* \bar{X} lb.	Dev. from \bar{X} , %	B. S. Loss, %	RBS* \bar{X} lb.	Dev. from \bar{X} , %	B. S. Loss, %
1	60	9.5	48	56	26.1	59	27	19.6	77	36	9.1	68
2	47	29.1	59	32	27.9	76	17	49.4	86	22	44.4	81
3	80	20.7	30	59	32.9	56	38	13.1	68	43	8.6	62
4	72	8.6	37	49	10.4	64	42	25.0	65	35	11.6	69
5	84	26.7	27	43	3.2	68	29	13.7	76	46	16.2	59
6	68	2.6	41	51	14.9	62	33	1.8	72	45	13.6	60
7	64	3.5	44	47	5.9	65	37	10.1	69	44	11.1	61
8	48	27.6	58	34	23.4	75	28	16.7	76	36	9.1	68
9	86	29.7	25	60	35.1	56	57	59.6	52	48	21.2	58
10	60	9.5	48	37	16.7	73	22	34.5	81	38	4.0	66
11	82	23.7	28	72	62.2	47	59	75.6	50	53	33.8	53
12	72	8.6	37	32	27.9	76	29	13.7	76	39	1.5	66
13	51	23.1	55	20	55.0	85	22	34.5	81	37	6.6	67
14	54	18.6	53	29	34.7	79	31	7.7	74	32	19.2	72
Ave.	66.3	17.3	42.1	44.4	26.9	67.2	33.6	27.5	71.6	39.6	15.0	65.0
Min.	47	2.6	25	20	3.2	47	17	1.8	50	22	1.5	53
Max.	86	29.7	59	72	62.2	85	59	75.6	86	53	44.4	81
Range	39	27.1	34	52	59.0	38	42	73.8	36	31	42.9	28

* Residual Breaking Strength (Average of 28 values).

TABLE VI. VARIABILITY OF ABRASION
OF 14 INSTRUMENTS ON 4 FABRICS

Standard Deviation, σ , lb.²

Lab.	HBT		Poplin		Sateen		2/1 Twill	
	Emery	Alox.	Emery	Alox.	Emery	Alox.	Emery	Alox.
1	6.0	10.2	8.1	8.7	11.5	6.1	10.3	7.9
2	8.3	12.9	12.5	9.9	8.2	5.9	7.9	7.9
3	8.3	10.6	8.6	7.4	8.9	6.0	6.7	6.3
4	6.2	9.4	6.5	11.3	8.9	9.6	7.4	5.9
5	7.4	6.5	10.8	9.2	10.0	5.7	10.3	8.0
6	6.3	11.6	10.8	13.3	9.4	11.0	9.7	8.8
7	10.5	11.1	7.8	11.3	10.1	7.8	8.0	7.5
8	6.6	7.2	11.0	8.6	6.7	5.5	9.7	7.5
9	6.2	6.9	13.1	13.5	8.9	13.1	5.8	9.9
10	7.2	14.8	9.1	13.9	8.7	9.8	10.9	12.0
11	4.7	7.3	6.9	8.6	12.2	12.7	8.5	10.0
12	7.0	8.8	14.7	4.8	9.5	7.7	8.1	10.7
13	7.8	11.9	10.4	17.1	9.4	11.6	8.1	12.9
14	7.1	11.9	9.6	13.9	9.5	7.6	8.1	8.4
$\bar{\sigma}$, lb. ¹	7.2	10.4	10.3	11.3	9.5	9.0	8.7	9.1
\bar{X} , lb. ²	93.3	66.3	94.4	44.4	66.3	33.6	69.1	39.6

\bar{X} Chart

UCL, lb. ³	96.0	70.2	98.3	48.7	69.9	37.0	72.4	43.0
LCL, lb. ³	90.6	62.4	90.5	40.1	62.7	30.2	65.8	36.2

σ Chart

UCL, lb. ⁴	9.1	13.2	13.1	14.3	12.0	11.4	11.0	11.5
LCL, lb. ⁴	5.3	7.6	7.5	8.3	7.0	6.6	6.4	6.7

