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FRICTIONAL PROPERTIES OF SOME PAKISTANI WOOLS

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The frictional properties of a few Pakistani wools have been measured by Lipson's method. The fibres have been classified into medullated, heterotypical and true types where applicable, and coefficients of friction, directional frictional effect and scaliness have been calculated for each type. A statistical analysis of the results together with their significance has been presented.

Introduction

As early as 1790, a French chemist, Monge,[1] noticed the preferential movement of wool fibre in the rootward direction when rubbed between the thumb and a finger and this led him to postulate that the wool fibre is covered with a ratchet-like scale structure. The presence of this saw-tooth structure has now been clearly established in all hair fibres. The scales are distinctly visible under an ordinary light microscope.

The surface scales overlap, project slightly from the shaft of the fibres and point towards the fibre tip. The frequency, height and extent of overlapping of the scales, however, vary considerably among hair fibres.[2] The coefficient of friction of a wool fibre is higher when motion takes place against the scales than when it is in the opposite direction. The "against-scale" frictional coefficient was denoted μ_2 and the "with-scale" frictional coefficient, μ_1 by Speakman and Stott[3] and other workers but this nomenclature, which will be used here, has sometimes been reversed. The difference $\mu_2-\mu_1$ is known as the "directional frictional effect" or D.F.E.[4] The ratios $(\mu_2-\mu_1)/\mu_1 \times 100$[3] and $(\mu_2-\mu_1)/\mu_2+\mu_1)$ measure the relative frictional difference[5,6] and were used as a measure of scaliness and D.F.E. respectively. Other combinations of μ_1 and μ_2 have also been used in order to relate these frictional parameters to felting.[7]

The characteristic frictional properties of wool are of vital importance throughout the processing in both the woollen and worsted systems[8] and in the felting of woollen goods in particular. The fibres actually migrate in a rootward direction[9,10] when woollen goods are subjected to compression during washing. This causes entanglements to take place between adjacent yarns and the fabric loses shape. On the other hand, the production of nonwoven felts, and high density textures is dependent primarily on the same preferential rootward migration. That is why the D.F.E. is regarded as a boon as well as a nuisance.[11]

It has been shown that natural variations in frictional properties among various wools, affect felting of end-products to various degrees.[3,12,13] A knowledge of the frictional properties of various Pakistani wools could provide a useful guide to the selection of wools according to our needs. Other factors being equal, the wool possessing lower D.F.E. will be more suitable for hosiery and apparel purposes which are washed frequently while in service, whereas the wools possessing higher D.F.E. may be employed for the production of nonwoven felts and high density fabrics. In practice, however, a variety of other factors such as fibre crimp are more significant than variations in D.F.E. among different wools.[13]

Materials and Methods

Twenty randomly drawn fibres from each of the available types among the seven wools investigated were collected. The fibres were thoroughly degreased with diethyl ether. Individual fibres were cemented to two metallic hooks (both 200 mg) with flexible collodion. Woollen yarn was wrapped round two similar capstans to stimulate the interfiber friction conditions encountered in practice.[14] The fibres were passed round these cylinders and small weights were added successively on one side till the fibre just began to slip.[15] The procedure was repeated for the other side. These data were obtained under room conditions of temperature and humidity. 0.1N HCl solution was then dripped over the capstan–fibre junction to saturate the fibres thoroughly and the experiment was repeated as before to give "wet" measurements. The choice of this dilute solution was dependent upon the fact that it was to be used as a felting medium in a separate study concerning the relationship between frictional properties and feltability.

If T_1 and T_2 are the tensions on the fibre ends at the onset of slippage, then the coefficient of friction can be calculated by the classical formula, based on Amonton's laws of friction i.e.

$T_2/T_1 = e^{\mu\theta}$ where μ is the coefficient of friction and θ is the angle of wrap $= \pi$ in this case. $\ln T_2/T_1 = \mu\pi$ or $\mu = 1/\pi \ln T_2/T_1$.

