Pakistan J. Sci. Ind. Res., Vol. 15, No. 3, June 1972

CHARACTERISTICS OF LOOSE WOOL COMPRESSIBILITY

MUHAMMAD ASHRAF ALI

PCSIR Laboratories, Rajshahi

(Received May 29, 1971; revised September 14, 1971)

Abstract. The regression coefficients of a load-thickness equation which has been derived empirically, show wide variations in a spectrum of raw, processed and treated wools. Throughout their changes secured by water-saturation, woollen or worsted processing, acid-relaxation and oxidation of the wool aseemblies, the compressional parameters appear to be interdependent as expected from their observed association with the reaction constants' of the polymer bending rate process. In addition, some of the parameters exhibit significant correlations with the natural variations of crimp form, fibre length, softness of handle and moisture content of the raw wools. Eventually, the nature of loose wool compressibility has been discussed in the light of the observed correlations.

Previous studies of pressure-thickness relation in random assembly,[1-3] top,[4] yarn[5,6] and fabric[7,8] showed considerable disagreements,[9] although the natural difference of specific compressional load tends to prevail at various stages of wool processing.[10] For example, the equation[2] derived from theoretical considerations of bending metal strips, failed to account for the compressive behaviour of the Australian wools,[10] probably, because the rheological model of polymer bending could differ from that of a metal cantilever.[11] With a view to gain additional insight deep into the disagreement, the present study aims at further analysis of the pressure-thickness relationship in a wide range of wool characteristics under varying conditions of measurement.

Loose fibre assembly is usually tested at constant pressure or strain of which the latter is more frequently used for its simplicity and sensitivity. The results may depend on piston size[12] due to dispersion of the compressive force beyond its circumference. The piston in a close fitted cylinder can affect both the compressive stress and recovery of the fibres due to the friction between fibres and cylinder wall, thereby, causing a 'wall effect'[3,14] and even a jamming tendency. The specimen size, preparation, cleanliness[15,16] and relaxation of the processed wool[10,17] may influence the load. Relative humidity[2,18] and rate of straining[19,20] normally affect the load in the same way as they change torsional rigidity and Young's modulus[21,22] of single wool fibre. Any deviation from the similarity of compressive and tensile behaviour could be accompanied by marked molecular changes[23] comparable to those occurring in the chemical and/or weathering damage[24,25] of wool fibre.

Further, compressibility seems to have considerable commercial implications owing to its high correlation with fibre bundle strength,[26,27] felting rate,[28,29] yield,[27,30] diameter, length and crimp form.[31,32] Although the process of compression is rather complicated, it is clear that substance and shape (form) are two critical factors of which the shape factor appears to be more important in the case of natural variation of the load since the substance difference between wool types is rather negligible.

Experimental

Materials. Samples were drawn at random from 8 Pakistani wools (of fibre dia 25.8–42.3 μ) and 14 Australian wools (20.4–37.4 μ) in the greasy state, washed in a 0.02% Nonidet (P40 Shell Chemicals) solution, air-dried and hand-carded. In order to ascertain any effect of fibre friction on the bulk compressibility, 5 samples of fine, down, long, crossbred and carpet wools were additionally drawn from the hand-carded wools for testing them before and after lubrication with 10% solution of SAE-30 oil in petroleum ether.

Merino 64^s, Southdown, Ryeland and Border Leicester wools were processed to derive random samples of their woollen slubbings, and worsted slivers, tops and noils, both before and after relaxing them for at least 1 hr in a 0.1N HCl solution at room temperature. In addition, the slubbings were shrink-resisted by oxidation with 4% $KMnO_4$ (on the weight of wool) in a saturated solution of NaCl at 40°C.[33] A metal cylinder (with a small hole at the base), internal dia 3.48 cm, and depth 7.55 cm, fitted up with a rigid piston of dia 3.45 cm, was always used for the compression tests.

Compression Testing. Unless otherwise stated, at least two 1-g wool specimens of each sample were tested at 21°C and 65% R.H. A specimen was subjected to cyclic compression inside the cylinder by its piston attached to the cross-head of an Instron Tensile Tester (model TT-BM) moving at a rate of 2 cm/min when the recorder running at the speed of 5 cm/min registered both the specific load L, and thickness V, of the assembly up to a constant strain given by $V=1.05$ cm, i.e. about 60% bulk compression giving $L=L_m$, the upper limit of the load. The initial thickness V_0 was noted from relative position of the piston just at the point of no compressive force other than the atmospheric pressure on the fibre assembly. Although the test continued for 4 complete cycles of compression and release, the 3rd compression curve (semi-cycle) provided the data for subsequent analyses. This procedure reduced differences in the initial packing of the wools and gave the compressional parameters which were largely determined by the elastic properties of fibre.