Notes * $\sigma = \sqrt{\frac{\sum (x - \bar{x})^2}{N - 1}}$

1. $\bar{\sigma}$ = Square root of average of 14 individual σ^2
2. Values from Table V.
3. For \bar{X} control chart,
Upper control limit, UCL, = $\bar{X} + 2 \frac{\bar{\sigma}}{\sqrt{28}}$
Lower control limit, LCL, = $\bar{X} - 2 \frac{\bar{\sigma}}{\sqrt{28}}$
4. For σ control chart,
Upper control limit, UCL, = $\bar{\sigma} + 2 \frac{\bar{\sigma}}{\sqrt{56}}$
Lower control limit, LCL, = $\bar{\sigma} - 2 \frac{\bar{\sigma}}{\sqrt{56}}$

Fig.5

CONTROL CHARTS ON THE AMOUNT OF ABRASION & VARIABILITY OF 14 WYZENBEEK MACHINES

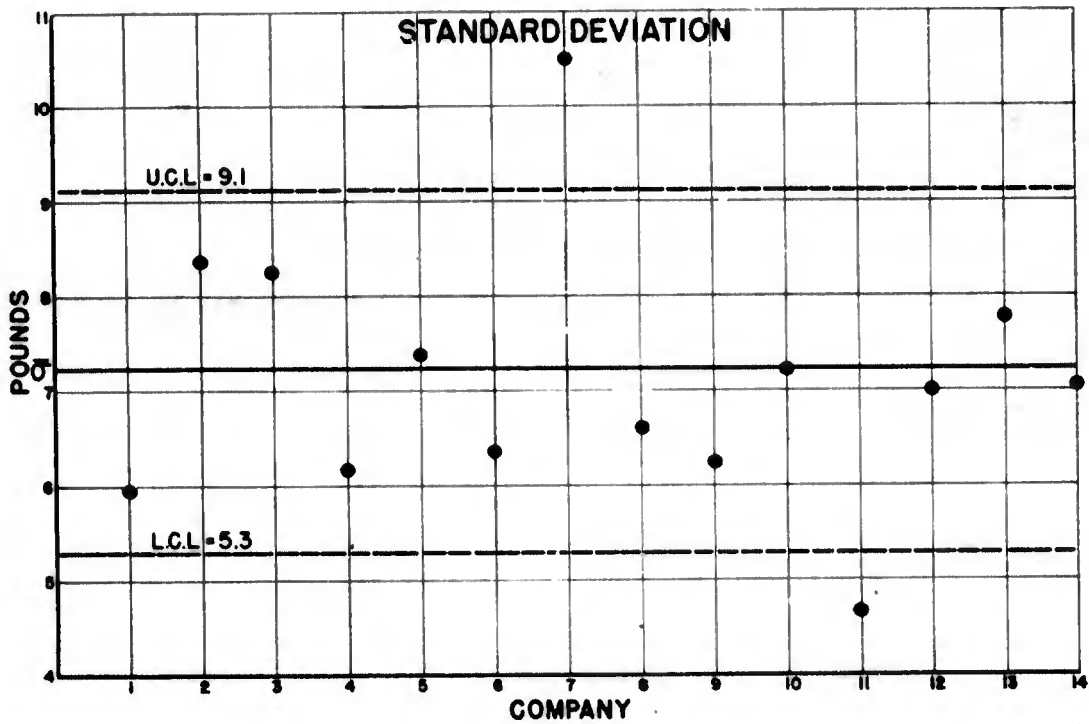
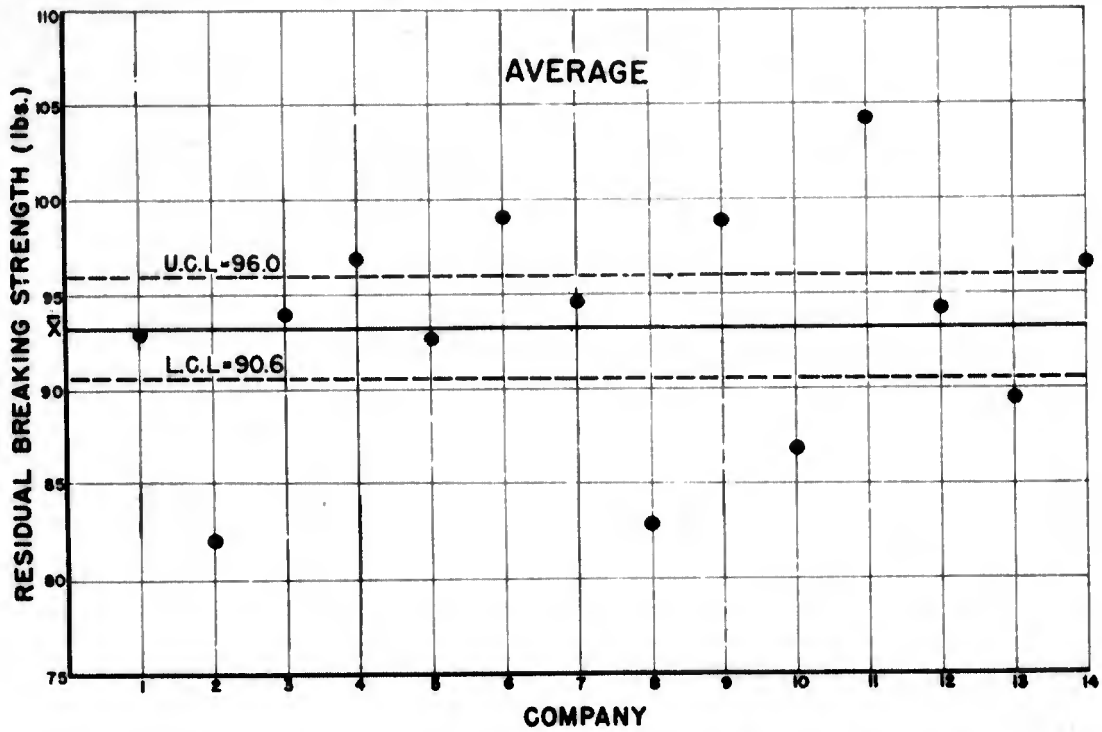
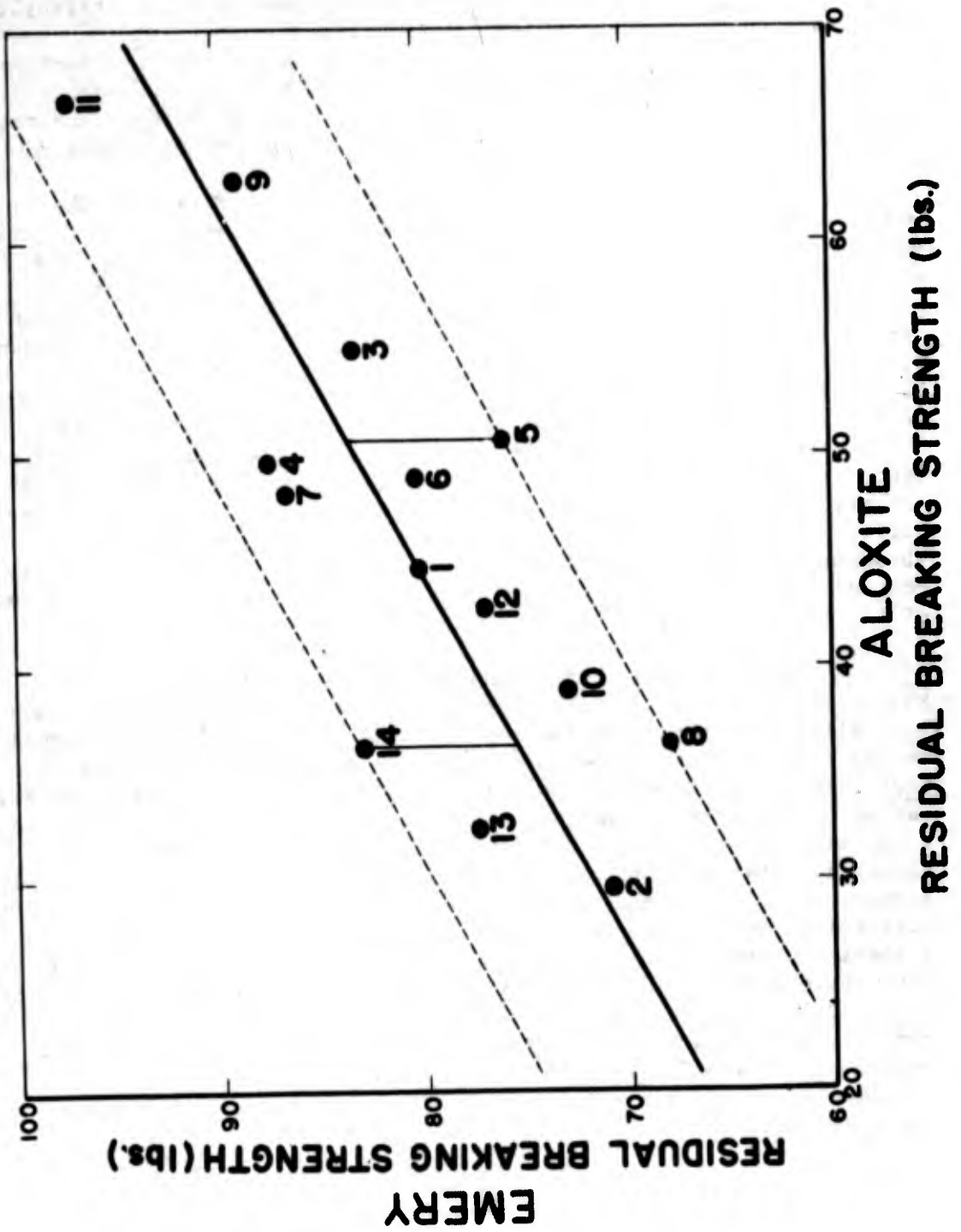