Results and Discussion

Detailed results for Kaghani wool are shown in Table 1, and the mean values for all the seven wools used are presented in Table 2. Measurements have been reported for true fibres only in the Kail breed due to the small proportion of medullated and heterotypical fibres in that breed.

The standard deviation (S.D.) and the coefficient of variation (coeff. of V), of μ_2, μ_1, D.F.E. and scaliness indicate the absolute and relative spread of the measurements and are within the range reported by other workers except that the variations in D.F.E. are rather high although they too can be considered acceptable under the present conditions of measurement. The higher values of coefficients of variation of the D.F.E. are also expected due to the joint variations in μ_2 and μ_1 and the comparatively lower values of the mean D.F.E. The standard error (S.E.) could be taken for a measure indicating the extent of accuracy in estimating the mean value of the respective parameter. The S.E. of ± 0.009 for the mean μ_2 (0.58) in the wet state of the medullated fibres of the Kaghani wool, for example, indicates that 95% of the time the mean value of μ_2 would range between 0.58 ± 0.019.[16]

TABLE 1.—FRICTIONAL COEFFICIENT OF KAGHANI WOOL (HAZARA DISTRICT).

No.	Dry state				Wet state			
	μ_2	μ_1	D.F.E.	Scaliness	μ_2	μ_1	D.F.E.	Scaliness
1	2	3	4	5	6	7	8	9
				(a) *Medullated Fibres*				
1	0.26	0.24	0.02	8.3	0.60	0.39	0.21	53.8
2	0.30	0.28	0.02	7.1	0.55	0.34	0.21	61.8
3	0.40	0.36	0.04	11.1	0.63	0.41	0.22	53.7
4	0.41	0.38	0.03	7.9	0.57	0.42	0.15	35.7
5	0.40	0.31	0.09	29.0	0.57	0.40	0.17	42.5
6	0.32	0.28	0.04	14.3	0.48	0.36	0.12	33.3
7	0.39	0.38	0.01	2.6	0.51	0.39	0.12	30.8
8	0.39	0.38	0.01	2.6	0.58	0.45	0.13	28.9
9	0.45	0.37	0.08	21.6	0.57	0.43	0.14	32.6
10	0.41	0.35	0.06	17.1	0.60	0.41	0.19	46.3
11	0.46	0.46	0.00	0.0	0.60	0.51	0.09	46.3
12	0.35	0.33	0.02	6.1	0.60	0.38	0.22	57.9
13	0.44	0.38	0.06	15.8	0.64	0.48	0.16	33.3
14	0.43	0.36	0.07	19.5	0.57	0.40	0.17	42.5
15	0.37	0.29	0.08	27.6	0.55	0.36	0.19	52.8
16	0.48	0.38	0.10	26.3	0.57	0.39	0.18	46.2
17	0.43	0.30	0.13	43.3	0.57	0.38	0.19	50.0
18	0.45	0.40	0.05	12.5	0.58	0.46	0.12	26.1
19	0.42	0.39	0.03	7.7	0.60	0.45	0.15	33.3
20	0.46	0.38	0.08	21.1	0.64	0.48	0.16	33.3
Mean	0.40	0.35	0.05	15.1	0.58	0.42	0.16	40.6
S.D.	0.057	0.052	0.035	11.6	.039	.045	.037	11.8
Coeff. of V(%)	14.2	14.9	70.0	76.8	6.7	10.7	23.1	29.1
S.E. (±)	0.013	0.012	0.008	2.6	0.009	0.010	0.008	2.6
				(b) *Heterotypical Fibres*				
1	0.44	0.35	0.09	25.7	0.66	0.48	0.18	37.4
2	0.48	0.36	0.12	33.3	0.60	0.42	0.18	42.8
3	0.57	0.53	0.04	7.6	0.76	0.58	0.18	31.0

(*Continued*)

