A Note on the Compressibility of Wool and its Relationship with Crimp

In the framework of a study on the influence of crimp on the physical properties of wool assemblies, the load–compression curves seem to provide very useful data for testing the contribution of the crimp properties on compression. Actually, some recent works[1,2] are mainly concerned with the influence of geometric factors on the compressional resistance and resilience of wool assemblies. Chaudri and Whiteley[1] studied the compressional characteristics of several wool types in relation to their crimp, as defined by the crimp frequency of single fibers, and concluded that crimp accounts for most of the observed variations in the compressional load of the wool types and that other parameters such as diameter and length are essentially nonsignificant. It is important to note that these conclusions were drawn from a statistical analysis of the interrelationships between the various parameters. Obviously, because of the mutual influences of various physical properties such as crimp, diameter, Young's modulus, friction, etc., during compression of various wool types, it is very difficult to isolate the direct contribution of the crimp effect. Such a study is, however, feasible only on wools having, except for crimp, all other physical properties identical. These wools were kindly obtained for this study from the I.W.S. Technical Centre, Ilkley, Yorkshire, where a new process[3,4] of crimping wool to different levels was developed.

In this work, results are presented on the load–compression behavior of differently crimped loose wool fiber samples. An empirical equation for this behavior is suggested which includes a parameter that depends on the crimp of the wool assemblies.

The wool used is of 46/48's quality, supplied in the form of webs crimped to five different levels. Samples of 2-g weight were hand carded and compressed at 65% R.H. at a constant rate of 2 cm/min, using the Instron tensile tester. The compression was carried out in a stainless steel container of 5-cm diameter, by a piston of 4.85-cm diameter, starting from a wool density of 0.0204 up to 0.1019 g/cm^3. Several compression and decompression cycles were applied, but the third one was considered for analysis since it yielded a regular curve.

The crimp of the samples is characterized in this work by the "web crimp," which is similar to the staple crimp in the naturally crimped wool. This is the artificial crimp imparted to the wool webs in the crimper and is the result of the various feeding ratios to the apparatus. The web crimp is measured as the number of crimps per cm of web length after conditioning the web at 65% R.H. for 24 hr (see Table I):

TABLE I
The Artificial Web Crimp of the Various Samples

Sample	Feeding ratio	Crimps/cm
Control	—	—
1	3:1	1.33
2	4:1	1.88
3	5:1	2.30
4	6:1	2.51
5	7:1	2.54

Figure 1 shows two pressure–volume curves for the two extreme levels of crimp. The intermediate crimped samples exhibit similar curves which fall between these two curves. If the pressure and the logarithm of the compression ratio V_0/V are plotted on two logarithmic axes, an approximate linear relationship is obtained for each of the crimp levels (see Fig. 2). It is seen from Figure 2 that the lines possess different slopes according to their crimp level. This means that increasing the crimp, as expressed by the web crimp, directly affects the load–compression curve of the wool by decreasing the