Fig.6
CONSISTENCY OF INDIVIDUAL WYZENBEEK



Reproducibility and Consistency of Results. The variability or dispersion of the breaking-strength values of the 28 abraded specimens of each fabric for each laboratory is shown by standard deviations in Table VI. Although the precision of the average values from one or two laboratories may have differed significantly from the rest, none was significantly less precise for more than one material.

Since this experiment yielded sufficient data from the four materials for the individual arms, the analysis of variance technique can be used to eliminate the role played by the heterogeneity of arms and differences among materials and so obtain the intrinsic variability, σ^2 , of the results from each laboratory. This intrinsic variability, listed by laboratories in Table VII, includes differences within the fabrics (known to be relatively minor) and the variability of the machines, exclusive of the effects of the arms. The intrinsic variability is shown to be the basic variability of the machines by the fact that approximately the same average value is obtained for all laboratories irrespective of abradant used. Therefore, it would be expected that within each laboratory, the ratio of the intrinsic variability obtained with emery abradant to that obtained with aloxite abradant equals approximately unity. If this ratio is significantly greater than one for a laboratory, the reproducibility and consistency of its instrument would be seriously questioned.

The internal consistency can be checked by using the chi-square technique, which evaluates the discrepancy between the values theoretically obtained on the basis of the assumption and the actual values. In this case, the chi-square analysis was used to ascertain significance of the difference between the actual and the theoretical ratios of the average residual breaking strengths of the four fabrics using each abrasive. The theoretical ratios were computed on the assumption that the residual breaking strength of each of the materials abraded in a laboratory should form a constant ratio regardless of the abradant in order that the results of a laboratory be considered consistent. Consequently, the reproducibility of the results from Laboratories 5 and 12 would be doubtful, their values for the ratio being 2.19 and 1.80, respectively, instead of being approximately 1.0. This conclusion is substantiated by their lack of consistency, for their values of σ^2 are 7.8 and 9.8, respectively. The high value of σ^2 for Laboratory 13 is a result of a sharp reversal of the data when emery and aloxite were used.

