Pakistan J. Sci. Ind. Res., Vol. 18, Nos. 1-2, February-April, 1975

FIBRE AND STAPLE CRIMP IN CARPET WOOLS

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(Received September 12, 1973; revised December 10, 1974)

Abstract. In addition to the staple crimp frequency, the fibre crimp frequency of various types of fibre viz true wool, heterotypical and medullated has been determined in a series of Pakistani carpet wools. The interrelationships of fibre crimp frequency with staple crimp frequency, diameter and length have been examined and results contrasted with known findings on fine wools. It has been revealed that although correspondence between staple crimp frequency and the usual primary fibre crimp frequency is negligible, a secondary crimp of a larger amplitude corresprnonds in varying degrees with the staple crimp, especially in the case of medullated fibres. A significant negative relationship is found to exist between fibre crimp frequency and diameter, provided that the range of diameter of fibres under examination is wide enough. In certain cases fibre crimp frequcncy has been found to have a positive relationship with fibre length.

Several studies have been made on the various aspects of occurrence of cimp in fine wools.[1,2] These studies have largely aimed at investigation of frequency, regularity, origin and significance in manufacture of staple crimp and also its relationships with other wool characteristics. Very few studies have, however, been made on the crimp characteristics of carpet wools, perhaps partly becuase of incidence of low staple crimp frequency in these wools. The majority of single fibres in these wools, nevertheless, appears to be associated with an incidence of crimp frequency similar to that of fibres of equal fineness in fine and medium quality wools. It is, threrefore, desirable to investigate the occurrence of crimp in these wools with a view to elucidating its relationships with other fibre characteristics and contrast the results with known data on fine wools.

In an earlier study on quality of Pakistani wools[3] the occurrence of both staple and fibre crimp was examined. It was observed that the pattern of frequency was different in true and medullated fibres. The estimates of fibre crimp frequency, without differentiating between the various fibre types are, therefore, not much useful in examining the various relationships with fibre diameter and other characteristics in the case of these wools.

Some workers have examined the relationship between staple and fibre crimp in fine wools.[4] The common belief has been that staple crimp is brought about by regularity in individual fibre crimp or by constraints associated with a minority of fibres. It would be desirable to know how fibre crimp frequency is related to the conspicuously low-staple crimp frequency in carpet wools. Likewise, the concept of crimp being a periodic phenomenon of time, necessitating its independence from fibre length, as suggested in the case of fine wools,[5,7] may well be examined in the case of carpet wools. In the case of these wools, apart from the above referred preliminary work carried out at these Laboratories on the said relationship between fibre and staple crimp,[3] no other study seems to be available.

The primary objective of the present study was to examine and compare crimp frequency of the various fibre types viz. true, heterotypical and medullated in carpet wools and to investigate its relationship with the staple crimp frequency. In addition, some of the other associated relationships such as those between fibre crimp frequency, fibre fineness and fibre length have also been investigated.

The term heterotypical as used in this study implies fibres with non-continuous medulla (both interrupted and fragmented) as distinct from medullated fibres with a continuous medulla.

Materials and Methods

Wool Source. A series of 13 samples of different Pakistani wools were employed for the study. Each sample was withdrawn at random from 10 to 30 different samples of the breed available at these Laboratories or the local sheep farms. This was not done to obtain representative samples of each breed but simply to have a cross-section of Pakistani wools so that a variety of samples is included with different levels of staple and fibre crimp frequency. It may be mentioned that, as revealed by the preliminary studies, the fibre and staple crimp frequency usually vary slightly from sample to sample within these breeds but appreciable differences occur at the between breed level. Hence one sample per breed was arbitrarily selected to serve the above purpose. In the case of Kaghani breed, however, the within breed variation in staple crimp frequency seemed conspicuous; in this case three samples were, therefore, selected with different levels of crimp frequency. One of the samples included was obtained from a sheep which was a cross between a local breed 'Kail' and the imported 'Rambouillet.'

