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WEARING QUALITY OF SOME VEGETABLE-TANNED SOLE LEATHERS

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ABSTRACT

The differences between the wearing qualities of vegetable-tanned commercial sole leathers are small, the difference between the best and worst of the 20 tannages studied amounting to less than 16 percent. Additional compression, similar to that given by heavy rolling, improved the wear 5 percent. The tests also indicated that there is no significant difference in the wear of leather tanned from domestic and from frigorifico hides; that water-soluble material and grease are lost from soles in service, with the greatest loss being shown by water-soluble ash; that the "rubber" and "leather" abrasive machines are of little use in predicting the relative wearing qualities of tannages; and that the water-soluble content, firmness, and degree of tannage are useful in estimating the wearing quality. These conclusions are based on tests in service of about 500 pairs of soles, mostly at Camp Lee, Va.

CONTENTS

I. INTRODUCTION

The present World War has greatly increased interest in the problem of improving the wear of sole leather. To this extent the history of the first World War has been repeated, for at that time researches on improving the quality of sole leather [1, 2, 3][1] and on measuring the resistance of leather to abrasion in the laboratory [4, 5] were first reported in the literature. This concern about the quality of sole leather is related directly to the excess of demand over supply in time of war. It finds expression in research in two directions, first, for substitutes for leather, and second, for methods of improving the wear of leather.

The investigation reported in this paper was concerned with the relation between physical and chemical properties of sole leather and its wearing quality. It was begun at the instance of the War Production Board, which requested that an effort be made to determine whether any of the ordinary commercial tannages would wear significantly better or worse than the average, and whether heavier rolling would improve the wear. The experiments were planned primarily to give the answers to these questions. At the same time, however, it was possible to get considerable information on the chemical and physical properties of the tannages studied, and to examine the relation between these properties and the wearing qualities of the tannages. This report is published with the expectation that the experimental results will be of interest to tanners of sole leather and to those responsible for the framing of specifications.

II. MATERIALS AND METHODS USED

1. SELECTION OF LEATHER

All domestic tanners of factory sole leather were invited, through the Tanners' Council, to cooperate in these tests. Each was asked to submit 10 bends of factory leather, representative of his current production, gaging 10 irons, tanned from domestic branded steers, clear and free of brands, with the name of the establishment or tannage stamped on the tail. Seventeen such lots of bends were received. There were also submitted three lots of bends tanned from South American hides. These were included in order to compare leather tanned from domestic and from frigorifico hides.

2. IDENTIFICATION AND MEASUREMENT OF BENDS

When the bends were received an identifying letter was assigned to each tannage, each bend was marked with the proper letter, and the other identifying marks were removed. The bends of each tannage were numbered from 1 to 10 in order of increasing thickness. The following observations were recorded for each bend: kind of hide (domestic or South American), right or left bend, gage in irons, width at butt and at shoulder, length, and an estimate of its solidity. The average dimensions and observations for each tannage are given in table 1.

3. PREPARATION OF SPECIMENS FOR TESTS

All taps were cut in the standard large military size, which could be used for all the shoes in the tests. The locations from which the taps were cut are shown in figure 1.

[1] Figures in brackets indicate the literature references at the end of this paper.

TABLE 1.—*Dimensions of bends of sole leather*

Tannage	Gage (irons)	Width at butt	Width at shoulder	Length	Area [1]	Notes
		in.	*in.*	*in.*	*in.*^{2}	
A	10	27	23	46	1,150	Domestic; flexible.
B	9½	27	26	48	1,270	South American; flexible.
C	10	26	24	49	1,220	Domestic; flexible.
D	9½	27	25	52	1,350	Do.
E	10	28	24	46	1,200	Do.
F	10	28	26	43	1,160	Domestic; firm.
G	10	26	26	55	1,430	South American; firm-flexible.
H	10	26	24	49	1,220	Domestic; flexible.
J	10	32	27	50	1,480	Domestic; firm-flexible.
K	9½	26	25	49	1,250	Domestic; flexible.
L	10	30	26	50	1,400	Do.
M	10	28	24	55	1,430	Domestic; firm-flexible.
N	10	28	27	53	1,460	Domestic; flexible.
P	10	27	24	50	1,280	Do.
Q	8½	27	25	50	1,300	South American; very ticky; flexible.
R	10	28	27	54	1,480	Domestic; firm-flexible.
S	9	28	24	52	1,350	Domestic; cows; flexible.
T	10½	27	27	50	1,350	Domestic; flexible.
U	10½	29	26	54	1,480	Do.
W	10½	25	24	50	1,220	Do.
Average	10	27.5	25.2	50.2	1,324	

[1] Area equals average of widths times length.

Cutting was started at the point where the wrinkles at the root of the tail ended. Six strips, each 6¾ in. wide, were cut, and four taps were cut from each strip, starting at the backbone edge. The 1st, 3d, and 5th strips from odd-numbered bends, and the 2d, 4th, and 6th strips from even-numbered bends, were cut into left taps, the others into right taps.

Taps 2 and 3 were used for chemical analyses and physical measurements; these correspond most nearly to the "A" location in the Official Methods of Sampling and Analysis of the American Leather Chemists Association. Taps 4, 10, 12, 22, and 24 were used for the comparison of wearing qualities of the tannages in actual service. Taps 8, 9, 15, 16, 18, 19, 25, and 26 from some bends were used for the study of the

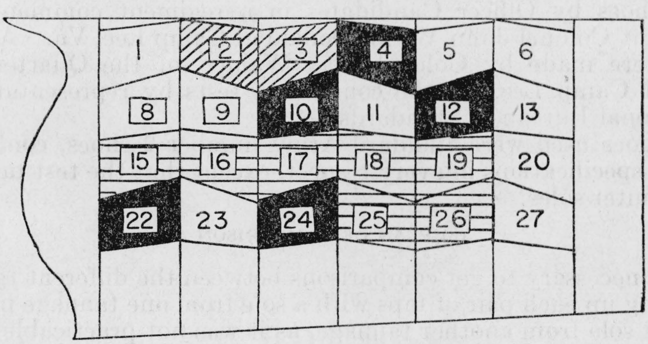

FIGURE 1.—*Location of taps for tests.*

Taps shown with solid shading were used for the comparison of wearing qualities of tannages; those indicated by horizontal lines were used for the study of the effect of compression and for measurement of resistance to abrasion in the laboratory; those marked with diagonal lines were used for chemical analyses and physical tests.

effect of compression on wearing qualities, as will be shown below. Taps 15, 16, 17, 18, and 19, with a few others from some bends, were used for measurements of resistance to abrasion in the laboratory. The weights and thicknesses of all taps were measured after conditioning in an atmosphere at 70° F and 65-percent relative humidity for 48 hours.