Table 1.—*continued*

1	2	3	4	5	6	7	8	9
4	0.45	0.34	0.11	32.3	0.66	0.47	0.19	40.4
5	0.49	0.39	0.10	25.6	0.66	0.48	0.18	37.4
6	0.48	0.38	0.10	26.3	0.68	0.48	0.20	41.7
7	0.52	0.43	0.09	20.9	0.72	0.44	0.28	63.6
8	0.48	0.36	0.12	33.3	0.64	0.40	0.24	60.0
9	0.48	0.36	0.12	33.3	0.69	0.46	0.23	50.0
10	0.51	0.40	0.11	21.8	0.69	0.47	0.22	46.8
11	0.51	0.39	0.12	30.8	0.71	0.46	0.25	54.3
12	0.48	0.37	0.11	29.7	0.65	0.43	0.22	51.2
13	0.46	0.37	0.09	24.3	0.73	0.45	0.28	62.2
14	0.49	0.38	0.11	28.9	0.67	0.44	0.23	52.3
15	0.48	0.39	0.09	23.1	0.65	0.42	0.23	54.8
16	0.44	0.32	0.12	37.5	0.59	0.35	0.24	68.6
17	0.44	0.32	0.12	37.5	0.63	0.35	0.28	80.0
18	0.45	0.29	0.16	55.2	0.61	0.31	0.30	96.8
19	0.45	0.34	0.11	32.4	0.60	0.35	0.35	71.4
20	0.45	0.34	0.11	32.4	0.56	0.33	0.23	69.7
Mean	0.48	0.37	0.11	29.6	0.66	0.43	0.23	55.6
S.D.	0.033	0.049	0.025	12.8	0.051	0.065	0.053	17.6
Coeff. of V (%)	6.9	13.2	22.7	43.3	7.7	15.1	23.0	31.7
S.E. (±)	0.007	0.011	0.006	2.9	0.011	0.014	0.012	3.9

(c) *True Fibres*

1	0.52	0.35	0.17	48.6	0.67	0.38	0.29	76.3
2	0.51	0.35	0.16	45.7	0.71	0.41	0.30	73.2
3	0.44	0.30	0.14	46.1	0.66	0.40	0.26	65.0
4	0.44	0.33	0.11	33.3	0.67	0.40	0.27	67.5
5	0.50	0.33	0.17	51.5	0.65	0.35	0.30	85.7
6	0.49	0.38	0.11	28.9	0.56	0.36	0.20	55.6
7	0.53	0.38	0.15	39.5	0.68	0.42	0.26	61.9
8	0.47	0.30	0.17	54.1	0.72	0.34	0.38	111.6
9	0.46	0.37	0.09	24.3	0.59	0.39	0.20	51.3
10	0.43	0.35	0.08	22.9	0.65	0.40	0.25	62.5
11	0.47	0.36	0.11	30.6	0.69	0.40	0.29	72.5
12	0.48	0.36	0.12	33.3	0.69	0.41	0.28	69.3
13	0.49	0.35	0.14	50.0	0.65	0.38	0.27	71.1
14	0.44	0.29	0.15	51.7	0.70	0.46	0.24	52.2
15	0.50	0.36	0.14	38.9	0.67	0.45	0.22	48.9
16	0.50	0.35	0.15	42.9	0.69	0.42	0.27	64.3
17	0.41	0.29	0.12	41.4	0.72	0.34	0.38	111.6
18	0.41	0.29	0.12	41.4	0.73	0.42	0.31	73.8
19	0.43	0.30	0.13	43.3	0.71	0.41	0.30	73.2
20	0.45	0.24	0.21	87.5	0.70	0.38	0.32	84.2
Mean	0.47	0.33	0.14	42.3	0.68	0.40	0.28	71.5
S.D.	0.036	0.038	0.031	17.3	0.043	0.033	0.048	16.8
Coeff. of V (%)	7.7	11.5	22.1	40.9	6.3	8.2	17.1	23.5
S.E. (±)	0.008	0.009	0.007	3.9	0.010	0.007	0.011	3.8

TABLE 2.—MEAN FRICTIONAL PARAMETERS.