Crimp Frequency and Length. For staple crimp, 20 staples were selected at random from each of the samples and the frequency determined by the method described earlier[3] viz. by measurement against a ruler. A typical staple with frequency corresponding to mean staple frequency of the sample was subsequently selected for measurement of fibre crimp. This staple was carefully divided into half and, if necessary, one-half was further divided into two parts so as to yield a bunch of about 200–400 fibres. Some tearing and breaking of fibres is possible in such a division; the investigations in this study pertain, however, to crimp characteristics of the fibres as released from the staples and sorted into various fibre types by the procedures described here and the evaluation of crimp characteristics of fibres in tact in the staples is not claimed. It was, incidentally, observed that such tearing and breaking was slight in these wools in comparison to fine wool, as the staples were less compact, the grease content was low and the fibres were rather loosely held in the staples. The bunch so obtained was sorted into true, heterotypical and medullated fibres by the benzene test.[8] Fibre crimp frequency and length of all the fibres of each type were then determined by the methods described earlier.[3] The term (staple and fibre) 'length', as used in this paper pertains to crimped length which was obtained by slightly straightening, if necessary, the staple or the fibre, as the case may be, so that it can be placed along a ruler but not stretching it to remove the crimp. The frequency was recorded as crimp per inch which would subsequently be denoted as c.p.i. Later on, in this study, a distinction has been made between a 'primary' and a 'secondary' crimp, but generally the term fibre crimp as used in this study refers to the primary crimp, unless otherwise stated. The incidence of kemp being low, these fibres were not included in the study.

Diameter. The mean fibre diameter of each fibre type in all the wool samples was determined by reducing the fibres to snippets[3] and measuring at a magnification of ×500. In addition, in the case of two typical carpet wools viz. Hashtnagri and Lohi, 15 fibres of each fibre type were selected at random, and were spared for within sample investigation on the relationship between fibre diameter and fibre crimp frequency. Subsequently, after noting the number of crimps of each fibre, its diameter was measured at about equidistant 20 points at a magnification of ×500.

Amplitude. The determination of amplitude of single fibres is rather complicated due to the difficulties associated with crimp form and the exact definition of fibre length.[9,10] However, as the objective of this study was simply to elucidate rather large differences in amplitude between the various fibre types, the simple technique of placing the fibre under a glass cover and measuring the depth by a low power microscope was employed. These studies were carried out employing the two typical carpet wools viz. Hashtnagri and Lohi, when the amplitude of crimps in about 15–20 fibres of each type drawn at random from a typical staple of each of these wools was determined.

Results and Discussion

The between sample mean results for staple as well as fibre length and the corresponding number of crimps per staple or fibre, as the case may be, are presented in Table 1, while those for fibre diameter have been given in Table 2, which also incorporates, for convenience, c.p.i. as calculated from the data of Table 1. Typical within sample data for Lohi wool comprising fibre length in inches and number of crimps per fibre have been given in Table 3; such data were recorded for the 13 different samples and the mean values so obtained were employed to construct Table 1. Likewise, Table 4 related to Hashtnagri wool is appended to give a view of the relationship between fibre diameter and c.p.i. as existing in the various fibre types within a sample. Table 5 gives the coefficients of correlation in the various cases. Table 6 presents results for amplitude measurements.

Staple and Fibre Crimp Frequency. The incidence of staple crimp being low in carpet wools, the differences in this parameter from staple to staple within a sample are small. Hence the discussion is limited here to the between sample case only.

The number of crimps per staple ranges between 2.0–8.0 in the samples studied (Table 1). The table also shows that the number of crimps per fibre is different for true, heterotypical and medullated fibres; the reltionship between number of crimps per staple and that per fibre will, therefore, be reviewed separately for each fibre type. It may be recalled that employing a number of different series of samples, and without differentiating between the various fibre types, it had earlier been revealed that in several cases the higher the number of crimps per staple, the higher the number of crimps per fibre, but that the latter number was several times higher than that per staple, i.e. there was no correspondence between the number of the two types of crimp. In the present study the number of crimps per fibre ranges between 4.9–24.5 in the case of true fibres (Table 1). On plotting a graph between the number of crimps per staple and that per fibre, however, a scatter resulted, indicating no relationship between the two. As against a mean of about 4.6 for the number of crimps per staple, the mean number of crimps per fibre for true fibres is 16.8, indicating that in these wools individual true wool fibres are about four times as much crimped as the staples.

The number of crimps per fibre ranges between 4.2–20.2 in the case of heterotypical fibres. On plotting a graph between these values and the corresponding number per staple, again a scatter resulted indicating no relationship between the two. The mean number of crimps per fibre was 11.1 in this case; the heterotypical fibres are, therefore, about 2½ times as much crimped as the staples, but are about two-third as much crimped as the true fibres.

The number of crimps per fibre ranges between 4.3–15.4 in the case of medullated fibres. There is again no relationship between this number and that per staple; medullated fibres are about twice as much crimped as the staples, but are about half as much crimped as the true fibres.

