HILGARDIA

A Journal of Agricultural Science Published by the California Agricultural Experiment Station

VOLUME 11 | JANUARY, 1938 | NUMBER 4

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UNIVERSITY OF CALIFORNIA · BERKELEY, CALIFORNIA

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SINGLE AND MULTIPLE-FIBER TESTS FOR DETERMINING COMPARATIVE BREAKING LOADS OF WOOL FIBERS[1]

J. F. WILSON[2] AND E. B. ROESSLER[3]

INTRODUCTION

FOR MANY YEARS wool technologists have tested the breaking load and the breaking stress of wool by using individual fibers. The number of fibers that must be broken individually in order to yield mean values of significance varies mostly with the uniformity of diameter of the fibers constituting the sample. Most staples or locks of wool, even from a small area on a purebred animal of an improved breed, will contain some fibers twice as coarse as others lying almost contiguous in the same sample. Among the breeds less improved from the standpoint of wool production, a lock taken from a small spot on the shoulder of the animal, where presumably the least variation might be found, may show differences as high as 400 per cent in fiber diameter. The sheep breeder aims to produce animals with uniform fleeces in which fiber diameter is the same over all parts of the body. As yet, however, man's effort to hasten the evolution of the sheep has not resulted in fleeces which can be called uniform if judged by standards for commodities other than wool. A staple of wool may be exceedingly uniform by comparison with a similar staple from another individual; but if its component fibers are compared in uniformity of diameter with drawn copper wire or with the fibers from a single cotton plant, the comparison is discouraging. In the field of wool production, therefore, uniformity is relative, not absolute.

As these statements indicate, though the accurate determination of the mean breaking load of one staple of wool may require x fibers, a similar determination for a less uniform staple may require $2x$ or $3x$ fibers. Obviously, too, such a determination, even on the very best wools, necessitates the use of relatively large numbers of fibers. The engineer may be able to test ten bars of a steel alloy and say with some certainty just what strains will cause rupture; the wool investigator cannot base conclusions on so small a number.

Considerations other than diameter variations must also be reckoned with in determining the breaking load of wool. Some fibers may be dam-

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aged by exposure or by mechanical means while on the sheep's back. Atmospheric conditions must be considered. Nutrition of the fiber during growth plays an important role; and conceivably certain fibers on one individual may be better nourished than others because of differences in the depth of implantation of the follicle with consequent variation in their proximity to the nutrient supply in the blood stream. The method of selecting the individual fibers for the test is of great importance. If the operator pulls them out from the end of the staple, he will inadvertently choose the coarser one. Only by taking the fibers as they come and pulling always from the side of the staple can he draw a fair sample. Bacteria such as the pink-rot organism described by Waters(1)[4] might conceivably affect the strength of one fiber differently from another and yet not measurably affect the diameter of either. Lastly, the type of apparatus used for the test is important because some devices are better designed to follow correct physical principles than are others, whereas some introduce uncontrollable human equations. Theoretically, although any apparatus tends to apply the same error, however large, to all tests, the better its design the fewer the tests which should be necessary.

McMurtrie,(2) testing 35,000 wool fibers for strength, found 30 fibers from each sample sufficient to give a fair average. In later work the same investigator used 50 fibers.

Matthews(3) stated specifically: "A fair test of average breaking strain. . . . may be obtained for any quality of fiber by testing about ten separate fibers." He recommended 25 or even 50 tests for wool which "does not run very uniform."

Hill(4) broke nearly 60,000 fibers involving 27 different samples of wool. Using the McKenzie fiber tester, an instrument subject to some criticism, and working under uncontrolled atmospheric conditions, he found that samples of 100 fibers each from the same staple of fine wool might vary as much as 34 per cent in breaking load. Even with samples of 1,000 fibers each from the same staple, the average breaking load might vary as much as 14 per cent. Admittedly, however, he had no means of determining the effect of temperature and humidity variations, which were observed to fluctuate widely during the experiment.

In testing the effect of the plane of nutrition on the strength of wool from the same animal, the writer(5) used 100 fibers of shoulder wool for each sample and broke them in the Deforden apparatus. For such a purpose, wholly comparative, the number was sufficient because the differ-

[4] Superscript numbers in parentheses refer to "Literature Cited" at the end of this paper.

ences involved were very large. In a later and different trial[6] 200 fibers of shoulder wool from each sample were used with less satisfactory results than had been obtained in the first experiment.