The compression curve of each specimen was analysed to estimate at least five different sets of L and V covering the range of L from 50 to L_m g. Log V always accounted for more than 99% of the variations of log L obeying the empirical equation 1,

$$L = A/V^{\beta} \qquad (1)$$

where the regression coefficients A and β represent the characteristics of loose wool compressibility, also, log $A = \alpha$. For a comprehensive load-thickness equation accounting for the lower limit of compression, a constant term L_o was added to the right-hand side of equation 1 and its value determined from the boundary conditions, $L = 0$ when $V = V_o$ as follows.

$$L_o = -A/V_o{}^{\beta} \qquad (2)$$

so that equation 1 becomes

$$L = A(1/V^{\beta} - 1/V_o{}^{\beta}) \qquad (3)$$

After the compression test in dry state, all the specimens of 14 Australian wools were separately saturated with distilled water and tested at 100% R.H. but the data of the 4 samples subjected to initial wet-compression appeared to be unsuitable for subsequent analyses. All specimens were then relaxed, dried and retested at 65% R.H. as before. All other samples were tested in the dry state.

Fibre Characteristics. At least 10 fibres drawn at random from each sample were studied by single-fibre-bulking-capacity method[34] for estimating the mean crimp frequency f on the basis of crimped fibre length. Fibre diameter d and length were, however, estimated by the standard procedures recommended by the IWTO Technical Committee.[35] The multiplication product $d.f$ was obtained as an index of sample crimp form.

The moisture content of the 22 raw wools was estimated by a CSIRO rapid dryer type 21 set at 104°C.[36] Besides, six independent judges subjectively examined the series of 14 Australian wools in a dark-room for assigning relative handle scores to each wool sample, average value of the 6 scores being its harshness index.[10]

Results and Discussion

Reproducibility. Table 1 presents cyclic variations of log $A(\alpha)$, β, V_o, L_o (cf. equation 1–3) and the specific compressional load L_m in the duplicate specimens of 4 widely different wools. The observations on the initial cycle were totally ignored owing to its large packing difference from the second cycle. But the next variations between the successive cycles appear to be practically comparable in their magnitudes. Thus, the results of the third cycle, which are mostly independent of the packing effect, seem to be highly reproducible. In addition, the between-breed variations are considerably larger than the corresponding differences observed between the specimens or the cycles. Hence, the compressional parameters are chiefly determined by wool characteristics, although in the present level of bulk compression, the 5 different wools tested before and after lubrication with oil-film revealed nonsignificant effect of fibre friction on the parameters.

Validity. This shows whether a test measures what it purports to estimate. Very satisfactory validity of the compressional parameters has been demonstrated here by the high correlation ($r = 0.998$ Fig. 1) between the observed L_m and its value L_m estimated by equation 3. Thus, L_m accounts for 99.7% of the variations of Lm according to the regression equation 4 of Fig. 1.

$$L_m = 24.1 + 0.9776\,\hat{L}_m \qquad (4)$$

where the standard error of predicting L_m from a given value of $\hat{L}_m$ is ± 29.4 g. This is equivalent to the coefficient of variation ($C.V.$) 2.4% of the mean L_m ($= 1208$ g). The prediction is tenable within the entire ranges of measurements on all the samples wherein A varies from 513 to 3162, β from 2.022 to 4.467, V_o from 2.03 to 4.78 cm, and L_m from 46 to 281 g/cm^2.

Inter-relatedness. Within the said ranges of their measurements, log $A(\alpha)$ is highly correlated with log L_m (Fig. 2) and log β, with log V_o (Fig. 3). In view of the different measuring conditions and treatments of the wool samples, the observations have always been identified to demonstrate their group-

TABLE 1. CHANGE OF COMPRESSIONAL PARAMETERS WITH CYCLIC COMPRESSION OF 2 RANDOM SPECIMENS DRAWN FROM VARIOUS WOOLS.