TABLE 1. BETWEEN SAMPLE DATA: MEAN VALUES FOR LENGTH AND NUMBER OF CRIMP.

Wool sample	Staple		True wool		Heterotypical		Medullated	
	Length (in)	Crimp (no.)	Length (in)	Crimp (no.)	Length (in)	Crimp (no.)	Length (in)	Crimp (no.)
Kaghani 1	1.9	6.7	1.3	4.9	1.6	5.9	1.8	5.7
Kaghani 2	1.5	8.0	1.9	14.6	1.6	11.9	1.7	13.6
Kaghani 3	1.8	3.1	1.9	19.6	2.1	19.1	2.0	13.1
Country	1.5	2.0	1.3	6.4	1.4	4.2	1.5	5.6
Kail x Rambouillet	1.5	4.2	1.8	17.7	—	—	—	—
Kail	1.4	8.0	1.6	16.5	1.3	12.9	1.7	15.4
Lohi	2.4	3.0	1.4	15.7	2.1	13.8	2.0	11.4
Damani	2.2	4.0	2.3	21.0	2.2	20.2	2.1	11.3
Bahawalpuri	2.2	2.0	1.7	11.5	1.8	8.2	1.9	4.9
Swati	3.3	4.6	2.5	21.5	2.4	9.5	4.4	11.3
Dumbi	2.8	3.1	1.5	24.5	2.6	8.7	2.2	4.3
Mixed	3.6	6.1	3.2	23.0	2.7	10.1	3.3	12.1
Hashtnagri	2.7	4.9	2.4	22.0	2.1	9.3	2.6	5.7
Mean	2.1	4.6	1.9	16.8	2.0	11.1	2.3	9.5

TABLE 2. BETWEEN SAMPLE DATA : MEAN VALUES FOR DIAMETER (μ) AND CRIMP/IN.

Wool sample	True wool		Heterotypical		Medullated	
	Diameter	Crimp	Diameter	Crimp	Diameter	Crimp
Kaghani 1	24.8	3.8	35.2	3.6	47.8	3.1
Kaghani 2	22.4	11.0	36.3	6.9	45.9	8.1
Kaghani 3	21.1	10.5	34.0	9.2	50.2	6.6
Country	23.7	4.9	38.4	3.0	53.1	3.5
Kail x Rambouillet	17.9	9.7	—	—	—	—
Kail	25.6	11.1	38.6	9.6	56.7	8.2
Lohi	26.4	11.1	42.0	6.9	62.3	5.8
Damani	26.3	9.1	36.1	9.2	64.2	5.4
Bahawalpuri	22.5	6.7	33.5	4.5	54.6	2.5
Swati	20.1	8.8	32.9	3.9	44.9	2.5
Dumbi	27.3	9.9	44.1	3.3	76.4	2.1
Mixed	26.4	7.1	43.4	3.9	76.0	3.6
Hashtnagri	42.2	9.2	39.9	4.4	71.3	2.2
Mean	23.7	8.7	37.9	5.7	57.9	4.5

Table 3. Within Sample Data for Lohi Wool: Values for Length and Number of Crimp.

True wool		Heterotypical		Medullated	
Length (in)	Crimp (no.)	Length (in)	Crimp (no.)	Length (in)	Crimp (no.)
1.6	15	2.5	21	2.0	8
0.8	9	1.5	6	1.6	7
0.7	11	2.6	22	1.8	6
1.0	15	2.4	19	1.7	8
1.2	16	2.7	22	1.6	6
1.8	23	1.8	13	2.3	19
1.5	19	1.6	15	1.5	15
1.3	16	1.8	13	1.3	9
1.0	17	2.5	9	2.0	7
1.2	13	3.1	11	2.3	6
1.6	20	1.2	11	2.1	14
0.7	11	1.4	15	1.3	7
1.2	19	2.7	23	1.2	5
1.1	15	2.5	17	1.3	5
1.6	17	1.9	13	2.3	4
1.3	13	1.5	11	2.6	9
1.2	15	2.8	23	2.7	8
1.4	22	2.5	19	3.0	11
1.8	24	2.9	25	1.3	5
1.3	14	2.1	18	2.6	8
1.7	18	2.4	21	1.2	3
1.0	10	3.2	28	2.1	4
1.2	21	1.9	17	2.8	6
1.4	17	2.6	24	2.3	9
1.1	19	2.9	27	2.3	10
1.5	14	1.7	13	2.4	11
1.3	16	1.9	14	1.8	6
1.2	19	1.3	15	2.2	9
1.3	11	1.3	12	1.8	11
1.7	15	1.7	17	1.6	13
1.5	18	2.0	18	1.5	10
1.8	17	2.3	21	1.3	9
0.8	9	2.4	23	2.1	13
1.2	13	1.9	19	2.5	17
1.5	17	1.7	17	1.9	16
1.6	19	1.3	18	2.4	14
1.7	16	1.6	13	1.3	9
1.3	17	2.3	19	2.3	13
1.4	13	2.6	24	2.6	15
1.2	11	1.8	17	1.7	14
1.5	13	1.7	19	1.9	13
1.7	19	1.3	15	1.3	11
1.9	18	1.8	13	1.6	12
2.0	16	1.5	15	1.9	14
1.5	13	1.9	17	2.5	17
1.8	11	2.2	19	2.3	19
1.7	15	1.8	13	1.8	9
1.3	17	1.7	11	1.7	8
1.4	19	1.6	8	1.6	11
1.6	13	1.3	14	1.2	13
1.7	14	1.8	16	1.4	12
1.8	17			1.7	15
1.3	19			1.8	8
1.4	13			2.1	13
1.5	14			1.3	17
1.6	11			2.2	10
1.8	17			1.4	7