TABLE VII. OVERALL COMPARISON OF AMOUNT OF ABRASION
AND REPRODUCIBILITY OF 14 WYZENBEEK TESTERS

Lab.	Emery Abradant			Aloxite Abradant			Reproducibility $\sqrt{e^2}/\sqrt{a^2}$	Consistency χ^2
	RBS, lb. ^x			RBS, lb. ^x				
	\bar{X}	$\sqrt{e^2}$	$\sqrt{e^*}$	\bar{X}	$\sqrt{a^2}$	$\sqrt{a^*}$		
1	80.1	77.10	8.8	44.7	53.53	7.3	1.44	3.1
2	70.9	66.35	8.2	29.4	62.18	7.9	1.07	5.0
3	83.3	65.52	8.1	54.7	60.39	7.8	1.08	4.0
4	87.6	53.10	7.3	49.4	45.62	6.8	1.16	5.2
5	76.1	91.48	9.6	50.5	41.78	6.5	2.19**	7.8***
6	80.4	51.60	7.2	49.0	52.73	7.3	0.98	1.4
7	86.7	77.80	8.8	48.0	64.81	8.1	1.10	3.7
8	68.0	46.53	6.8	36.3	48.01	6.9	0.97	2.1
9	89.1	69.40	8.3	62.8	88.23	9.4	0.79	3.6
10	72.8	62.83	7.9	38.9	84.92	9.2	0.74	5.2
11	97.2	68.13	8.3	66.5	85.39	9.2	0.80	1.4***
12	77.0	102.85	10.1	42.8	57.04	7.6	1.80**	9.8***
13	77.6	66.28	8.1	32.4	83.23	9.1	0.80	12.2***
14	83.2	60.69	7.8	36.2	72.05	8.5	0.84	4.5
Ave.	80.7		8.3****	45.8		8.0****		

Notes: x Residual breaking strength of 112 specimens.

* Variability of apparatus and technique, after elimination of variability caused by material and differences among arms.

** Highly significant, indicating lack of reproducibility of results due to apparatus or technique.

*** Highly significant lack of consistency.

**** $\sqrt{\quad}$ = Square root of average of 14 individual $\sqrt{\quad}^2$.

Contributory Causes of Variability. Hitherto the discussion of results has not considered possible causes of the heterogeneity of the arms, but a study of the Wyzenbeek tester would not be complete without an analysis of this factor. The data of Table VIII, which are the average breaking strengths of the specimens inserted into each arm of each instrument, show the arms which yield results significantly different from their mates. As the rubber pads used in the Wyzenbeek apparatus may differ considerably in physical characteristics, and thus in their abrading efficiency, employment of homogeneous pads would result in greater reliability. Further, by bringing the differing arm into line with the others, much closer control limits would be obtained. In a separate experiment, interchanging the pads among the arms of a single instrument resulted in a reranking of the arms. Thus, differences in the rubber abrading pads is an important factor contributing to the differences among instruments, but it is not the only machine factor.

This study indicates that the use of 1/0 Emery abrasant yields results having 50 per cent less variability than does the use of 320 Aloxite abrasive. As previously mentioned, an excellent consistency exists in the individual evaluation of all the fabrics tested by each laboratory when emery is employed. The consistency is much less apparent when aloxite is used.

A comparison of the two types of endpoints is made possible by the two interlaboratory tests since herringbone-twill fabric was used in each. In the first test a subjective endpoint was studied, namely the number of cycles of abrasion required to produce a described change in appearance. In the second test the endpoint was objective, for the loss in breaking strength after an arbitrary number of cycles of abrasion was noted. Comparative values of the coefficients of variation for the two endpoints are shown in Table IX.