Breed	Specimen	Cycle No.	Compressional parameters				
			Log A	β	V_o (cm)	L_o (g)	L_m (g)
Merino	a	2	3·149	2·334	3·59	71	1200
		3	3·128	2·390	3·49	68	1170
		4	3·104	2·312	3·52	69	1150
	b	2	3·122	2·132	3·85	75	1110
		3	3·115	2·243	3·69	70	1080
		4	3·115	2·402	3·57	61	1060
Border Leicester	a	2	3·088	2·655	3·81	35	1030
		3	3·093	3·112	3·68	22	1000
		4	3·098	3·244	3·70	19	1000
	b	2	3·031	2·690	3·47	38	960
		3	3·053	2·867	3·29	37	940
		4	3·055	3·041	3·25	32	930
South Down	a	2	3·405	2·642	3·40	100	2100
		3	3·401	2·562	3·30	108	2050
		4	3·390	2·770	3·40	83	2020
	b	2	3·448	2·684	3·46	100	2280
		3	3·450	2·822	3·50	82	2240
		4	3·405	2·845	3·41	77	2210
Cross breed	a	2	3·332	2·849	3·37	67	1880
		3	3·354	2·929	3·21	59	1840
		4	3·330	3·302	3·19	53	1810
	b	2	3·305	2·761	3·29	75	1700
		3	3·293	2·908	3·21	74	1660
		4	3·286	2·849	3·15	73	1640

deviations from the expected values, e.g. those points lying on the line of regression. Figure 2 clearly shows that log L_m accounts for 99.1% of the variations of α and vice versa. Thus, one of them can be predicted from a knowledge of the other. The prediction by equation 5a of Fig. 2 gives a standard error of ±0.0055 or $C.V. = 0.17\%$ of α and that by an alternative equation 6a shows the standard error of ±0.0057 or $C.V. = 0.18\%$ of log L_m.

$$\alpha = 0.0698 + 1.0018 \log L_m \qquad (5a)$$

or on removing the logarithm

$$A = 1.1743\, L_m^{1.0018} \qquad (5b).$$

Alternatively, $\log L_m = 0.9888\, \alpha - 0.0403$ (6a)

or on removing the logarithm

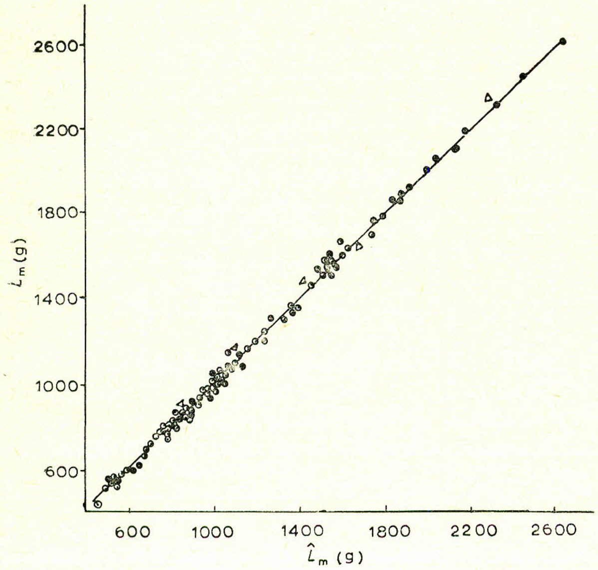


Fig. 1. Correlation between the observed L_m and the estimated ($\hat{L}_m$) specific compression load of ⊙= untreated, ●=wet, O=oxidised and Δ=oiled loose wool, r=0·991, highly significant.

$$L_m = (A^{0.9888})/1.0973 \qquad (6b)$$

Log V_o, however, accounts for 55.3% of the variations of log β following the regression equation 7a of Fig. 3 and a standard error of prediction ±0.0405 or $C.V. = 9.4\%$ of the latter.

$$\text{Log}\, \alpha = 0.1111 - 0.5407 \log V_o \qquad (7a)$$

or on removing the logarithm

$$\beta = 1.2915/(V_o^{0.5407}) \qquad (7b).$$

Besides, the remaining 44.7% of the variations of log β may be associated with the differences of fibre diameter and crimp form. Both of them, for example, showed positive correlations with β-parameter of the raw wools, although the correlations appeared to be distinctly stratified into 3 groups of fine (Merino), medium(Down) and coarse(Carpet) wools; the stratifications could arise from strong genetic effect on crimp form and fibre diameter of the 3 major wool types.