For the study of the effect of additional compression, 80 pairs of taps, 4 from each of the 20 tannages, were used. The 4 pairs of taps from each tannage were taken from the following hides and locations:

Hide	Location
1	8 and 9.
4	15 and 16.
7	18 and 19.
10	25 and 26.

After measurements of thickness and weight, 1 tap of each pair was taken, and to each of the group of 80 taps so formed there was added 10 percent by weight of water. This amount was chosen because it gave a total percentage of water approximately equal to that used by many tanneries when rolling sole leather. The taps were placed over water in a tightly closed container overnight to sammy. Each was then subjected to a pressure of 3,000 lb/in.^{2} for 3 minutes between flat, parallel metal surfaces. The compressed taps were reconditioned in the standard atmosphere and their thickness again measured.

After the taps had been matched in pairs, according to the procedure that will be described below, the serial number assigned to each pair for identification was stamped with dies about 1 inch from the base of each tap, on the flesh side, and was protected with a coat of cellulose acetate dope.

4. TESTS IN SERVICE

(a) WEARERS AND SHOES

By permission of the Quartermaster General, Major General Edmund B. Gregory, facilities were made available for the wearing of the shoes by Officer Candidates in a regiment commanded by Lieutenant Colonel John W. McDonald at Camp Lee, Va. Arrangements were made by Colonel Max Wainer, of the Quartermaster Board at Camp Lee, for the conduct of tests by representatives of the National Bureau of Standards.

The shoes used were standard Army number 2 shoes, conforming to Army specifications in every respect, except that the test taps were used as outer soles.

(b) PLAN OF COMPARISON

It was necessary to get comparisons between the different tannages by making up each pair of taps with a sole from one tannage matched against a sole from another tannage, as it was not practicable for the men at Camp Lee to keep daily records of the number of hours that the shoes were worn. This plan had the advantage of giving direct comparisons between the tannages, rather than depending on the size of the sample to give reliable figures for the length of time that a given tannage would wear.

In matching the pairs, the following rules were observed:

(1) Each tannage was matched at least twice against every other tannage and against itself. Thus each tannage was represented on at least 40 pairs of shoes. Matching each tannage against itself twice gave 40 pairs of soles from which could be calculated an independent estimate of the variance due to other sources than differences between tannages.

(2) The two taps in each pair had the same location numbers. This minimized differences in wear attributable to differences in location on the hide.

(3) The two taps in each pair came from bends numbered in sequence. As the bends were numbered in order of thickness, this tended to minimize differences in thickness between the taps.

(4) The five locations used for the tests in service were selected in cyclic order in such a way that different locations were used for each comparison between two given tannages. This tended to minimize variations attributable to possible different patterns of wear over the bend for different tannages. For example, it might be supposed that tannages having the same amounts of water-soluble matter in the region of the backbone, but different amounts in the belly areas might give different relative wear between the taps of a pair selected from the first region as compared with the relative wear of a pair of taps from the latter region.

(c) CONDUCT OF THE TESTS

The numbered taps were clipped together in pairs and shipped to a factory experienced in the manufacture of Army shoes. From the factory the shoes were shipped directly to Camp Lee, where about 450 pairs were issued to the Officer Candidates. Fifty pairs were issued to workers employed in various war industries, such as machinists, laborers, glass makers, shipyard and railroad workers, and laboratory personnel.

During part of the period of wear, the men were engaged in training activities in the camp, and during the remainder they were occupied with practice maneuvers in the field. The period of wear extended over about 7 weeks in June, July, and August. The weather was warm, with light to moderate rainfall. The soils in the area appear to be chiefly sandy and silt loams, in part under forest cover, with occasional small mucky areas in the region of the practice maneuvers. The pH values of the soils are in the neighborhood of 4.5 to 5.5.

Periodic inspections of the shoes were made by observers from the National Bureau of Standards. When either sole of a pair was worn through, that pair was withdrawn from service. When the wearers left Camp Lee, their shoes were sent to the laboratory.

(d) MEASUREMENT OF TAPS

Dirt was removed from the worn taps by scraping and brushing, using solvent to remove accumulations of adhesive where necessary. The taps were then conditioned in the standard atmosphere. Their thicknesses were measured by the method of Whitmore and Downing [6], they were weighed, and the area of each tap was measured with a planimeter. In a few instances where parts of the tap were worn completely away, those parts of the outline of the tap still present were projected to form the complete outline of the tap, and the area of this outline was measured.

5. TESTS IN THE LABORATORY

(a) CHEMICAL ANALYSES

Composite samples of the unworn leathers were prepared for chemical analysis, using portions from each of the 10 bends in each tannage. The official methods of the American Leather Chemists Association [7] were used. Total ash, water-soluble material, hide substance, grease, degree of tannage, and pH were determined for the A, B, and J locations. Portions of the worn soles were similarly analyzed, except that no classification according to location was made.

(b) PHYSICAL TESTS

The resistance to abrasion was measured by three laboratories, using the provisional method of the American Leather Chemists Association [8]. From each tannage, 12 pairs of taps were taken, at least 1 pair but not more than 2 from each bend. The 2 taps of each pair were located with their wider ends adjacent in the bend. Two specimens for this determination were cut from each tap. Of the 4 specimens from each pair of taps, each laboratory received 1, so that the 3 laboratories had nominally identical samples of 12 specimens each from each tannage. In all the laboratories, the 12 specimens from each tannage were run on the wheel of the abrasion machine at the same time.

The resistance to abrasion was also measured by two laboratories using the machine designed by Holt for measuring this property of rubber [9], and used by some laboratories for leather. Two nominally identical samples were used for this purpose. Each consisted of 12 specimens from each tannage, taken from the taps mentioned in the preceding paragraph.

The apparent density of the specimens for measurement of abrasion was determined from the weight and dimensions of the specimens. Pieces cut from the worn soles were used for measurements of apparent density by the apparatus and method of Wallace and Kanagy [10].

The compressibility was measured by the change in thickness of a specimen subjected to the process of compression described in section II–3 of this paper.

III. RESULTS AND DISCUSSION

1. TESTS IN SERVICE

(a) VARIATION IN WEAR BETWEEN TANNAGES

The results of the tests showed that two tannages were significantly worse than the average, and that three were better. In no case, however, did the difference between any tannage and the average exceed 9 percent.