From this table, it will be seen that the coefficients of the subjective endpoints are approximately thrice that of the objective endpoint.

TABLE VIII - NON-HOMOGENEITY OF ARMS BASED UPON RESIDUAL BREAKING STRENGTH

LABS	ABRADANT	HBT ARM				POPLIN ARM				SATEEN ARM				2/1 TWILL ARM				AVERAGE OF ALL FABRICS ARM				RANKING OF ARMS
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	
1	E	97.3	93.0	89.7	91.7	99.6	97.0	89.9	97.6	74.4	67.7	62.3	63.1	70.6	63.3	58.9	65.4	85.5	80.2	75.2	79.5	3-42-1
	A	62.7	63.7	50.9	64.1	57.4	53.3	48.7	62.6	31.9	30.1	24.0	23.1	39.7	34.9	29.4	38.4	47.9	45.5	38.3	47.1	3-241
2	E	81.7	82.9	75.1	88.6	92.6	83.1	71.6	91.3	57.9	58.4	55.6	61.7	57.9	60.3	52.3	63.7	72.5	71.2	63.6	76.3	3-214
	A	41.4	53.3	38.6	53.4	21.7	29.9	32.4	43.7	13.0	18.9	16.1	19.7	20.0	24.4	15.7	28.1	24.0	31.6	25.7	36.3	13-24
3	E	92.4	92.0	59.1	92.9	96.3	106.0	105.7	99.6	63.1	67.9	65.1	64.0	72.7	69.7	71.9	74.3	81.1	83.9	85.5	82.7	1423
	A	75.4	83.3	81.6	77.0	60.9	59.0	59.1	58.0	37.3	40.1	33.9	38.7	40.3	44.7	47.0	38.4	53.5	56.8	55.4	53.0	4132
4	E	98.4	97.6	95.3	95.7	107.9	113.0	106.0	100.0	72.1	81.0	74.7	72.6	73.6	68.4	67.9	69.4	88.0	90.0	86.0	86.4	341-2
	A	74.1	74.7	59.4	77.7	44.9	61.3	36.9	53.4	46.9	47.0	31.9	42.0	43.7	43.0	53.3	45.4	50.5	54.2	40.2	52.8	3-142
5	E	96.3	89.1	94.6	91.0	83.4	79.4	90.1	87.4	53.4	60.0	58.3	59.4	63.9	64.9	72.4	73.6	74.2	73.4	78.9	77.9	214-3
	A	83.3	82.1	85.3	86.7	36.0	37.3	46.0	51.3	25.1	24.9	33.6	30.7	43.7	43.0	53.3	45.4	47.0	46.8	54.5	53.5	214-3
6	E	104.9	96.6	99.1	95.3	98.6	82.4	87.4	79.0	69.7	59.3	70.3	57.1	78.0	73.3	65.9	59.4	87.8	80.4	80.7	72.7	4-23-1
	A	78.4	72.0	67.7	54.3	60.6	59.6	45.9	36.0	43.7	37.1	30.3	19.0	55.3	46.3	38.7	39.3	59.5	53.7	45.6	37.1	4-32-1
7	E	91.9	92.0	96.4	97.4	108.3	107.0	101.9	101.1	79.7	71.7	76.4	69.3	81.0	68.9	68.9	75.3	90.2	84.9	85.9	85.8	243-1
	A	71.1	58.4	60.1	66.4	41.0	43.0	43.0	59.6	42.0	30.9	33.4	42.0	42.9	42.9	38.6	52.1	49.2	43.8	43.8	55.0	231-4
8	E	85.1	80.9	84.0	81.3	72.3	77.7	97.7	75.0	39.9	40.9	50.1	41.1	67.7	69.0	66.1	59.7	66.2	67.1	74.5	64.3	412-3
	A	51.7	47.4	51.6	41.7	35.4	36.3	31.6	30.6	28.6	23.1	32.3	26.9	35.7	36.0	39.9	32.3	37.9	35.7	38.8	32.9	4-213
9	E	95.3	100.1	100.7	99.6	102.7	104.7	106.0	81.7	76.4	87.6	84.6	80.7	71.4	74.6	72.4	78.7	86.5	91.7	90.9	87.2	14-32
	A	83.4	86.6	84.3	88.1	44.9	62.3	72.0	61.9	43.6	67.0	61.1	55.9	50.6	50.4	47.1	45.4	55.6	66.6	66.1	62.8	1-432
