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The Decrimping of Single Wool Fibers. II. The Dependence of Bulk Compression, Felting, and Tactile Properties on Decrimping Parameters

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Synopsis

Three important characteristics of loose wool bulks; compression, felting, and handle score are shown to be dependent upon the decrimping properties of the fibers. The relationship between decrimping energy and compressional load is very strong and it is suggested that rapid measurement of compressional properties may be of use in commerce and manufacture.

INTRODUCTION

In part I of this series, some information was reported on the mechanical properties of wool fibers in the decrimping region. This work was limited to a study of fibers of a particular geometric description which behaved in accordance with relationships postulated for a twisted sine wave. In the present paper it was hoped to estimate the technological significance, if any, of this particular region by determining the relationship between decrimping parameters and three important characteristics of wool bulks, namely, compression, felting, and softness of handle.

MATERIALS AND METHODS

Wool Samples

Fourteen wool types exhibiting wide variations in felting and compressional behavior[1,2,3] were studied. With the exception of Scottish Blackface, which was derived from a scoured commercial sample, the wools were selected in the greasy state. They were purified with diethyl ether, ethanol, and finally distilled water.

Measurement of Decrimping Parameters

Single fibers (8) were drawn at random from each sample; and after preliminary soaking in distilled water for 20 hr at 20°C, the fibers were

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decrimped at a rate of 0.2 cm/min. At the end of each extension, the fibers were immediately unloaded at the same rate.

The fibers were then rested for 5 hr in water at 20°C before reextending over a higher load range to obtain the Hookean slopes. The decrimping curves of the loading cycle were analyzed similarly to the method employed by Balasubramaniam and Whiteley[4] to obtain the decrimping stress F_c and the decrimping energy E_c for each of the fibers.

Per Cent Resilience

Per cent resilience was defined as

$$\% \text{ Resilience} = \frac{\text{area under the reverse cycle}}{\text{area under the decrimping cycle}} \times 100.$$

Measurement of Bulk Properties

Compression. Bulk compressional properties were measured using a piston-and-cylinder arrangement. This technique was employed in a joint study with Dr. M. A. Chaudri.[5] The results used in the present chapter were previously reported by Chaudri and Whiteley.[6]

The conditions for the experiment involved a copper cylinder (3.48 cm internal diameter and 7.55 cm depth), fitted with a piston capable of completely free vertical movement. Exactly 1 g of the conditioned sample randomized by hand-carding was introduced into the cylinder with a minimum amount of compression. The piston was then lowered at a rate of 1 cm/min until the required final volume was attained. The load to compress was measured by a Statham pressure transducer connected to a sensitive chart recorder.

At the end of each cycle, the sample was immediately unloaded, and a rest period of only 1 min was allowed between successive cycles.

It was found that the compressional properties do not change markedly after the first cycle.[5,6] In general, only four cycles were completed, and the mean of the values obtained during the last three cycles is quoted here.

Felting and Handle. Felting and handle results on the wool involved in the present study were obtained from previously published information.[2,7]

RESULTS AND DISCUSSION

Bulk Compression and Decrimping

Results presented in Table I show a wide range of compressional properties. The compressional loads vary from 620 g (English Leicester) to 2312 g (Suffolk Down).

The linear regression coefficient of compressional load on fiber length, crimp amplitude, and S_{30} proved to be nonsignificant (Chaudri[1] 1968). However, Chaudri (1968) showed that crimp frequency and crimp form were highly significant and accounted for 52% and 81%, respectively, of the observed variation in compressional load.

Even though fiber diameter has been found to be nonsignificant and accounted for only 2% of the variation in load, Chaudri (1968) showed

TABLE I
Bulk Compression, Felting and Decrimping Characteristics of Various Wool Types

Sample	Compressional load, g	Felt Ball diameter, mm	F_c,[a] kg/mm^2	$E_c \times 10^5$,[a] Joule/m^3	Resilience,[a] %
English Leicester	620	25.2	0.06	0.012	78%
Merino Sample B	752	24.2	0.16	0.079	92%
Lincoln	773	26.6	too low to measure		
Merino Sample C	783	25.0	0.12	0.074	73%
Romney Marsh	842	25.2	0.16	0.078	76%
Dorset Down	1059	30.2	0.20	0.16	85%
Scottish Blackface	1126	27.4	0.25	0.15	84%
Shropshire	1193	34.7	0.18	0.19	74%
Cheviot	1233	34.0	0.21	0.26	90%
Tasmanian Merino	1282	29.4	0.19	0.21	84%
Ryeland	1609	39.3	0.23	0.28	90%
Hampshire	1659	36.5	0.34	0.44	92%
Southdown	1914	40.2	0.28	0.47	83%
Suffolk Down	2312	40.4	0.26	0.55	76%

[a] Mean values of eight fibers.