The results were first calculated by the usual method as "quality indexes" [6] for each pair of taps, with the index for the better tap of each pair set arbitrarily at 1.00, and the index for the worse one expressed as a decimal fraction. The sets of indexes calculated thus did not lend themselves readily to the estimation of significant differences between tannages, as the distribution of frequencies was not normal but J-shaped. Some distributions for single tannages had additional maxima at lower values. If, however, the average index for each pair of taps is made equal to 1.00, a normal frequency distribution is obtained. The calculation is given by the formula

$$Q_x = \frac{2y}{x+y},$$

where Q_x is the index of a tap X in a pair X,Y, and x,y are the thicknesses worn away from X and Y, respectively. For convenience in interpretation, all indexes were based on 100 instead of 1.00. An index calculated in this manner is designated "quality ratio" to distinguish if from the original "quality index."

The average quality ratio for each tannage was calculated. This index, based only on the thickness worn away, will be called Q_t. The values of Q_t are given in the second column of table 2. Q_t is the measure of wearing quality that is of most interest to the wearer of shoes who pays a price that is negligibly affected by the weight of the sole leather. It is the index that most nearly reflects the interests of the average individual consumer.

An analysis of the variance of individual values of Q_t was made.[2]

TABLE 2.—*Relative wear of tannages*

Tannage	Q_t	Standard error of Q_t	Density	Q_d	Q_h	Q_{hd}	Q_w
1	2	3	4	5	6	7	8
			g/cm^3				
A	95.3	1.5	0.92	103.3	90.0	96.7	103.3
B	99.4	1.5	.96	103.2	91.6	95.2	107.2
C	95.4	1.6	.97	98.1	94.1	96.8	97.4
D	98.2	1.7	1.02	96.0	105.1	102.8	90.7
E	99.4	1.6	0.96	103.2	95.3	99.0	105.0
F	109.0	1.7	1.07	101.6	111.3	103.8	100.6
G	102.4	1.6	1.00	102.1	100.8	100.5	101.9
H	97.2	1.5	1.02	95.0	107.1	104.7	96.5
J	101.5	1.6	1.01	100.2	101.2	99.9	98.2
K	107.2	1.7	1.03	103.8	106.0	102.7	107.7
L	107.7	1.6	1.02	105.3	104.1	101.8	104.1
M	97.8	1.7	1.00	97.5	98.0	97.8	94.0
N	93.5	1.6	0.99	94.1	92.7	93.5	94.3
P	101.8	1.8	.99	102.5	101.7	102.5	101.2
Q	104.8	1.7	1.05	99.5	99.5	94.5	104.8
R	95.7	1.7	1.00	95.4	103.9	103.7	89.0
S	95.9	1.7	0.95	100.6	94.8	99.6	100.6
T	100.3	1.8	.96	104.2	91.7	95.3	107.4
U	97.2	1.7	1.03	94.1	110.7	107.2	90.9
W	99.8	1.7	0.99	100.5	100.3	101.1	102.2

[2] Analysis of variance of Q_t:

Source	Degrees of freedom	Sum of squares	Mean square
Total	815	106,127	130.217
Between tannages	19	15,071	793.210
Within tannages	796	91,056	114.392

$$\frac{\text{Mean square between tannages}}{\text{Mean square within tannages}} = 6.93$$

Standard deviation $= 10.7$

The standard deviation was 10.7. The standard deviation calculated from the results of 35 nominally identical pairs of taps, that is, with both taps from the same tannage, was 8.6. The difference between the two values was less than twice the standard error of the difference. A weighted average value 10.6 has been used in subsequent calculations.

The standard error for the mean of each tannage was calculated. These values are given in column 3 of table 2. When the difference between the mean for a tannage and 100 (the mean of all ratios) exceeded three times the standard error, this fact was taken as indicating a significant difference. By this criterion, two tannages, A and N, are worse than average, and three, F, K, and L, are better. In no case, however, is the difference greater than 9 percent. This variation is much less than many persons familiar with sole leather had expected.

The quality ratios are given as adjusted on the basis of weight, under the symbol Q_d. This adjustment is necessary from the point of view of the purchaser of sole leather as such, since he does not buy leather on the basis of thickness and area alone, but pays for it by the pound. Any index of wearing quality, to be useful to him, should take account of the weight. This has been done in at least two previous investigations [2, 11] by dividing by the density. This operation was therefore performed on Q_t, using the figures for density of specimens for the abrasive tests, given in column 4 of table 2, and readjusting the results to an average of 100. The results are given in column 5. The maximum difference from the average is now less than 6 percent. This is an indication that part of the apparent difference in quality, judged on the basis of thickness alone, is caused by greater density of leather, which, in turn, may have been the result of heavier rolling. This point will be considered again below.

Another method of adjusting the quality ratios is on the basis of the hide substance in the leather. This is important from the point of view of conservation of hides. The relative wear per unit of hide substance, used as an indication of efficient utilization of hides, was calculated by dividing Q_t by the percentage of hide substance (see table 4) and multiplying by a constant factor so as to give an average of 100 for all tannages. The results, designated Q_h, are given in column 6 of table 2. A variant method is to divide Q_t by both hide substance and density, and then to adjust the quotients to an average of 100, as before. These results, Q_{hd}, are given in column 7. Both Q_h and Q_{hd} leave something to be desired in that they do not directly take into account the weight of hide substance coming into the tannery, that is, they give no indication of the efficient operation of the beamhouse in conserving hide substance, as distinct from the operation of the tanyard. They are, however, the best measures available from analyses of the finished leather.

As the percentage of hide substance is on the basis of weight, it is perhaps preferable that a quality ratio based on hide substance should also take into account the density, as does Q_{hd}. Q_{hd} also seems to be of particular interest, as it reflects to some extent the interests of the buyer, the wearer, and the conservationist.

The weight of leather worn away from a sole in service may be considered as a measure of the average thickness worn away over the whole area of the sole. It has little immediate practical significance, as the useful life of a sole is determined by the time when the maximum thickness worn away becomes equal to the original thickness of the sole, or nearly so, and not by the average thickness worn away. The results of measurements of the loss in weight of the soles in this experiment are included for the benefit of those who may wish to use the data in theoretical studies.