The latent load of wool assembly L_o (cf. equation 2) varied from 15 to 78 g with a mean value of 48 g, giving the mean pressure of 5.2 g/cm², in the 78 samples tested in dry state, and exhibited high correlation ($r = 0.765$) with the α-parameter. On excluding the 4 samples of oxidised slubbings, Fig. 4 shows a high correlation ($r = 0.777$) between log L_o and log L_m of the 74 untreated loose wool samples whose results have been identified to distinguish Merino, Down and Carpet wools. The observations are clustered to manifest 3 distinct crests and troughs on the correlogram but they seem to fit into a simple regression line described by equation 8a. Thus, log L_o accounts for 60.4% of the variations of log L_m and vice versa, the standard error of prediction being ±0.1079 or $C.V. = 3.5\%$ of log L_m.

$$\text{Log}\, L_m = 1.649 + 0.8508 \log L_o \qquad (8a)$$

or on removing the logarithm

$$L_m = 44.566\, L_o^{0.8508} \qquad (8b)$$

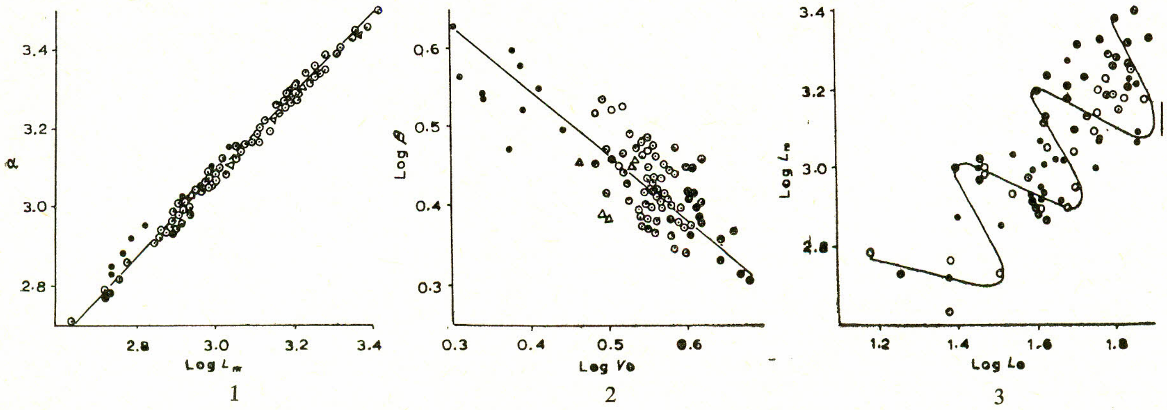


Fig. 2. Correlation between logarithm of specific compressional load, (log L_m) and the parameter α; ⊙= untreated, ●=wet, O=oxidised and Δ=oiled samples showing pooled r=0·995, highly sig. Fig. 3. Correlation between logarithm of the parameters V_o and β of the load–thickness equation; ⊙=untreated, ●=wet O=oxidised and Δ=oiled wools showing pooled r=0·744, highly significant. Fig. 4. Correlation between logarithm of specific compressional load (log L_m) and that of the load at atmospheric pressure (log L_o) for the raw and processed wools—Merino ●, Down ⊙ and Carpet O, pooled r=0·777 being highly significant.