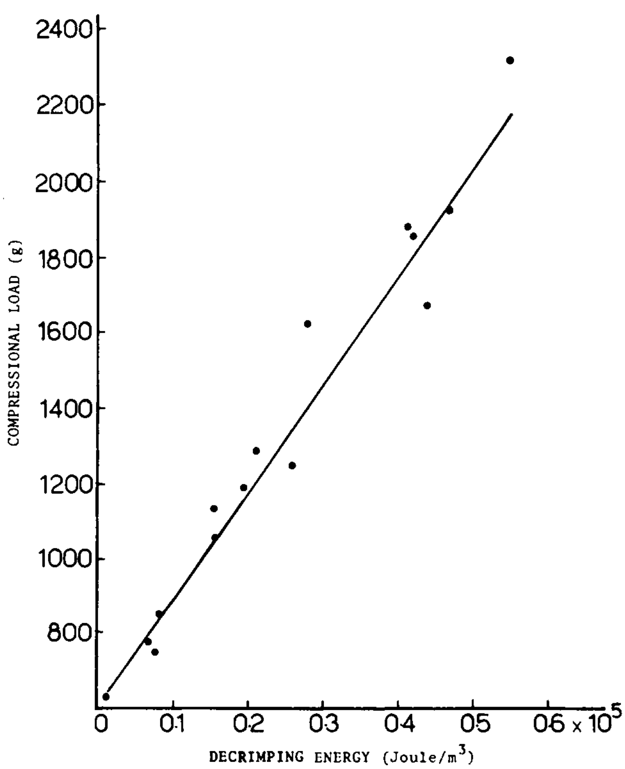

Fig. 1. Linear relationship between compressional load and decrimping energy.

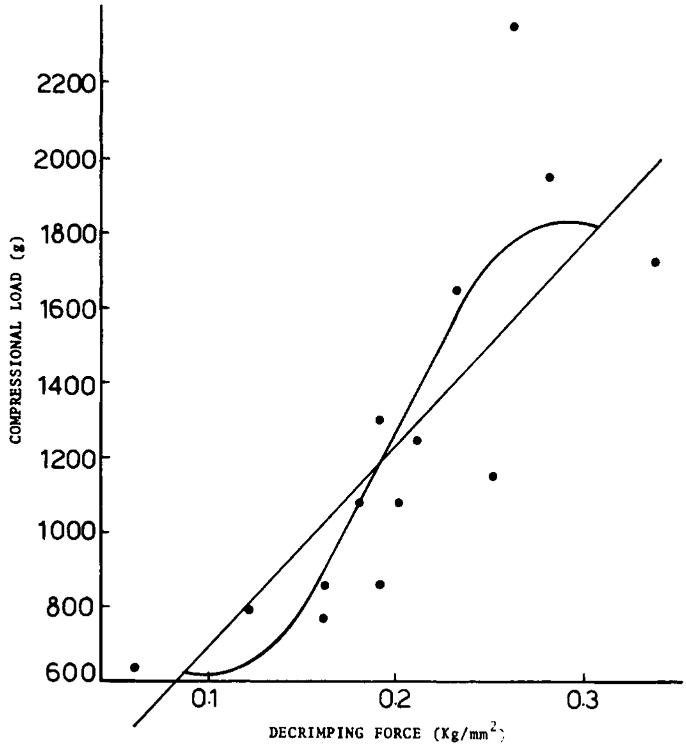

Fig. 2. Linear and cubic relationships between compressional load and decrimping force.

that the product of fiber diameter and crimp frequency accounted for 89% of the variation in compressional load. Thus, it appears that the observed variations in compressional load are attributable to differences in the crimp structure of the fibers.

Table 1 also reveals parallel variations in E_c and F_c with compressional load. The energy to decrimp (E_c) varied from 0.012×10^5 Joule/m^3 (English Leicester) to 0.55×10^5 Joule/m^3 (Suffold Down), and the plot of E_c versus compressional load is given in Figure 1.

The linear regression of compressional load on E_c is represented by

$$\text{compressional load} = 605.8 + 2881.43\, E_c. \quad (1)$$

The variation in compressional load accounted for by E_c is 95%.