It was necessary to calculate the loss of weight of a tap by an indirect method, since the weight of the tap, after being attached to the shoe and trimmed to fit, was not obtainable. Let W_c and A_c be the weight and area of the original cut tap as measured in the laboratory; let W_t and A_t be the weight and area of the tap after being trimmed to fit the shoe; and let W_w and A_w be the measured weight and area of the worn tap. Then it is approximately true that $W_t/W_c = A_t/A_c$ and that $A_t = A_w$; hence $W_t = (A_w W_c)/A_c$, and L, the loss of weight in service, is given by $L = W_t - W_w = (A_w W_c)/A_c - W_w$.

The quality ratios from the data on loss of weight were calculated in the same way as those from the data on change in thickness. The results are given in column 8 of table 2 (Q_w).

(b) EFFECT OF ADDITIONAL COMPRESSION ON WEAR

As was stated earlier, 80 pairs of matched taps were used for this experiment, 1 tap of each pair having been compressed. The measurements of the thickness of the worn taps were used to calculate results in two ways, on the basis of the absolute change in thickness for each tap, and on the basis of the change in thickness as a fraction of the original thickness of the tap.

The basis of the absolute change in thickness for each tap is of particular interest to the consumer who purchases sole leather on the basis of thickness, since he is concerned with the relative wear of two leathers, of the same thickness after one has been rolled heavily. The basis of the change in thickness as a fraction of the original thickness, when put on the shoe, is of more interest to the conservationist, since he is concerned with the effect of heavy rolling on the rate of wear of the original material, that is, with the relative wear of two taps having the same thickness before one is rolled heavily.

Let T_o be the original thickness of each tap in a pair, and let T_c be the thickness of one tap after compression. Let T_{ow} and T_{cw} be the thicknesses of the worn taps corresponding to T_o and T_c, respectively. Then the quality ratio for the compressed leather with respect to the normal leather may be calculated either as

$$\frac{T_o - T_{ow}}{T_c - T_{cw}} \qquad (1)$$

or as

$$\frac{(T_o - T_{ow})/T_o}{(T_c - T_{cw})/T_c},$$

that is,

$$\frac{(T_o - T_{ow})T_c}{(T_c - T_{cw})T_o}. \qquad (2)$$

These are the two methods of calculation mentioned in the preceding paragraph.

It was found from measurements that the thickness of the original taps was 1.12 times the thickness of the same taps after compression. That is,

$$T_o=1.12T_c. \tag{3}$$

The loss in thickness of the uncompressed taps in service was 1.205 times the loss in thickness of the compressed taps. That is,

$$\frac{T_o-T_{ow}}{T_c-T_{cw}}=1.205. \tag{4}$$

The average change in thickness of the uncompressed taps in service, expressed as a fraction of their original thickness, was 1.075 times the average change in thickness of the compressed taps, expressed as a fraction of their original thickness. Using the notation adopted, we may write

$$\frac{(T_o-T_{ow})T_c}{(T_c-T_{cw})T_o}=1.075. \tag{5}$$

It has been suggested that a decompression may take place during wear, that is, that the leather fibers may spring out of the positions into which they have been forced by rolling. In order to check this point, the apparent densities of samples of worn soles were measured. The results indicated that the density of the normal leathers was about 2 percent less after wear, and that the density of the compressed leathers was about 4 percent less after wear than before. This supports the idea that decompression takes place. A correction in the results of the service tests of the compressed and normal leathers is therefore necessary. This was effected by decreasing the figures for the average thickness of the worn normal soles by 2 percent, and that of the worn compressed soles by 4 percent, before proceeding with the other calculations.

Let the corrected figures for the thicknesses of the worn soles be T'_{ow} and T'_{cw}. Then

$$T'_{ow}=0.98T_{ow}, \tag{6}$$

and

$$T'_{cw}=0.96T_{cw}. \tag{7}$$

It was known from the measurements that the average thickness worn away from the normal soles was 0.561 times the original thickness, that is,

$$T_o-T_{ow}=0.561T_o \tag{8}$$

or

$$T_{ow}=0.439T_o. \tag{9}$$

From eq 6 and 9,

$$T'_{ow}=0.430T_o. \tag{10}$$

From eq 4, 3, and 9,

$$T_{cw}=0.427T_o. \tag{11}$$

From eq 11 and 7,

$$T'_{cw}=0.410T_o. \tag{12}$$

The value of expression 1, using values of T_c, T'_{ow}, and T'_{cw} obtained from eq 3, 10, and 12, now becomes

$$\frac{T_o-0.430T_o}{.0893T_o-0.410T_o}=1.18.$$

Similarly, the value of expression 2 becomes 1.054.

These results are tabulated below:

Improvement in wear caused by heavy rolling

Thickness of sole	Original data	Data corrected for decompression in service
	%	%
Soles equally thick after rolling one heavily	20.5	18.0
Soles equally thick before rolling one heavily	7.5	5.4

From these results, the purchaser of sole leather on the basis of thickness might reasonably expect leather, heavily rolled as in this experiment, to wear about 18 percent longer than lightly rolled leather of the same thickness.

The results also indicate that a given tap will wear 5.4 percent longer if it is rolled heavily enough to give compression equivalent to that obtained in this experiment. This figure, 5.4 percent, is the one that is important to the conservationist, as it indicates the improvement in wear that might be expected if all sole leather were heavily rolled.

A test [3] of soles in service in Army camps in the southwestern part of this country showed that soles rolled according to usual commercial practice wore 16 percent better than unrolled soles. This figure corresponds roughly to the figure, 20.5 percent, reported here, although the tests represent comparisons covering different degrees of compression.

(c) COMPARISON OF LEATHERS FROM DOMESTIC AND FROM FRIGORIFICO HIDES

The data yielded a direct comparison of the wear of leathers from domestic and from frigorifico hides. The pertinent information is given in table 3. Tannage B, for which South American hides were

TABLE 3.—*Comparison of leathers from frigorifico and domestic hides*

	Tannery No. 1		Tannery No. 2	
	Frigorifico (B)	Domestic (T)	Frigorifico (G)	Domestic (W)
Ash, %	2.6	2.8	3.7	3.7
Water-soluble matter, %	25.1	25.1	29.1	30.1
Hide substance, %	40.9	41.2	38.3	37.5
Grease, %	5.8	6.1	3.2	4.7
Degree of tannage	68.9	67.1	77.0	73.6
pH	3.4	3.4	3.4	3.4
Water absorbed (24 hr), %	34	33	35	39
Change in thickness on compression, %	12.6	13.4	12.0	11.7
Q_t	99.4	100.3	102.4	99.8
Q_{hd}	95.2	95.3	100.5	101.1
Q_w	107.2	107.4	101.8	102.2