	Dry state				Wet state			
	μ_2	μ_1	D.F.E.	Scaliness	μ_2	μ_1	D.F.E.	Scaliness
1	2	3	4	5	6	7	8	9
(a) *Kaghani Wool (Hazara District)*								
(i) *Medullated Fibres*								
Mean	0.40	0.35	0.05	15.1	0.58	0.42	0.16	40.6
S.D.	0.057	0.052	0.035	11.6	0.039	0.045	0.037	11.8
Coeff. of V(%)	14.2	14.9	70.0	76.8	6.7	10.7	23.1	29.1
S.E. (±)	0.013	0.012	0.008	2.6	0.009	0.010	0.008	2.6
(ii) *Heterotypical Fibres*								
Mean	0.48	0.37	0.11	29.6	0.66	0.43	0.23	55.6
S.D.	0.033	0.049	0.025	12.8	0.051	0.065	0.053	17.6
Coeff. of V(%)	6.9	13.2	22.7	43.2	7.7	15.1	23.0	31.7
S.E. (±)	0.007	0.011	0.006	2.9	0.011	0.014	0.012	3.9
(iii) *True Fibres*								
Mean	0.47	0.33	0.14	42.3	0.68	0.40	0.28	71.5
S.D.	0.036	0.038	0.031	17.3	0.043	0.033	0.048	16.8
Coeff. of V(%)	7.7	11.5	22.1	40.9	6.3	8.2	17.1	23.5
S.E.(±)	0.008	0.009	0.007	3.9	0.010	0.007	0.011	3.8
(b) *Hashtnagri Wool (Peshawar District)*								
(i) *Medullated Fibres*								
Mean	0.47	0.34	0.13	41.8	0.62	0.36	0.26	73.8
S.D.	0.058	0.034	0.051	16.9	0.032	0.030	0.036	14.5
Coeff. of V(%)	12.3	10.0	39.2	40.4	5.2	8.4	13.8	19.6
S.E.(±)	0.013	0.008	0.011	3.8	0.007	0.007	0.008	3.2
(ii) *Heterotypical Fibres*								
Mean	0.41	0.31	0.10	33.1	0.61	0.36	0.25	70.4
S.D.	0.057	0.051	0.031	9.8	0.024	0.028	0.042	12.4
Coeff. of V(%)	13.9	16.4	31.0	29.6	3.9	7.8	16.8	17.6
S.E.(±)	0.013	0.011	0.007	2.2	0.005	0.006	0.009	2.8
(iii) *True Fibres*								
Mean	0.43	0.30	0.13	45.4	0.65	0.42	0.23	55.2
S.D.	0.048	0.038	0.047	20.1	0.088	0.097	0.047	20.3
Coeff. of V(%)	11.2	10.6	36.1	44.3	13.5	23.1	20.4	36.8
S.E. (±)	0.011	0.009	0.010	4.5	0.020	0.022	0.010	4.5
(c) *Kail (Azad Kashmir)*								
True Fibres only								
Mean	0.43	0.31	0.12	41.1	0.65	0.39	0.26	67.4
S.D.	0.034	0.035	0.041	19.2	0.051	0.039	0.041	14.8
Coeff. of V(%)	7.9	11.3	34.2	46.7	7.8	10.0	15.8	21.9
S.E. (±)	0.008	0.008	0.009	4.3	0.011	0.009	0.009	3.3

(Continued)