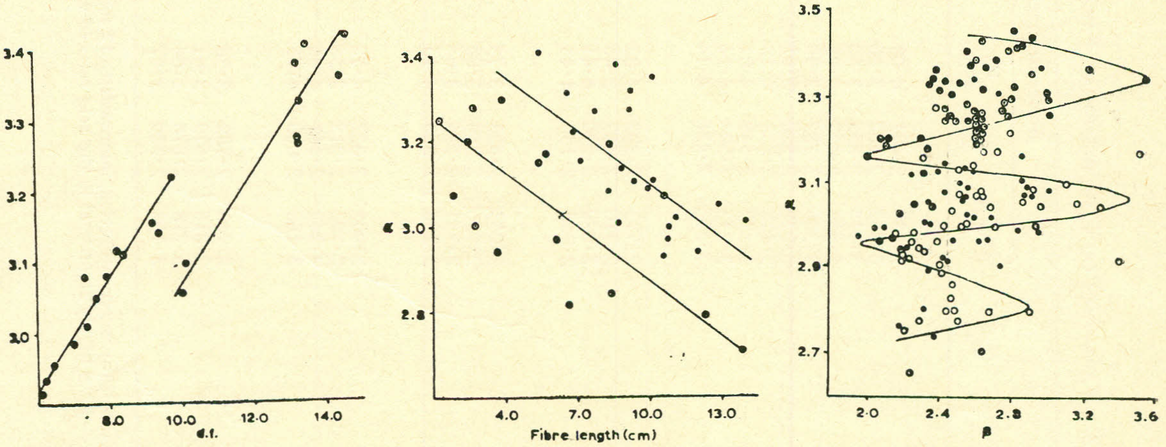
Fibre Attributes. Natural variation of the harshness (ranging from 1.2 to 14.0) exhibited by the 14 Australian wools is significantly correlated ($r = 0.552$) with the latent load L_o which, thereby, accounts for 30.5% of the variations of the harshness index as expected from an early point of view.[1] Their crimp configuration index, $\sqrt{\tan\theta}$ varying from 0.452 to 0.667 where θ represents the angle of natural twist in wool fibre,[31] accounted for 71.4% of the variations of L_o and conversely. Another index *d.f* of crimp form is highly correlated with the parameter α of the said 14 and the 8 Pakistani wools as shown in Fig. 5.

The dichotomous splitting of the results in Fig. 5 may be due to an 'overcrimping,[32] manifested by 4 Merino and 5 Down wools. After statistical adjustment of the observations for overcrimping effect, *d.f* accounts for 96.8% of the variations of α. In addition, α-parameter which is highly correlated ($r = 0.677$) with L_o, shows a significant correlation ($r = 0.439$) with moisture content, varying from 12.5 to 13.7% also reported elsewhere,[36] of these raw wools. In agreement with a previous analysis demonstrating a significant effect of fibre length on the bulk compressibility,[31] Fig. 6 shows negative correlation between α and fibre length of the 22 raw and 16 processed wools. Thus, α is likely to be influenced by fire growth rate and/or processing strain.

Although it is highly correlated with the parameter V_o of the 22 raw wools ($r = 0.726$), α shows a nonsignificant correlation ($r = 0.347$) with β ranging from 2.209 to 3.076 with a mean value of 2.595. The correlation ($r = 0.202$) between V_o and β is also nonsignificant here but on adjusting for V_o the partial correlation between α and β ($r_{\alpha\beta \cdot V_o} = 0.733$) becomes highly significant. Hence, both α and β may depend on the natural variation of a common attribute of wool fibres.

Water-saturation, Acid-relaxation and Oxidation. These treatments often employed in back-washing and finishing of wool products definitely affect the compressional parameters (Table 2). Water-saturation decreased α (log A), L_m and V_o as expected from their correlations with each other, and increased β in agreement with its negative correlation with V_o but in contrast to its positive correlation with α. Student ratio (t-test) shows highly significant increase of L_o, although the exceptions are manifested by the medullated crossbred and Down wools. The general trend of the differences was confirmed by retesting the same 10 wools at 65% R.H. even though they gave the compressional characteristics mostly lying between the initial dry and the wet measurements. It may, however, be pointed out that hot-water relaxation of Merino, Ryeland and Border Leicester worsted rovings on their bobbins, which minimised fibre crimps, significantly lessened all the compressional parameters. The fibres were thus weakened. The change of α, nevertheless, was positively correlated with that of β. On the other hand, relaxation of slivers, tops and noils of the Merino, Southdown, Ryeland and Border Leicester wools in 0.1N HC always increased α, β and L_m (Table 2), althoughtil depleted both L_o and V_o significantly. Besides, the oxidation of their slubbings with $KMnO_4$ clearly enhanced all the characteristics save V_o. In fact, the 3 treatments diminished the bulk parameter V_o significantly.

Whilst the physical processing usually strains the weak H-bonds of wool fibres, the shrink-proofing type oxidation is most likely to attack the strong H-bonds and/or the disulphide cross-links. This difference may explain the reduction of L_o in the 12 processed wools in contrast to its considerable rise in the 4 oxidised slubbings. Moreover, under suitable conditions of relaxation the strained chemical bonds tend to acquire more stable equilibrium than that of their initial positions. Thus, they become more difficult to rupture as evident from higher values of L_m and α in the relaxed wools (Table 2). The increase of β in the said wools is probably attributable to the involvement of different chemical bonds, e.g. the new and initial positions of H-bonds, in the fibre bending rate process.