The relationship between compressional load and F_c illustrated in Figure 2 appears to be curvilinear. A quadratic expression produced little improvement, but a cubic expression proved to be significant.

The linear and cubic regressions are given in eqs. (2) and (3), respectively:

$$\text{compressional load} = 156.4 + 5436\, F_c \quad (2)$$

$$\text{compressional load} = 1625.8 - 25633\, F_c + 179767\, F_c^2 - 304835\, F_c^3. \quad (3)$$

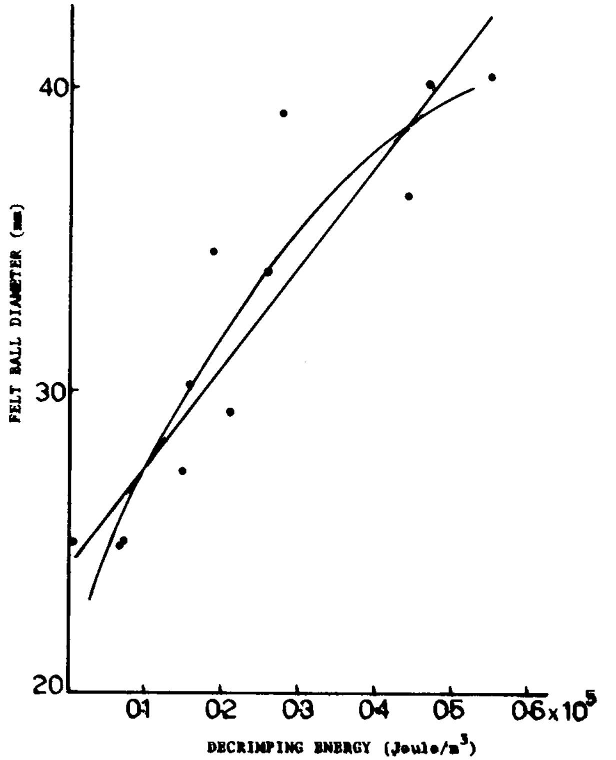

Fig. 3. Linear and quadratic relationships between felt ball diameter and decrimping energy.

The variation in compressional load accounted for by the linear relationship is 63% and by the cubic, 74%.

Felting and Decrimping

Preliminary studies in these laboratories have revealed extremely large variations in felting properties that appear to be a function of the spatial configuration of the crimp wave[2,5] and, consequently, of compressional properties.

Chaudri and Whiteley[2] attributed these large variations in the felting of loose wool almost entirely to variations in bulk compressional properties; they found that 87% of the variations in loose wool felting was accounted for by compressional load and about 90% by work to compress.

Figures 3 and 4 show the plot of felting properties versus E_c and F_c. The linear and quadratic regressions of felting on E_c are represented in eqs. (4) and (5):

$$\text{ball diam.} = 24.13 + 33.20\, E_c \tag{4}$$

$$\text{ball diam.} = 21.64 + 60.98\, E_c - 49.31\, E_c^2. \tag{5}$$

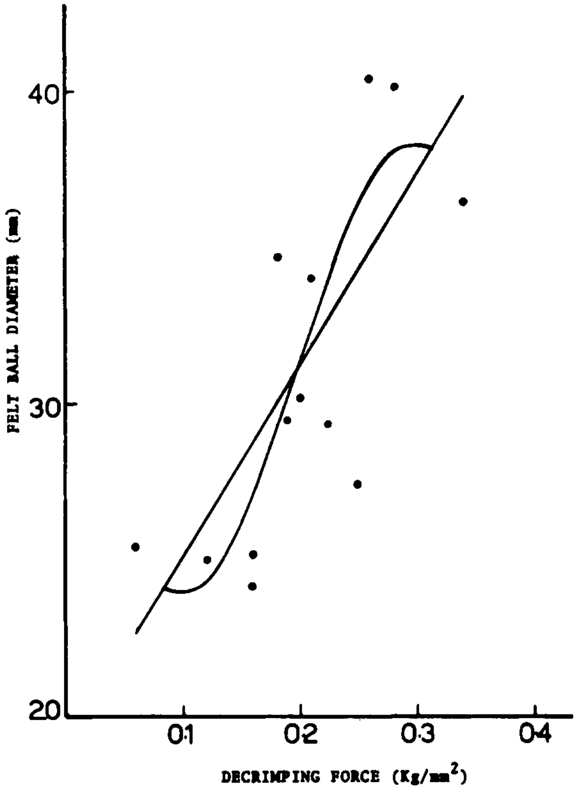

Fig. 4. Linear and cubic relationships between felt ball diameter and decrimping force.