TABLE 4.—*Chemical analyses of leathers*

Tannage	Ash				Water soluble				Hide substance				Grease				Degree of tannage				pH		
	A	B	J	Avg	A	B	J	Avg	A	B	J	Avg	A	B	J	Avg	A	B	J	Avg	A	B	J
	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%							
A	4.1	5.0	6.0	5.0	24.0	28.0	32.6	28.2	42.8	40.5	36.4	39.9	3.9	4.1	4.1	4.0	68.1	66.7	72.8	69.2	3.1	3.1	3.2
B	2.0	2.6	3.1	2.6	22.5	24.2	28.7	25.1	42.8	40.9	38.9	40.9	6.3	5.9	5.3	5.8	66.2	70.9	69.7	68.9	3.4	3.3	3.4
C	4.6	5.3	6.0	5.3	27.2	29.7	33.0	30.0	40.5	38.1	36.0	38.2	4.0	3.7	4.4	4.0	68.9	73.5	72.5	71.6	3.4	3.4	3.5
D	5.8	7.1	7.6	6.8	30.4	35.0	37.5	34.3	38.3	34.5	32.9	35.2	6.2	4.5	5.3	5.3	64.8	74.5	72.9	70.7	3.5	3.4	3.5
E	3.3	4.2	4.8	4.1	26.2	28.1	31.3	28.5	41.7	39.6	36.6	39.3	5.4	3.9	5.0	4.8	63.3	70.7	73.0	69.0	3.5	3.4	3.5
F	3.6	4.8	5.5	4.6	28.4	31.1	33.2	30.9	39.0	37.1	34.7	36.9	5.4	4.1	4.1	4.5	69.5	74.4	80.4	74.8	3.2	3.1	3.2
G	3.7	3.5	3.9	3.7	26.7	29.4	31.2	29.1	40.6	39.0	35.2	38.3	2.8	2.7	4.0	3.2	73.4	73.8	83.8	77.0	3.4	3.3	3.5
H	4.4	5.2	5.6	5.1	30.2	33.8	37.4	33.8	35.6	35.0	32.1	34.2	5.7	5.1	5.9	5.6	79.2	72.7	75.7	76.2	3.3	3.3	3.4
J	2.8	3.4	3.6	3.3	25.8	29.2	34.9	30.0	38.1	40.0	35.2	37.8	6.3	4.6	4.9	5.3	77.0	65.3	70.7	71.0	3.3	3.3	3.5
K	3.9	5.2	5.0	4.7	27.8	30.6	31.7	30.0	40.8	37.6	36.0	38.1	2.7	2.2	2.4	2.4	69.9	78.5	82.8	77.1	3.2	3.2	3.3
L	2.7	3.2	3.7	3.2	22.9	25.6	28.1	25.5	40.8	39.1	37.0	39.0	5.8	4.6	5.6	5.3	73.5	77.7	78.4	76.5	3.2	3.2	-----
M	3.3	3.9	4.6	3.9	29.0	31.2	34.2	31.5	38.3	38.4	36.0	37.6	5.1	4.7	5.4	5.1	70.8	66.1	66.9	67.9	3.3	3.3	-----
N	4.0	5.3	5.7	5.0	27.4	31.1	36.0	31.5	39.9	38.2	35.8	38.0	5.6	2.4	3.3	3.8	67.4	72.8	68.2	69.5	3.1	3.0	-----
P	2.9	3.8	4.0	3.6	24.9	26.8	32.0	27.9	39.0	37.1	37.1	37.7	5.7	3.4	2.9	4.0	77.4	87.3	74.7	79.8	3.3	3.3	-----
Q	2.0	3.0	2.4	2.5	28.9	32.3	36.8	32.7	42.0	38.6	38.4	39.7	1.0	1.2	.7	1.0	66.7	72.0	62.5	67.1	3.3	3.2	-----
R	4.8	5.7	6.7	5.7	29.3	32.1	37.6	33.0	37.1	35.5	31.4	34.7	5.6	4.0	4.6	4.7	74.7	79.2	83.1	79.0	3.1	3.1	-----
S	3.6	4.3	6.4	4.8	27.2	29.9	32.6	29.9	40.1	38.3	36.0	38.1	5.5	5.4	6.5	5.8	67.7	67.9	68.1	67.9	3.3	3.2	-----
T	1.9	3.7	2.9	2.8	21.8	25.0	28.4	25.1	43.5	41.0	39.0	41.2	6.8	5.7	5.7	6.1	63.9	68.8	68.7	67.1	3.6	3.3	-----
U	5.5	6.7	7.4	6.5	31.0	36.4	42.5	36.6	37.7	33.2	28.5	33.1	5.2	5.6	6.8	5.9	68.7	73.8	76.8	73.1	3.5	3.3	-----
W	2.7	4.7	3.8	3.7	27.3	30.2	32.8	30.1	39.1	37.9	35.4	37.5	4.4	3.9	5.9	4.7	74.4	73.6	72.9	73.6	3.6	3.3	-----
Average	3.6	4.5	4.9	-----	27.0	30.0	33.4	-----	37.9	38.0	35.4	-----	5.0	4.1	4.6	-----	70.3	73.1	73.7	-----	-----	-----	-----
Average	-----	-----	-----	4.3	-----	-----	-----	30.1	-----	-----	-----	37.1	-----	-----	-----	4.6	-----	-----	-----	72.3	-----	-----	-----

used, was manufactured at the same tannery as T, which was made from domestic hides. Tannage G, from South Americans, came from the same tannery as W, from domestics. The comparison of chemical and physical data shows the identity of the treatment of the domestic and frigorifico hides in each tannery. For most of the items the differences are small enough to be within the range of experimental error. The results from the tests in service are very nearly alike. There is no evidence here that frigorifico hides will yield sole leather differing in quality from that from domestic hides.

2. TESTS IN THE LABORATORY

(a) CHEMICAL ANALYSES

The results of chemical analyses of the new leathers are given in table 4. As this is a fairly representative indication of current practice in the manufacture of sole leather in the United States, the entire body of data is reproduced, although no further use will be made of some of the data in this paper.

Chemical analyses of the worn soles are given in table 5. The results appear to be generally consistent, although there are a few aberrations, probably caused by fortuitous exposure of the shoes of some wearers to such materials as oil or water, a hazard that the size of the samples was too small to overcome. The general averages at the bottom of the table, however, may be regarded with a considerable degree of confidence, as they include a large number of specimens.