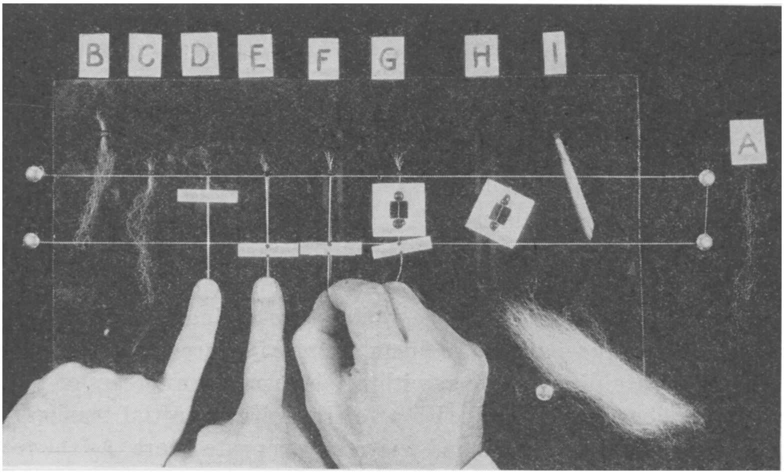

Fig. 1.—Steps in making "yarn" for test in the modified Deforden apparatus: (1) a piece of black or dark-colored velvet is smoothed out and secured to the worktable; (2) white thread is tightly stretched over the surface of the velvet in two parallel lines at the desired distance apart; (3) a piece of clear glass is laid over the velvet and the thread.

A, 20 fibers of wool are selected and laid over each other with either proximal or distal ends coinciding as nearly as possible.

B, The 20 fibers are picked up with tweezers, the ends compressed as closely as possible and cemented to the glass plate at any convenient point, with melted beeswax 15 per cent and rosin 85 per cent.

C, The glass is oriented until the drop of cement is over the upper thread.

D, A piece of cardboard about 7 mm × 35 mm is inserted under the fiber bundle. Using a small camel's-hair brush, *I,* the bristles of which have been cut short and square, the operative strokes the fiber bundle alternately with the brush and with the index finger of the opposite hand until the fibers are parallel and under uniform tension.

E, Holding the fiber bundle taut, with the finger, the operative moves the cardboard until its upper edge coincides with the lower thread. Two minute drops of cement are used to stick the fiber bundle to the cardboard. The upper drop should be placed on the edge of the cardboard.

F, The ends of the fibers are raised with one hand. With the thumb and index finger of the other hand, the cardboard is turned the required number of times to achieve the twist per unit length. The cardboard is then lowered near the surface of the glass to prevent untwisting.

G, The Deforden mount is slipped under the twisted yarn, and cement applied.

H, The ends of the yarn are cut free.

In technological studies of the breaking load and the breaking stress of wool, most experiments involve a comparison of wools with the object of determining the relative strength of two or more samples, rather than the actual or specific strength. For comparative purposes the greater the difference in the strength of two samples the fewer the fibers which need to be tested in order to show that a significant difference exists.

To make such data even reasonably accurate involves a large amount of time and laborious repetition if single fibers are used for the test. It would seem desirable, therefore, to evolve some method of using more than one fiber at a time to determine the mean breaking load; and this paper will show the possibilities of using a multiple-fiber test to supplant the testing of single fibers.

As early as 1911 Hill[7] reported his intention of "measuring the strength of a sample of wool by testing the breaking strain of a number of fibers tightly twisted together."

In 1934 the writer[6] published results of research in which multiple-fiber tests were shown to have given a somewhat better idea of the strength of each sample than was obtained by testing 200 single fibers. The technique of preparing the fibers, by making predetermined numbers of them into pieces of yarn with predetermined numbers of twists per inch of fiber length, and with a fairly uniform initial tension per fiber, was described in detail, and will not be repeated here. As the technique involved is not easily described, a photograph, showing progressively the steps necessary to make the yarn, is included in this paper (fig. 1).

EXPERIMENTAL METHODS

A sample of crossbred Romney-Rambouillet wool of 56's quality, weighing about 10 grams, furnished all the material used in the test to be described. The sample was taken from a small spot on the shoulder of one animal and was cleaned by the alcohol-benzol method.