Table 2—*continued.*

1	2	3	4	5	6	7	8	9
				(d) *Local Country Breed (Azad Kashmir)*				
*True Fibres only**								
Mean	0.44	0.34	0.10	30.2	0.64	0.42	0.22	54.2
S.D.	0.042	0.027	0.033	8.0	0.045	0.043	0.056	17.2
Coeff. of V(%)	9.5	8.0	33.0	26.5	7.0	10.2	25.4	31.7
S.E. (±)	0.009	0.006	0.007	1.8	0.010	0.010	0.013	4.0
				(e) *Buchi Wool (Bahawalpur District)*				
(i) *Medullated Fibres*								
Mean	0.49	0.40	0.09	21.3	0.77	0.58	0.19	34.1
S.D.	0.054	0.045	0.029	8.6	0.028	0.044	0.042	9.7
Coeff. of V(%)	11.0	11.2	32.2	40.4	3.6	7.6	22.1	28.5
S.E. (±)	0.012	0.010	0.006	1.9	0.006	0.001	0.009	2.2
(ii) *Heterotypical Fibres*								
Mean	0.49	0.40	0.09	21.3	0.77	0.56	0.21	36.7
S.D.	0.031	0.025	0.025	5.7	0.33	0.027	0.037	7.1
Coeff. of V(%)	6.3	6.2	27.8	26.8	4.3	4.8	17.6	19.3
S.E.(±)	0.007	0.006	0.006	1.3	0.007	0.006	0.008	1.6
(iii) *True Fibres*								
Mean	0.46	0.34	0.12	35.0	0.79	0.54	0.25	48.5
S.D.	0.016	0.022	0.017	10.8	0.034	0.031	0.035	17.7
Coeff. of V(%)	3.1	5.4	15.4	30.9	4.1	5.4	14.0	36.5
S.E.(±)	0.004	0.005	0.004	2.4	0.008	0.007	0.008	4.0
				(f) *Harnai Wool (Loralai District)*				
(i) *Medullated Fibres*								
Mean	0.44	0.34	0.10	31.4	0.58	0.43	0.15	34.7
S.D.	0.036	0.040	0.041	12.0	0.037	0.038	0.047	12.8
Coeff. of V(%)	8.2	8.5	41.0	38.2	6.4	8.8	31.3	36.9
S.E. (±)	0.008	0.009	0.009	2.7	0.008	0.009	0.011	2.9
(ii) *Heterotypical Fibres*								
Mean	0.40	0.32	0.08	23.2	0.59	0.43	0.16	38.1
S.D.	0.041	0.029	0.032	9.1	0.056	0.043	0.049	12.3
Coeff. of V(%)	10.2	9.1	40.0	39.2	9.5	10.0	30.6	32.3
S.E. (±)	0.009	0.006	0.007	2.0	0.013	0.010	0.011	2.8
(iii) *True Fibres*								
Mean	0.43	0.32	0.11	36.6	0.055	0.38	0.17	45.9
S.D.	0.040	0.032	0.035	13.8	0.040	0.024	0.044	13.0
Coeff. of V(%)	9.3	10.0	31.8	37.7	7.3	6.3	26.0	28.3
S.E. (±)	0.009	0.007	0.008	3.1	0.009	0.005	0.010	2.9

Continued

Table 2.—*continued*

1	2	3	4	5	6	7	8	9
				(g) *Dumba Wool* (*Dadu District*)				
(i) *Medullated Fibres*								
Mean	0.46	0.35	0.11	31.8	0.61	0.43	0.18	43.3
S.D.	0.025	0.034	0.028	10.1	0.034	0.034	0.034	9.6
Coeff. of V(%)	5.4	9.7	25.5	31.8	5.6	7.9	18.9	22.2
S.E. (±)	0.006	0.008	0.006	2.2	0.008	0.008	0.008	2.1
(ii) *Heterotypical Fibres*								
Mean	0.44	0.33	0.11	36.4	0.62	0.38	0.24	64.2
S.D.	0.034	0.038	0.028	14.4	0.030	0.038	0.037	16.4
Coeff. of V(%)	7.7	11.5	25.5	39.6	4.8	10.0	15.4	25.5
S.E. (±)	0.008	0.009	0.006	3.2	0.007	0.009	0.008	3.7
(iii) *True Fibres*								
Mean	0.39	0.30	0.09	28.4	0.60	0.37	0.23	64.3
S.D.	0.017	0.023	0.028	12.1	0.027	0.041	0.039	14.0
Coeff. of V(%)	4.4	7.7	31.1	42.6	4.5	11.1	17.0	21.8
S.E.(±)	0.004	0.005	0.006	2.7	0.006	0.009	0.009	3.1

*Medullated and heterotypical fibres were too short to conduct measurements with this method.