10	E	80.4	92.7	87.3	87.1	74.9	92.9	85.4	82.7	56.9	68.4	56.3	53.7	56.9	66.1	62.1	60.3	67.2	80.0	72.8	71.0	1-43-2
	A	45.6	79.7	58.7	54.0	28.0	53.4	28.7	35.7	20.1	29.9	17.3	19.4	28.7	43.4	45.9	33.1	30.6	51.6	37.6	35.6	1-43-2
11	E	104.6	104.3	104.7	103.9	112.3	116.6	116.1	109.9	84.6	81.0	95.1	86.6	82.3	83.7	89.6	80.4	95.9	96.4	101.4	95.2	412-3
	A	83.6	85.4	84.1	75.3	71.7	77.7	74.9	63.3	58.7	54.7	59.4	62.6	55.9	60.3	47.9	48.7	67.5	69.5	66.6	62.5	4132
12	E	96.9	88.4	98.1	93.1	84.7	84.0	86.9	91.7	61.9	58.4	67.1	61.4	65.7	57.4	68.6	67.7	77.3	72.1	80.2	78.5	2-143
	A	75.4	67.3	80.0	65.6	30.7	28.1	33.7	33.9	33.4	23.3	25.3	31.7	36.6	35.4	43.4	40.9	44.0	38.5	45.6	43.0	2-413
13*	E	84.1	90.1	94.7	---	95.1	80.4	95.9	---	58.0	64.4	64.6	---	67.7	67.4	69.1	---	76.2	75.6	81.1	---	21-3
	A	44.1	49.4	60.4	---	6.7	12.7	41.3	---	14.9	21.7	28.3	---	32.1	26.6	51.0	---	24.5	27.6	45.2	---	12-3
14	E	94.3	95.5	98.4	98.7	91.6	85.0	91.6	104.4	69.6	65.3	74.6	75.9	70.1	73.9	67.4	74.4	81.4	79.9	83.0	88.4	321-4
	A	42.3	45.6	68.6	61.7	26.3	21.3	30.3	37.7	30.4	22.1	30.7	38.6	30.0	23.3	35.1	39.1	32.2	28.1	40.2	44.3	213-4

*THREE-ARM MODEL

TABLE IX. VARIABILITIES OF THE TWO TYPES OF ENDPOINTS
 USING EMERY ABRADANT AND HBT FABRIC

	Objective Endpoint Residual B.S., %	Subjective Endpoint			
		1st Rupture		Threadbare	
		<u>W</u>	<u>F</u>	<u>W</u>	<u>F</u>
% Dev. from Mean					
Average	4.9	68	64	56	59
Range	11.8	261	295	175	210
Coef. of Var., V	30.2	104	109	78	87
Ratio of V_{sub}/V_{obj}	----	3.5	3.6	2.6	2.9

Conclusions

On the basis of the results reported in this paper, the following conclusions may be stated;

1. In its present state, the Wyzenbeek Precision Wear Test Meter
 - (a) can be used in evaluating differences among materials by a given laboratory;
 - (b) can be utilized by cooperating laboratories for interlaboratory checks if their instruments are predetermined to be sufficiently similar in abrasive action and reproducibility;
 - (c) cannot be employed in establishing a general standard.

2. Increase in precision may be achieved by
 - (a) using an objective endpoint whenever feasible;
 - (b) employing a mild uniform abradant;
 - (c) utilizing control-chart techniques to ensure consistency among arms and tests.

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