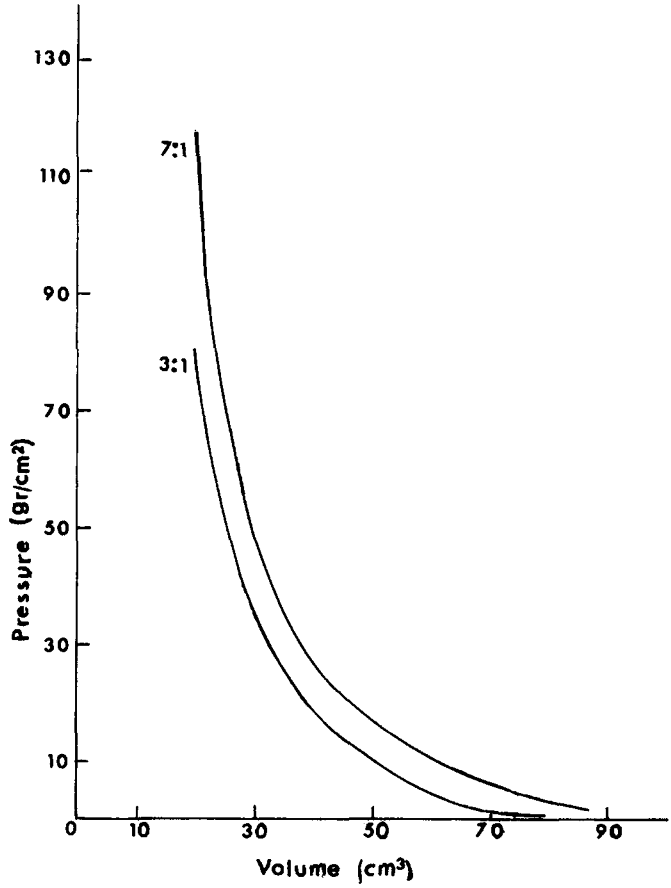

Fig. 1. Pressure–volume curves of two differently crimped wool samples (see text).

slope of its logarithmic curve as plotted in Figure 2. This dependence is clearly shown in Figure 3, where it is seen that a linear relationship, at the level of significance of 0.01, exists between the slope $1/c$ of the lines and the web crimp of samples.

The lines in Figure 2 may be expressed algebraically in the following way:

$$\ln P = \frac{1}{c} \ln \left(\ln \frac{V_0}{V} \right) - \ln a \quad (1)$$

where a is a constant and $1/c$ is the parameter found to be linearly related to the web crimp. This equation can be brought to the form

$$(aP)^c = \ln \frac{V_0}{V}$$

and then to

$$\frac{V_0}{V} = e^{(aP)^c} \quad (2)$$

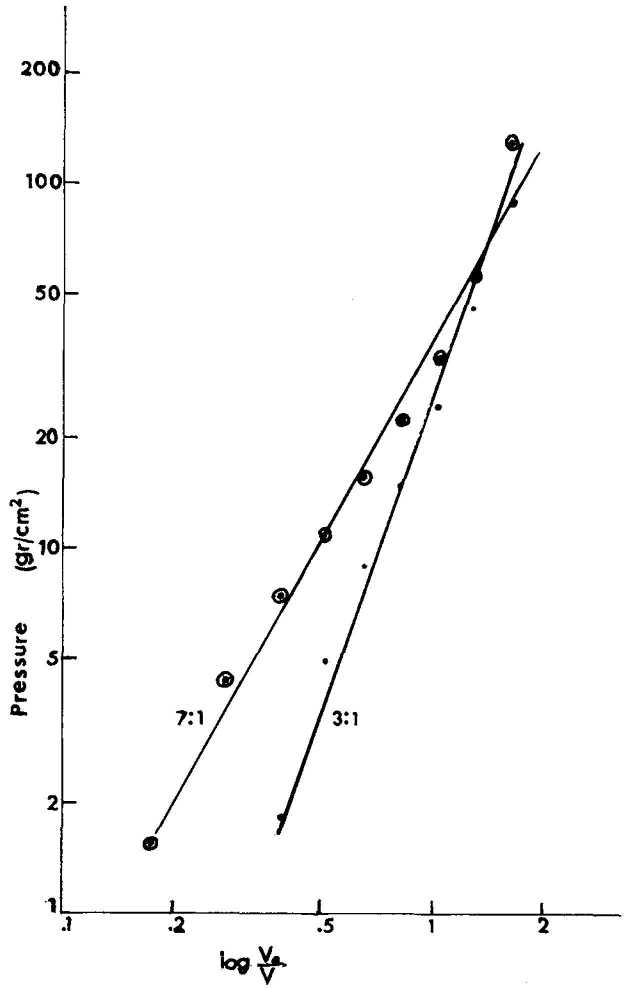

Fig. 2. Iterated logarithmic load–compression curves of samples 3:1 and 7:1; V_0 and V are, respectively, initial and decreasing volumes of the container occupying the wool bulks.

or to

$$\frac{\Delta V}{V_0} = 1 - e^{-(aP)^c}. \tag{3}$$

Equation (2), which relates the volume of the compressed wool to the pressure, may be regarded as an equation of the state of this material. It includes two constants, a and c, where one of them, c, is linearly related to a crimp parameter of the wool The constant a is also related, but to a lesser level of significance, to the web crimp.