From a comparison of the general averages of chemical analyses of the new and worn soles, certain conclusions may be drawn about changes occurring in the leather during wear. The insoluble ash has increased from about 0.2 percent to about 1.1 percent. Visual and tactual examination shows that this is due to gritty particles of soil becoming embedded in the leather. The soluble ash has decreased

TABLE 5.—*Chemical analyses of worn soles*

Tannage	Total ash	Insoluble ash	Water-soluble	Hide substance	Grease	Degree of tannage	pH
	Percent	*Percent*	*Percent*	*Percent*	*Percent*		
A	2.7	1.1	18.5	46.5	2.5	67.5	3.5
B	1.7	0.9	16.6	45.8	4.1	71.2	3.5
C	2.9	1.2	19.8	44.8	3.7	68.1	3.6
D	2.9	1.4	19.2	42.9	4.3	75.1	3.7
E	2.8	1.6	18.0	45.0	3.4	71.1	3.5
F	2.6	1.1	20.0	42.8	3.2	76.5	3.3
G	2.2	0.8	21.3	43.5	2.4	73.7	3.4
H	3.0	1.3	25.3	40.0	2.4	77.5	3.5
J	2.0	0.8	19.7	46.2	3.4	64.7	3.5
K	2.8	1.0	19.7	43.6	2.1	74.3	3.5
L	2.2	1.1	19.0	43.1	4.2	71.4	3.4
M	2.7	1.1	21.7	43.5	3.0	70.3	3.4
N	3.0	1.0	18.0	42.1	4.3	82.2	3.5
P	2.5	1.1	19.1	40.6	3.8	87.2	3.5
Q	2.2	0.9	23.7	43.8	1.5	68.9	3.6
R	3.2	1.2	22.3	40.7	4.2	77.6	3.4
S	2.2	1.2	17.1	46.2	2.9	70.6	3.5
T	2.2	0.7	20.7	41.8	6.7	73.4	3.6
U	2.9	1.2	21.9	39.3	3.7	84.8	3.7
W	2.6	0.9	21.5	40.0	5.5	80.3	3.6
Average	2.6	1.1	20.4	43.1	3.6	74.3	3.5

from about 11 percent on the basis of the hide substance to about 3.5 percent, showing that a major part of the added salts is lost in service, probably by being leached. Other water-soluble material decreased from about 70 percent to about 44 percent on the basis of the hide substance, indicating a loss caused by leaching, but only at about half the rate for the inorganic materials. The percentage of grease also shows a marked decrease. Some small increases shown by individual tannages may be only apparent, because of the unequal distribution of oil through the thickness of the leather, as shown by microscopical examination at the Tanners' Council Laboratory, or because of chance exposure, in service, of some specimens to oil. Either alternative suggests the desirability of further experiments planned especially to study the behavior in service of the oil in sole leather.

The increase in the degree of tannage is so small that it may not be significant. It is, however, in the direction that would result from increased fixation of water-soluble tannins by the hide substance, and decreases still further the apparent loss of water-souble organic matter as compared with the water-soluble ash.

(b) PHYSICAL TESTS

The results of measurements of resistance to abrasion by the three laboratories are given in table 6. The orders in which the tannages were ranked by each machine in each laboratory are given, with ranks assigned by the midrank method when ties occurred. The indexes are expressed in the units customarily used for each type of machine. Each column shows some correlation with the results of tests in serv-

TABLE 6.—*Abrasive indexes*[1] *of sole leather*

Tannage	"Leather" machine							"Rubber" machine				
	Laboratory A		Laboratory B		Laboratory C		Average index	Laboratory B		Laboratory C		Average index
	Index	Rank	Index	Rank	Index	Bank		Index	Rank	Index	Rank	
A	2340	18	2980	12½	4550	7	3290	0.288	15	0.217	17	0.252
B	2660	14	3450	5	3120	13	3080	.242	3	.126	1	.184
C	4660	1	2860	15	7140	4½	4890	.252	5	.164	4	.208
D	3130	8	3350	6	2700	20	3060	.307	17	.222	18	.264
E	3170	7	2640	19	2940	16	2920	.264	7	.180	8½	.222
F	2700	11	3740	2½	2940	16	3130	.263	6	.196	15	.230
G	3240	4	3100	8	6670	6	4340	.239	2	.168	5	.204
H	2830	10	2680	18	4000	8	3170	.295	16	.236	20	.266
J	3280	3	3000	11	9090	2½	5120	.285	13	.186	12½	.236
K	3050	9	2980	12½	11110	1	5710	.243	4	.182	11	.212
L	2480	16	3170	7	2780	18½	2810	.274	11	.175	7	.224
M	2560	15	3080	9	7140	4½	4260	.270	10	.181	10	.226
N	3210	6	3740	2½	3230	11	3390	.286	14	.186	12½	.236
P	2260	19	2910	14	3330	10	2830	.313	18	.193	14	.253
Q	3220	5	3490	4	9090	2½	5270	.193	1	.163	3	.178
R	2250	20	2500	20	2780	18½	2510	.314	19	.197	16	.256
S	3430	2	2730	17	3120	13	3090	.277	12	.180	8½	.229
T	2450	17	3040	10	3840	9	3110	.268	9	.139	2	.204
U	2690	12	3890	1	2940	16	3170	.317	20	.231	19	.274
W	2670	13	2760	16	3120	13	2850	.266	8	.173	6	.220
Average	2860		3100		4780		3580	0.273		0.185		0.229

[1] The indexes for the "leather" machine are revolutions per millimeter; for the "rubber" machine, inches per 500 revolutions.

ice, as measured by Q_t. The best correlation was that obtained by laboratory B with the "rubber" machine, with a coefficient of correlation, −0.52. The negative sign shows that a high value for resistance to abrasion in the laboratory was accompanied by a low value for Q_t. As a high numerical value for the measurement in the laboratory indicates poor wear, there is actually a positive correlation between the machine and actual service. Somewhat better correlation was obtained with the "rubber" than with the "leather" machine. The agreement between laboratories, based on ranks, is also better for the "rubber" machine. For both machines, the averages show that absolute values obtained by different laboratories are not comparable. The rather poor degree of correlation indicates that, although resistance to abrasion may be one factor affecting wear, it is so much overbalanced by other factors, or these methods of abrading the leather are so far different from the kind of abrasion encountered in service, that these methods in their present stage of development are of little use in distinguishing between tannages.

The results of the measurements of compressibility are given in table 7. Determinations were made on two groups of specimens. The first consisted of rectangles, 50 by 98 mm, cut with a die from locations 2 and 3; the results are given in column 2. The second consisted of taps used in the tests in service; the results are in column 3. The average of the determinations on the two groups, given in column 4, is taken as the measure of compressibility used in this paper. The order of relative firmness (inverse order of compressibility) is given in the fifth column.