(5) (6) (7)

Fig. 5. Correlation between the parameters α and '*d.f*' (product of crimp frequency and fibre diameter); when adjusted for overcrimping pooled r=0·984, highly significant. Fig. 6. Correlation between fibre length and the parameter α of the raw (r= —0·635 highly sig. for points ●) and processed (r= —0·668 highly sig. for points ⊙) wools. Fig. 7. Correlation between the parameters α and of β the load-thickness equation for the raw processed wools using at least 2 replications of each loose wool sample — Merino ●, Down ⊙ and Carpet O, pooled r= 0·305 highly significant.

TABLE 2. VARIATION OF COMPRESSIONAL PARAMETERS WITH WATER-SATURATION, ACID-RELAXATION AND OXIDATION OF THE WOOL SAMPLES.

Sample	Before treatment					After treatment					Difference due to treatment				
	Log A	β	V_o (cm)	L_o (g)	L_m (g)	Log A	β	V_o (cm)	L_o (g)	L_m (g)	△ Log A	△ β	△ V_o (cm)	△ L_o (g)	△ L_m (g)
Raw Wool															
Merino 1	3·139	2·491	4·09	41	1145	2·844	2·938	2·37	55	550	—0·295	0·447	—1·72	14	— 595
Merino 2	3·012	2·582	3·50	41	840	2·918	3·646	2·05	60	615	—0·094	1·064	—1·45	19	— 225
Merino 3	3·115	2·885	3·50	35	1075	2·882	3·469	2·20	59	590	—0·233	0·584	—1·30	24	— 485
Merino 4	3·056	2·453	3·95	39	985	2·826	3·418	2·20	60	550	—0·230	0·965	—1·75	21	— 435
Merino 6	3·339	2·785	3·99	48	1850	3·025	3·297	2·47	56	835	—0·314	0·512	—1·52	8	—1015
B. Leic	3·078	2·980	3·61	29	1055	2·953	4·467	2·03	32	670	—0·125	1·487	—1·58	3	— 385
S. Down	3·408	2·853	4·18	59	2075	3·074	3·121	2·77	49	950	—0·334	0·268	—1·41	—10	—1125
Suffolk	3·322	2·549	4·01	63	1780	3·094	3·524	2·59	47	1000	—0·228	0·975	—1·42	—16	— 780
Dorset H	3·273	2·508	4·14	53	1664	3·153	3·925	2·40	46	1085	—0·120	1·417	—1·74	— 7	— 579
Cross br.	3·258	2·428	4·14	58	1560	3·052	3·759	2·46	50	925	—0·206	1·331	—1·68	— 8	— 635
Top															
Merino	2·773	2·292	4·02	24	523	2·907	2·388	3·81	32	710	0·0134	0·096	—0·21	8	187
B. Leic.	2·710	2·457	3·46	24	430	2·859	2·949	3·85	15	605	0·149	0·492	0·39	— 9	175
S. Down	3·039	2·270	4·41	38	940	3·260	2·733	3·85	48	1490	0·221	0·463	—0·56	10	550
Ryeland	2·960	2·135	4·43	39	817	3·161	2·469	3·92	50	1232	0·201	0·334	—0·51	11	415
Noil															
Merino	3·053	2·523	3·75	45	930	3·063	2·896	3·57	29	980	0·010	0·373	—0·18	—16	50
B. Leic	2·936	2·288	3·80	41	760	3·059	2·812	3·73	25	975	0·123	0·524	—0·07	—16	215
S. Down	3·251	2·596	3·64	63	1507	3·343	3·408	3·12	43	1684	0·092	0·812	—0·52	—20	177
Ryeland	3·206	2·383	4·15	54	1327	3·276	3·020	3·58	40	1540	0·070	0·637	—0·57	—14	213
Sliuer															
Merino	2·903	2·022	4·78	41	715	2·952	2·348	3·54	46	805	0·049	0·326	—1·24	5	90
B. Leic.	2·782	2·315	3·56	32	527	2·788	2·709	3·71	18	540	0·006	0·394	—0·15	—14	13
S. Down	3·242	2·361	4·56	65	1431	3·251	2·534	3·78	61	1515	0·009	0·173	—0·78	— 4	84
Ryeland	3·188	2·060	4·65	60	1373	3·225	2·605	4·01	42	1395	0·037	0·545	—0·64	—18	22
Slubbing															
Merino	2·940	2·788	3·56	25	745	3·270	3·282	3·06	48	1505	0·330	0·494	—0·50	23	760
B. Leic.	2·816	2·579	3·61	24	575	2·998	2·811	3·27	39	870	0·182	0·232	—0·34	15	295
S. Down	3·278	2·876	3·66	48	1600	3·500	3·342	3·31	61	2610	0·222	0·466	—0·35	13	1010
Ryeland	3·168	2·380	3·87	42	1310	3·450	3·14	3·20	62	2310	0·282	0·934	—0·67	20	1000