Five hundred fibers were individually mounted for test in the Deforden apparatus (fig. 2), using that portion of the fiber as near the distal end as possible. The fibers were selected at random by choosing always the one nearest the right, although all fibers less than full staple length were discarded on the assumption that they were of too recent origin. Fibers for the yarn test were selected in exactly the same manner by the same operative.

The experiment was carried out under controlled atmospheric conditions of 65 per cent relative humidity and 70° Fahrenheit temperature.

Single-fiber tests were made with the Deforden apparatus. This device has a capacity of only 40 grams, enough for nearly all wool fibers but quite insufficient for breaking 20 fibers at a time. For the multiple-fiber tests, a balance of 600-grams capacity was suitably mounted, and the loading device and fiber clamps from the Deforden apparatus were in-

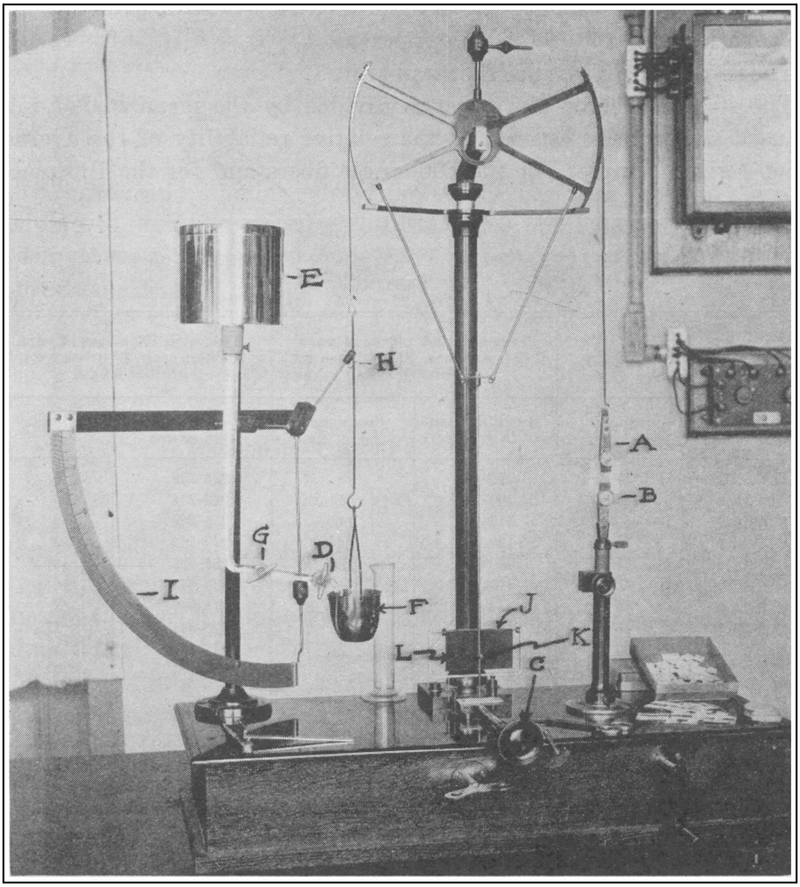

Fig. 2.—The Deforden fiber tester.

With the balance lifted in rest position, the fiber, cemented across a hollow square of cardboard, is secured between the clamps *A* and *B*. The two sides of the cardboard are then cut, allowing the fiber to be free. The balance is lowered onto its fulcrum by the knob *C*. The stopcock *D* is turned, allowing water to flow by gravity from the container *E*, into the cup *F*, the rate of flow (loading rate) being regulated in advance by adjustment of the stopcock *G*. When the fiber breaks, the stopcock *D* is shut off, the balance is raised to rest position, the cup *F* is removed and placed on the hook *H* which is part of the auxilliary balance *I*. After the weight of water required to break the fiber has been noted, the water in the cup is returned to the container *E*.

For stretch determinations, a spring-wind motor in the base of the apparatus actuates the rectangular frame *J* up and down, and a stylus attached to and at right angles with the pointer *K* inscribes a record of the stretch on a piece of blackened cardboard *L*, while the stylus moves to the right as weight increments are added. The actual stretch is measured from the inscribed graph by the use of dividers and scale.

stalled as part of the unit. It was therefore identical in principle and in operation with the Deforden apparatus.