The data in this table give another means of testing the suggestion advanced in section III–1–(a), that the firmness affects the wearing quality. In figure 2, the values of Q_t are plotted in the order of decreasing firmness, or increasing compressibility. It appears that the firmer leathers wear better. If a straight line is drawn so as to pass

TABLE 7.—*Compressibility of sole leather*

Tannage	Compressibility			Order of firmness
	Small specimens	Taps	Average	
	Percent	*Percent*	*Percent*	
A	11.1	13.5	12.3	19
B	10.3	12.6	11.5	17
C	10.1	12.7	11.4	16
D	5.7	9.8	7.8	5
E	8.4	12.3	10.4	13
F	1.3	5.4	3.4	1
G	9.8	12.0	10.9	15
H	8.5	9.6	9.0	8½
J	6.6	8.0	7.3	4
K	8.2	8.5	8.4	7
L	4.5	6.6	5.6	2
M	7.6	11.4	9.5	10
N	8.1	12.1	10.1	12
P	5.8	10.8	8.3	6
Q	4.8	9.7	7.2	3
R	7.1	11.0	9.0	8½
S	12.4	12.6	12.5	20
T	10.3	13.4	11.8	18
U	7.9	11.2	9.6	11
W	9.4	11.7	10.6	14

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through the tops of most of the bars, the bars representing seven tannages fall below the line, that is, the relative wear of these tannages is not as good as might be predicted from their firmness. Of these seven, five D, H, M, R, and U, have high contents of water-soluble matter. The bars for four tannages extend considerably above the line, that is, their relative wear is better than the firmness would lead us to expect. All four contain less than the average amount of water-soluble matter.

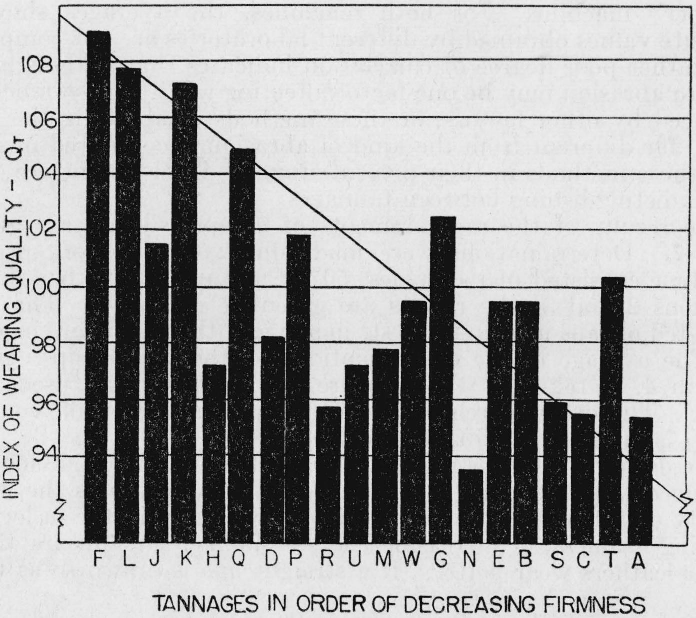

FIGURE 2.—*Indexes of wearing quality, Q_t arranged in order of decreasing firmness.*

As pointed out earlier, the index of wearing quality most useful to the purchaser of sole leather as such is that which has been adjusted on the basis of density, Q_d. There is a very low degree of correlation between Q_d and compressibility. This indicates that most of the correlation between compressibility and Q_t is due simply to the fact that when greater compression is applied, there are more fibers per unit volume to take the brunt of the wear. This confirms the results of the tests in service of taps compressed in the laboratory.

The correlation of Q_d with water-soluble content is shown in figure 3, in which the average content of water-soluble matter in the A, B, and J locations has been used. It appears to be true through the commercial range of water-soluble content that an increase of water-soluble matter results in decreased wearing quality. Some effect of heavy rolling is still apparent. The firm leathers L, K, F, Q, and D all have higher indexes than others with the same amount of water-soluble matter.

There is a rough relationship between Q_d and the amount of water-soluble material lost during service, as shown in figure 4. This supports in part the hypothesis that poor wear may be caused by removal

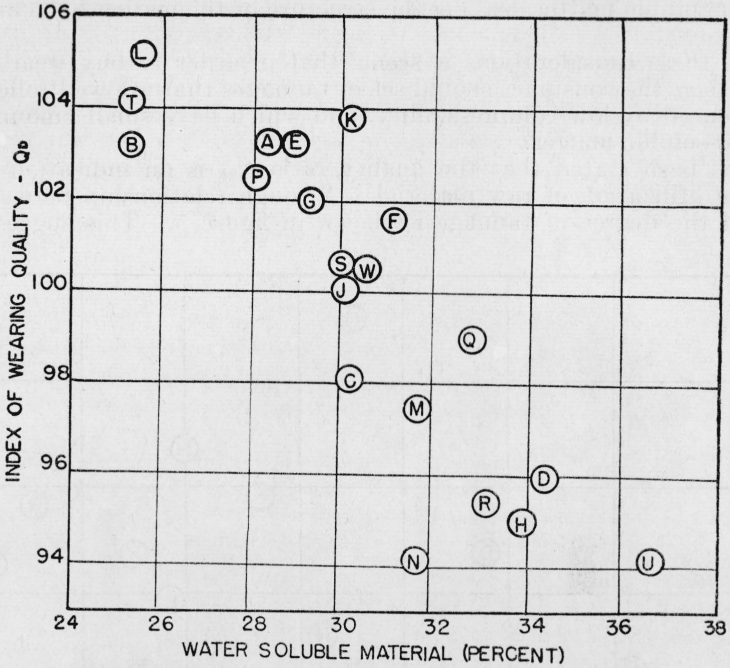

FIGURE 3.—*Relation between water-soluble material and index of wearing quality, Q_d.*