Initial 10 wools for water-saturation, intermediate 12 for acid-relaxation and the last 4 for oxidation treatments. For △L_o, $t=10·5$ highly significant in the water saturated wools and = — 22·5 highly significant in the acid relaxed wools.

As to the negative correlation between the changes of α and β in the 10 water-saturated wools, excess waert molecule may polarise the active H-bonds in wool fibre.[37] They break more easily, as indicated by considerable decrease of α and L_m in the wet state, than the unpolarised H-bonds of dry wool. Since both the polarised and unpolarised bonds are dissociated in compression testing, the average increase of β-value by 0.905 in the wet wools is most likely to arise from the participation of additional H-bonds of the polarised type. Therefore, β-parameter may represent the order of molecular reactions in the rate process of fibre bending.

Nature of Compressional Characteristics. The intercept and slope of the 'log L vs log V' regression line are respectively given by α and β. Figure 7 presents a highly significant positive correlation between them, although the results have been differently marked to distinguish the Merino, Down and Carpet wools. It also shows the measurements on individual specimen of all the untreated samples tested in the dry state because the sample mean observations are likely to even down any cyclic pattern of variations (cf. Fig. 4).

The results in Fig. 7 clearly manifest 3 maxima and minima in the probability (frequency) of β-distribution, which may suggest that β-parameter varies directly with the order of molecular reactions in the rate processes of fibre bending, as also noted before. In the light of potential energy distribution for various rate processes,[38] the present correlation may imply a direct association, of α-parameter with the 'activation energy' of molecular reactions under the test conditions. This proposition conforms to the present author's observation that the equations 1–3 are also capable of explaining more than 99% of the variations of yarn compressbility even though the compressional parameters may be significantly affected by interaction between yarn geometry and wool type, and between yarn twist and tex.[39]

Equation 1 is somewhat similar to a load-thickness relation, $L=(12.9/V)^{3\cdot 33}$ derived empirically for pile slivers[4] but it lacks in the correction term for zero point as given by L_o in equation 2 here. The corrected equation 3 closely corresponds to those derived from theoretical models[1] of gas compressibility, i.e. $L=L_o V_o \Upsilon \left(\frac{1}{V^{\Upsilon}}-\frac{1}{V_o^{\Upsilon}}\right)$ and metal cantilever,[2] $L=K\left(\frac{1}{V^3}-\frac{1}{V_o^3}\right)$ but the values of their 'constant characteristics', i.e. L_o, V_o, and K, differ very widely[9] due, perhaps, to the differences between theory and practice, and between various testing conditions. Nevertheless, equation 3 accounts for most of the variations commonly encountered in a wide range of loose wool fibre ensembles.

Obviously, the latent load, L_o is a complex function of α, β and V_o. The gradient of compressive force in a random fibre assembly being inversely proportional to its initial thickness, V_o will introduce some bias in the estimation of the load L_m which is the limiting value of bulk modulus $\left(\propto V\frac{dL}{dV}\right)$ at constant volume.[31] Although the bias becomes largely negligible at the slow rate of loading as employed here, at the slower loading rates the plastic flow (molecular slippage) may become more important than the elastic straining of chemical bonds whereupon the fibre deformations tend to be largely irreversible.