E_c accounted for 82% of the variation in felt ball diameter in linear regression, 83% in quadratic regression, and 86% in cubic regression. Similarly, F_c accounted for 53%, 53%, and 64% of the variation in felt ball diameter.

It appears, therefore, that the energy and forces involved in modifying crimp structure result directly in large differences in compressional load and consequently in felting properties.

Handle and Decrimping

Previous studies on softness of handle (Ali, Whiteley and Chaudri[7] 1971) have shown that about 87% of the variation in softness of handle is dependent on diameter and either crimp frequency or bulk compressional properties, diameter alone accounting for 67% of the variation among different wool types.

In view of the relationship between bulk compression and decrimping properties, there may be a similar relationship between handle, diameter, and E_c or F_c. In other words, values of E_c and F_c may account for deviations from the expected handle–diameter relationship, and Figure 5 confirms this hypothesis. For example, Southdown and Suffolk Down wools

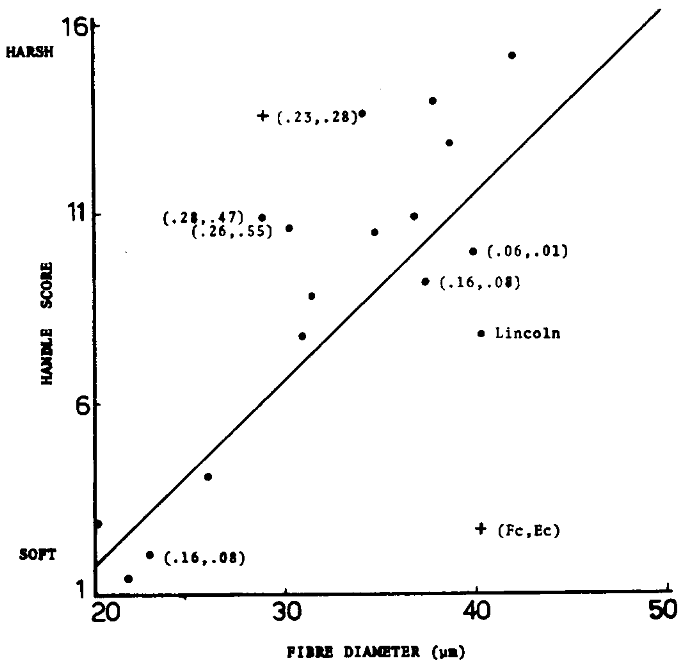

Fig. 5. Linear regression of handle score on fiber diameter. Bracketed entries refer to values for decrimping force and decrimping energy.

with mean diameters of 30 μm have an exceptionally harsh handle score of 11 which represents a large deviation above the regression line and is attributable to decrimping properties.

Similarly, Lincoln, with a diameter of 40 μm, has an exceptionally "soft" handle score of 8 as against a predicted value of 11 (Fig. 5). In this case, and once again in relation to the low compressional load value of 773 g, the decrimping parameters were too small to measure. For the purpose of comparison with Suffolk Down (0.55×10^5 Joule/m^3, 0.26 kg/mm^2) and Southdown (0.47×10^5 Joule/m^3, 0.28 kg/mm^2), one may refer to the E_c and F_c values for English Leicester (0.12×10^5 Joule/m^3, 0.06 kg/mm^2) as the latter's crimp structure is similar to Lincoln.

Thus, it is clear that large deviations from the regression of handle on diameter may be attributed to fibers with exceptional decrimping properties.

GENERAL DISCUSSION

It has already been clearly established that bulk compression is of considerable significance in determining various properties in loose wool, yarns, and fabrics. The present paper provides strong evidence to suggest that the fourfold variations observed in the bulk compressional behavior of wool bulks can be attributed to the mechanical properties of single wool fibers in the decrimping region.

Of equal significance is the fact that there is a strong relationship between the crimp content of single fibers and the curvature of the follicles that produce them.[8] Crimp frequency is also strongly related to the composition and ultrafine structure of the keratin complex,[9] to the ability of sheep to produce heavy fleeces, and to produce them with high efficiency in regard to the conversion of food to wool.[10]

The influence of dimensional characteristics such as strength, length, and diameter from a processing and enduse point of view are well established. Single-fiber crimp characteristics probably offer an additional important aspect of quality among various wool types used for special purposes.

Measurement of these single-fiber crimp characteristics is too tedious for routine work, but resistance to compression can be measured very rapidly and appears to have considerable possibilities as a technique in wool commerce.

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