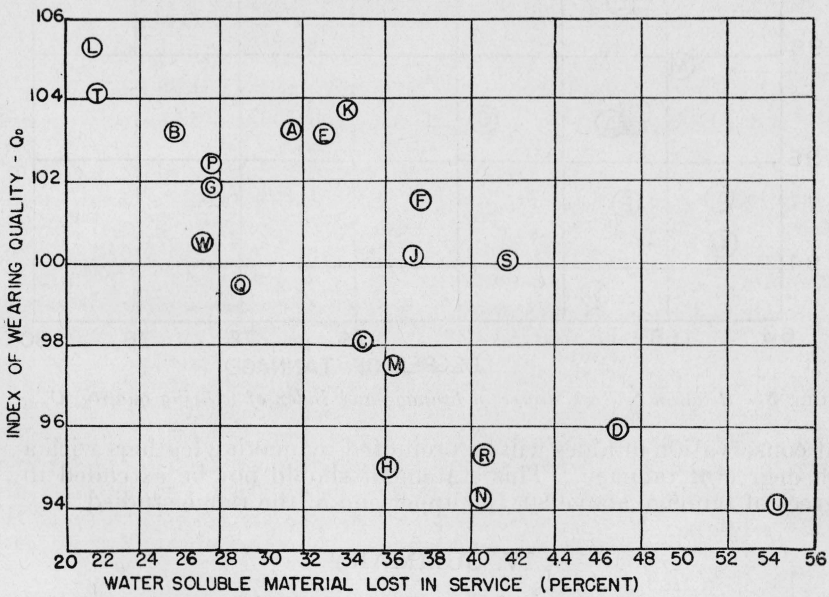

FIGURE 4.—*Relation between water-soluble material lost in service and index of wearing quality, Q_d.*

of water-soluble matter, leaving the structure of the leather open and flabby.

From these considerations it seems that in order to buy wear in sole leather, the consumer should select tannages that are well rolled, as evidenced by low compressibility, and which have small amounts of water-soluble matter.

It has been stated that the quality ratio Q_{hd} is an indication of effective utilization of raw material. A rough relationship between Q_{hd} and the degree of tannage is shown in figure 5. This suggests

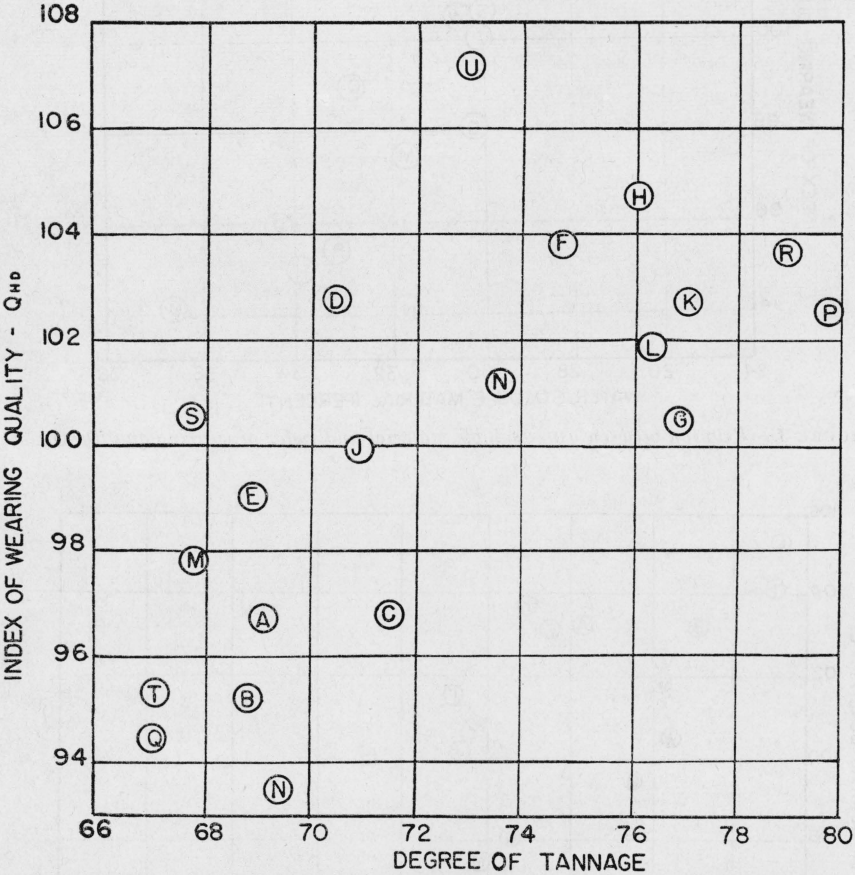

FIGURE 5.—*Relation between degree of tannage and index of wearing quality,* Q_{hd}.

that conservation of hides will be promoted by making leathers with a high degree of tannage. This statement should not be extended to degrees of tannage above 80, the upper end of the range studied.

IV. SUMMARY

The experiments showed that the differences in the wearing quality of the commercial tannages of sole leather studied were small, as illustrated by a maximum difference, between the best and worst tannages, of less than 16 percent. It was shown further that additional compression improves the wear, so that extra rolling would be expected to improve the total wear obtainable from a given piece of leather by about 5 percent.

These experiments also lead to several other conclusions that seem reasonable. They are, first, that leathers from domestic and frigorifico hides have equal wearing quality; second, that water-soluble material and grease are lost from the soles in service, with the greatest loss being shown by water-soluble ash; third, that the "rubber" and "leather" abrasive machines are not very useful for predicting the relative wearing quality of tannages; and fourth, that water-soluble content, firmness, and degree of tannage are useful in predicting the wearing quality of tannages.

V. REFERENCES

[1] F. P. Veitch and J. S. Rogers, J. Am. Leather Chem. Assn. **13,** 86 (1918).
[2] P. L. Wormeley, R. C. Bowker, R. W. Hart, L. M. Whitmore, and J. B. Churchill, BS Tech. Pap. 138 (Oct. 6, 1919).
[3] F. P. Veitch, R. W. Frey, and I. D. Clarke, U. S. Dept. Agriculture Bul. 1168 (Sept. 5, 1923).
[4] Lloyd Balderston, J. Am. Leather Chem. Assn. **11,** 429 and 498, (1916).
[5] Lloyd Balderston, J. Am. Leather Chem. Assn. **12,** 523 (1917).
[6] L. M. Whitmore and G. V. Downing, J. Am. Leather Chem. Assn. **37,** 150 (1942).
[7] Methods of Sampling and Analysis, Methods Book, Sec. B. American Leather Chemists Association (1943).
[8] Methods of Sampling and Analysis, Methods Book, Sec. E. American Leather Chemists Association (1943).
[9] Federal Specification ZZ–R–601a. Rubber Goods; General Specifications; page 17.
[10] J. R. Kanagy and E. L. Wallace, J. Am. Leather Chem. Assn. **38,** 314 (1943).
[11] R. B. Hobbs and H. E. Bussey, J. Am. Leather Chem. Assn. **39,** 109 (1944).

WASHINGTON, October 10, 1944.