It is interesting to note that eq. (2) may be expanded to the series

$$\frac{V_0}{V} = 1 + (aP)^c + \frac{(aP)^{2c}}{2!} + \frac{(aP)^{3c}}{3!} + \dots \tag{4}$$

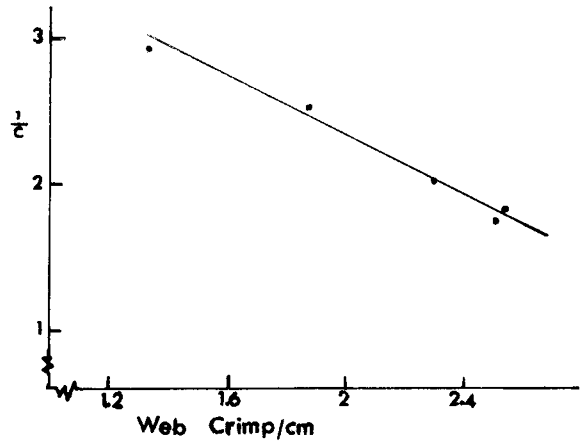

Fig. 3. Slope $1/c$ for all five crimped samples vs. their web crimp.

When considering only the terms up to that containing the first term of P, and by substituting integer 3 for $1/c$, eq. (4) can be approximated to

$$P = \frac{1}{a}\left(\frac{V_0}{V} - 1\right)^3, \tag{5}$$

a form which is similar to that obtained by Van Wyk[6] following his theoretical treatment on the compressiblity of wool. It is worth noting that the $1/c$ value in this work is found to be 2.93 for the lower level of crimp, decreasing to 1.81 for the highest crimped sample (see Fig. 3). The $1/c$ value for the nontreated wool is 3.29.

When comparing the compressional behavior of wool to that of other materials, it will be important to observe that eq. (3) resembles an equation[5] which characterizes the behavior of solid materials containing dispersed void inhomogeneities in their structure. By another approach, it may be useful to mention the application of an analog of van der Waals equation for gas compressiblity:

$$(P + m)(v - n) = C. \tag{6}$$

Though this equation refers to the gaseous state and not to solid or polymeric materials, it may well be possible to approximate two parameters, m and n, which would provide a constant value C for the different wool samples. These parameters were found to be essentially dependent on the crimp level of the samples. However, eq. (2), though slightly less convenient, seems to be more preferable. It involves only two parameters, a and c, instead of the two parameters and a constant C, as in eq. (6).

Surland[5] found that when the compressibility of such materials in which the compression modulus is much greater than the shear modulus μ, the change of volume, referred to the initial volume, may be expressed by the equation

$$\frac{\Delta V^*}{V_0} = \frac{\Delta V}{V_0} + \delta\left(1 - e^{-\frac{3P}{4\mu}}\right) \tag{7}$$

where $\Delta V^*/V_0$ and $\Delta V/V_0$ are fractional volume changes of the material with and without void content, respectively, and δ is the initial void content. The above formula is based on an infinitesimal analysis of the deformation of a hollow pressurized sphere. Though it will be an oversimplification to assume a correspondence between the case of polymeric voided solids and that of loose wool bulks, the Surland approach[5] points to theoretical considerations which may lead to an interpretation of the empirical formula (3).

It may, at least, be suggested that a model, assuming an inhomogenenous voided structure of the wool bulks may be compatible for the compressional characteristics of wool.

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