Conclusions

An empirical equation (equation 3) which accounts for most of the increase of specific compressional load with the decrease of bulk thickness of a loose wool assembly, is somewhat analogous to those derived from the models of gas compressibility[1] and metal cantilever,[2] although the models are not fully representative of a random fibre assembly. The regression coefficients of equation 3 are highly correlated with crimp form, fibre length, moisture content and softness of a wide variety of wool fibres. The coefficients are inter-related even when they are modified by mechanical processing, wetting, acid-relaxation and oxidation of the wool fibres. It has also been suggested that the compressional parameters may well be the functions of 'activation energy' and order of molecular reactions occurring in the fibre bending rate processes.

References

1. M. Eggert and J. Eggert (1925) quoted after C.M. Van Wyk, Ref. No. 2(1946).
2. C.M. Van Wyk, Onderstepoort J. Vet. Sci. Ani. Ind., **21,** 99 (1946).
3. K. Wakayama and T. Hattori, J. Textile Machinery Soc. Japan, **5,** 25(1955).
4. J. Schofield, J. Textile Inst., **29,** T239 (1938).
5. S.L. Anderson and G.E. Settle, Proc. Int. Wool Textile Res. Conf. Paris, **4,** 255 (1955).
6. W.J. Onions, E. Oxtoby and P.P. Townend, J. Textile Inst., **58**(7), T239 (1967).
7. R.M. Hoffman and L.F. Beste, Textile Res. J., **21**(2), 66 (1951).
8. H. Bogaty, N.R.S. Hollies, J.C. Hintermaier and M. Harris, Textile Res. J., **23,** 108(1953).
9. P. Larose, Textile Res. J., **23,** 730 (1953).
10. M.A. Ali, M. Sc. thesis, University of New South Wales, Sydney (1968).
11. D.E. Boseley, Textile Res. J., **38,** 141 (1968).
12. P.C. de McCarty and J.H. Dusenbury, Textile Res. J., **25,** 875 (1955).
13. W.H. Rees, J. Textile Inst., **39,** T131 (1948).
14. K.R. Fox and T.G. Finzel, Textile Res. J., **26,** 684 (1956).
15. K.R. Fox and E.R. Schwarz, Textile Res. J., **12,** 2 (1942).
16. N.F. Roberts and E. Sebestyen J. Textile Inst., **54,** T49 (1963).
17. R.I. Slinger and S. Smuts, SAWTRI Tech. Rep. No. 89 (1967).
18. L.M. Pidgeon and V. Winson, Can. J. Res., **10,** 1 (1934).
19. J.H. Dillon, Textile Res. J., **17,** 207 (1947).
20. M. Takikawa and K. Kawamura, J. Japan Soc. Textile Engg., **17**(4), 301(1961).

21. J.B. Speakman, Trans. Faraday Soc., **25**,92 (1928).
22. J.B. Speakman, J. Soc. Chem. Ind., **49**, T209 (1930).
23. J.B. Miles, Textile Res. J., **30**, 408 (1960).
24. H. Zahn and G. Blankenburg, Textile Res. J., **32**, 986 (1962).
25. R.I. Slinger, Textile Res. J., **35**, 856 (1965).
26. A. Demiruren and R.H. Burns, Textile Res., J., **25**, 665 (1955).
27. M.A. Ali, Pakistan J. Sci. Ind. Res., **14**(3), 288 (1971).
28. M.A. Ali, Pakistan J. Sci. Ind. Res. **4**(3), 293 (1971).
29. G. Blankenburg, J. Textile Inst., **56**, T145 (1965).
30. R.H. Burns and A. Johnson, J. Textile Inst., **28**, T13 (1937).
31. M.A. Ali, Pakistan J. Sci. Ind. Res., **14**, 150 (1971).
32. G.E. Scheepers and R.I. Slinger, SAWTRI Tech. Rep. No. 103 (1968).
33. J.R. McPhee, Textile Res. J., **30**, 349 and 359 (1960).
34. L.W. Rainard and D. Abbott, Textile Res. J., **20**, 301 (1950).
35. Int. Wool Textile Organ. Tech. Comm., Wool Sci. Rev., Special Issue (1966).
36. M.A. Ali, Pakistan J. Sci. Res., in press.
37. M.A. Ali, Sci. Chron., **7**(4), 32(1969).
38. S. Glasstone, K.J. Laidler and H. Eyring, *The Theory of Rate Processes* (McGraw-Hill, New York, 1941), p. 85.
39. M.A. Ali, unpublished data (1971).