A two-way analysis of variance[16] (Table 3) of the frictional parameters revealed that in the dry state, (a) μ_2, D.F.E. and scaliness are significantly different neither among the breeds studied nor among the fibre types under the present conditions of measurement, (b) μ_1 is highly significantly different (1% level) among breeds as well as among fibre types.

In the wet state ((0.1N HCl), (a) μ_2, μ_1 are highly significantly different (1% level) among the breeds but neither of the two differs significantly among the fibre types; (b) D.F.E. differences among the breeds just fail to reach significance (at the 5% level, $F_{4,8}$ required=3.84, $F_{4,8}$ obtained =3.60). D.F.E. also tended to differ to the same extent among the medullated, heterotypical and true fibres (Table 3). (c) Scaliness was significantly different (5% level) among the breeds but not between the fibre types.

The frictional coefficients, particularly μ_1, for Pakistani wools presented in Tables 1 and 2 are significantly higher than the values reported in literature.[3,13,17] It can also be seen (Table 2) that μ_2, μ_1, D.F.E. and scaliness values in wet state are, as usual, markedly higher than the dry values. It would appear that, due to swelling in wet state, the scales project from the fibre shaft more prominently and this, in combination with a larger area of contact in wet state, causes increase in μ_2 and μ_1. The increase in μ_2 is comparatively greater than in μ_1. The actual coefficients are due to cohesion effects measured by the formula $F=SA$ where F=force of friction, S=shearing

TABLE 3.—SIGNIFICANCE LEVELS OF FRICTIONAL PARAMETERS THROUGH ANALYSIS OF VARIANCE.*

	μ_2	μ_1	D.F.E.	Scaliness
		Dry (*room conditions*)		
Breeds	—	***	—	—
Fibre types	—	***	—	—
		Wet (0.1N HCl)		
Breeds	***	***	*	**
Fibre types	—	—	Nearly * (F required =3.11, F2,8=2.98)	—

* In view of the data being not available (see text) for medullated and heterotypical fibres, the two Azad Kashmir wools are not included in this analysis.

—, not significant.

*, significant at 10% level.

**, significant at 5% level.

***, significant at 1% level.

strength and A=area of contact.[18] In addition μ_2, μ_1 are affected by the geometry of the surface which endows μ_2 with a ploughing effect in addition to choesion but does not increase μ_1 appreciably.[13]

The frictional parameters (except μ_1) in case of true fibres are not much different from those of the medullated and heterotypical types. The high values of the frictional coefficients would, therefore, appear to be a unique characteristic of Pakistani wools. As differences between fibre types were not significant, the existence of a medulla which could in turn indicate a unique fibre substance, does not affect the results. This lends further support to the view that the higher values of coefficients of friction are purely the outcome of surface factors.

It is expected that wools containing a generous proportion of medullated and heterotypical fibres would prove more resistant to compression. If this speculation is true then it can be inferred that in Pakistani wools the presence of medullated and heterotypical fibres lends necessary strength in the manufacture of carpets where the true fibres present intertwine and entangle themselves giving further support to the structure. It would appear that the medullated and heterotypical fibres act as natural girders having sufficient strength but lesser material and true fibres bind them together and act as cementing material. Furthermore, the high frictional coefficients could inhibit the disintegration of the carpet structure prepared from these fibres. This combination of the two types of fibres in a wool may be responsible to maintain the structure with passage of time and traffic and for giving the carpet the essential durability.

The frictional measurements of other wools will be presented and an attempt will be made to correlate all these results to feltability in a subsequent investigation.

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