The results of the test are shown in table 1.

The standard error of the mean divided by the mean, σ_M/M, may be used as a way of estimating the relative reliability of the average from a given sample. For the 500 single fibers and for the 100 pieces

TABLE 1

BREAKING-LOAD TESTS OF CROSSBRED 56'S WOOL ACCORDING TO VARIOUS METHODS OF TESTING

Tests with 500 single fibers		Test with 100 pieces of yarn of 10 fibers each, 20 twists per inch of fiber length		Test with 100 pieces of yarn of 20 fibers each, 20 twists per inch of fiber length	
Breaking load in grams	Frequency	Breaking load in grams	Frequency	Breaking load in grams	Frequency
5.0– 6.9	13	90– 99	5	225–239	3
7.0– 8.9	38	100–109	6	240–254	10
9.0–10.9	60	110–119	13	255–269	12
11.0–12.9	68	120–129	17	270–284	22
13.0–14.9	71	130–139	19	285–299	19
15.0–16.9	65	140–149	14	300–314	16
17.0–18.9	46	150–159	9	315–329	13
19.0–20.9	45	160–169	8	330–344	2
21.0–22.9	30	170–179	7	345–359	1
23.0–24.9	25	180–189	2	360–374	2
25.0–26.9	21				
27.0–28.9	10				
29.0–30.9	6				
31.0–32.9	2				
Total	500		100		100
Statistical measures		Statistical measures		Statistical measures	
M, grams	15.78±0.25*	M, grams	136.3±2.2*	M, grams	288.6±2.8*
σ, grams	5.67±0.18	σ, grams	22.0±1.6	σ, grams	28.2±2.0
V, per cent	35.9±1.3	V, per cent	16.2±1.2	V, per cent	9.8±0.7
$\frac{\sigma_M}{M}$	0.016	$\frac{\sigma_M}{M}$	0.016	$\frac{\sigma_M}{M}$	0.0098

* Standard error.

of yarn of 10 fibers each, $\sigma_M/M = 0.016$; for the 100 pieces of yarn of 20 fibers each, $\sigma_M/M = 0.0098$. Evidently 100 pieces of yarn of 10 fibers each furnish as reliable an index of the mean breaking load as that obtained from breaking 500 single fibers; the mean breaking load of 100 strands of 20 fibers each has a much smaller relative standard error and is, therefore, a more reliable index.

The ratio σ_M/M can be used to ascertain how many pieces of yarn of 20 fibers each are necessary to secure the same reliability as is obtained from 500 single fibers. The required σ_M/M is 0.016.

$$\text{Then } 0.016 = \frac{\frac{\sigma}{\sqrt{n-1}}}{M}$$

The mean and standard deviation of the breaking load of the new sample will not differ greatly from the values obtained from the sample of 100 pieces of yarn of 20 fibers each. Substituting these values in the expression above,

$$0.016 = \frac{\frac{28.2}{\sqrt{n-1}}}{288.6}$$

from which $n = 38.3$

SUMMARY

These data indicate that the mean breaking load obtained from breaking 39 or 40 pieces of yarn of 20 fibers each would furnish as reliable an index of the true breaking load as that obtained from tests of 500 individual fibers.

The yarn test described has such an advantage over single-fiber tests for breaking-load determinations that its substitution is indicated. The time required to make the pieces of yarn and mount them is, of course, greater than the time required to mount an equal number of single fibers, but the time and patience and expense involved in breaking 40 pieces of yarn are far less than if 500 single fibers are tested. Breaking stress of the fibers used in the yarn can also be observed by measuring fiber diameters after the yarn is broken. The yarn method is not adaptable to measuring fiber stretch, but for breaking load and breaking stress it would appear to be more nearly commensurate with the methods used by textile manufacturers who as yet have not widely adopted single-fiber testing as a means of evaluating the strength of the wool fiber.

Tests for breaking load of wool fibers are chiefly valuable for wool technologists. Measurement of the effect on wool of disease, nutritional regimen, bacteria or fungi, varying systems of sheep husbandry, and the like, necessarily include measurement of the strength of fiber. Too often in the past the strength has not been measured, because of the enormous number of tests necessary to yield significant data. The method herein described should partially remedy this situation.

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