(Continued)

Table 3 continued

1.3	11	1.8	6
1.5	14	1.6	11
1.8	17	1.7	9
2.0	21	2.1	8
1.5	17	2.4	13
1.4	13	2.8	15
0.7	11	1.9	19
0.5	10	2.1	20
1.3	13	2.7	15
1.7	15	1.9	14
1.8	21	2.1	13
1.4	17	2.0	15
1.7	19	2.2	17
1.8	20	2.5	13
1.3	18	2.1	14
1.4	13	1.8	15
1.5	17	1.6	11
1.7	19		
1.2	14		
1.1	13		
1.3	19		
1.8	19		
1.5	20		
1.7	19		
1.8	17		
2.0	22		
1.4	17		
1.2	15		
1.0	13		
1.9	13		
1.7	11		
1.6	18		
1.2	16		
1.9	11		

TABLE 4. WITHIN SAMPLE DATA FOR HASHTNAGRI WOOL: DIAMETER (μ) AND CRIMP/IN.

	True		Heterotypical		Medullated	
	Diameter	Crimp	Diameter	Crimp	Diameter	Crimp
	22.2	7	43.5	6	66.0	2
	21.0	8	39.6	6	72.0	2
	23.4	8	41.9	5	74.2	2
	29.8	8	43.4	4	70.0	3
	24.7	9	43.2	5	69.3	2
	26.1	9	31.0	5	66.4	2
	21.6	8	38.3	4	75.2	1
	21.3	11	42.1	6	65.3	3
	22.0	11	38.7	5	78.1	2
	20.4	7	43.9	4	80.6	2
	24.5	8	37.0	5	65.3	2
	26.1	8	36.3	6	70.5	2
	23.3	9	42.4	5	78.4	3
	26.9	9	35.2	4	75.8	2
	26.2	9	35.8	6	71.7	1
Mean	23.3	9	40.1	4	71.3	2

Table 5. Coefficients of Correlation.

Characteristics	Level	No. of pairs of data	Coefficient of correlation
Fibre c.p.i. and diameter	Between sample (composite sample of mean values for true heterotypical and medullated fibres of each sample)	37	—0.582†
,,	Within sample: Lohi wool (composite sample of values for all the 45 fibres)	45	—0.728†
,,	Within sample: Hashnagri wool (composite sample of values for all the 45 fibres)	45	—0.910†
Staple length and number of crimps per staple	Between sample	13	—0.111
Fibre length and number of crimps per fibre.	Between sample: true	13	0.656*
,,	Between sample: heterotypical	12	0.214
,,	Between sample: medullated	12	0.130
,,	Between sample: (composite sample comprising the above cases No. 5, 6 and 7)	37	0.164

* Significant at the 5% level. † Significant at the 1% level.

Table 6. Crimp Amplitude (mm).

Wool sample	Primary crimp			Secondary crimp		
	True	Heterotypical	Medullated	True	Heterotypical	Medullated
Hashtnagri	0.9	0.8	0.5	2.9	4.6	5.5
Lohi	0.7	0.6	0.6	2.1	3.0	2.9
Mean	0.8	0.7	0.6	2.5	3.8	4.2

Further examination of the fibres revealed that these are associated with two types of crimp. In addition to the usual crimp which may conveniently be called 'primary', after the terminology of Lang and Campbell,[12] a crimp of a larger amplitude and wavelength was superimposed on it; this latter crimp may be denoted as 'secondary'. The two types of crimp have been illustrated in Fig. 1. The incidence of the secondary crimp was the lowest among the true fibres and the highest among the medullated fibres. The amplitude of both the crimp types also varied. The dominant crimp in the medullated fibres was the secondary while the primary with low incidence as well as low amplitude was much less prominent. In fact, due to the negligible expression of the latter type, the medullated fibres seemed to possess only the secondary crimp on a casual look.

The lack of a relationship between the number of crimps per staple and fibre in all the three cases was further studied after the method of Goldsworthy and Lang.[4] Thus, two staples each of Hashtnagri and Lohi wool were dye-branded and fibres withdrawn from them gradually. It was observed that the correspondence between the number per staple and fibre was almost negligible in the majority of the cases. Further examination revealed that in these wools the pattern of correspondence was different in the cases of true, heterotypicala nd medullated fibres. The true wool fibres with the highest primary and lowest secondary c.p.i. appeared to have little or no correspondence with the staple c.p.i. which is very low in these wools. There were a few fibres among the heterotypical type whose secondary crimp corresponded with the staple crimp in number. The correspondence was, however, the highest among the medullated fibres where the secondary crimp in about 30% of the fibres corresponded with the staple crimp in number and also in amplitude in varying degrees (Fig. 2). This trend was more obvious towards the tip-end of the staple where the correspondence was almost perfect in

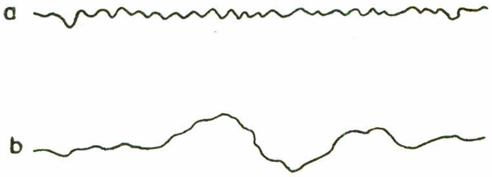

Fig. 1. (a) Primary crimp (usual pattern in true wools); (b) secondary crimp of larger amplitude superimposed on the primary (usual pattern in medullated fibres).

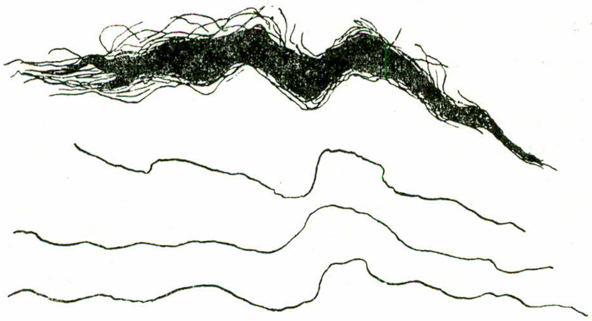

Fig. 2. Schematic diagram of medullated fibres withdrawn from staple exhibiting the secondary fibre crimp corresponding in varying degrees to the staple crimp.

over 60% of the cases. It appears, therefore, that the primary crimp of the fibre and the staple crimp have little or nothing in common but that the secondary crimp is associated in varying degrees with the staple crimp.

In contrast to this lack of correspondence, the number of secondary crimps, their configuration and wavelength almost all coincided in varying degrees with the corresponding parameters of the staple crimp, especially in the case of medullated fibres. The common belief in the case of Merino wool that the staple crimp is due to a minority of fibres may now by interpreted. Thus the 'minority' of the fibres may well be those with secondary crimp in these wools coinciding with the staple crimp but the distinction between the two types of crimp may well have been overlooked simply as the secondary crimp is not so much pronounced in true wool fibres as it is in medullated fibres. In fact, secondary crimp has been observed not only in steely wools,[11] but also in some cases of other normal Merino wools.[12] In view of present observations on carpet wools, the relationship between staple and fibre crimp parameters may desirably be reinvestigated in Merino wools with special reference to secondary crimp.

Fineness and Fibre c.p.i. The relationship of fibre fineness to staple c.p.i. in carpet wools has been reported earlier.[3] The relationship between fibre fineness and fibre c.p.i. may be discussed in four distinct cases: (a) within sample, separately for true, heterotypical and medullated fibres; (b) within sample, overall situation; (c) between sample, separately for the three types of fibres and (d) between sample, overall situation.

For the purposes of within sample relationship, studies were made on the two typical carpet wool samples viz. Hashtnagri and Lohi. Crimp frequency and diameter of individual fibres of each fibre type were determined as described. Plots of fibre fineness against fibre c.p.i. resulted in scatter in all the three cases of true, heterotypical and medullated fibres, in both the wools studied for this purpose. However, when results for all the three types of fibre within a sample were plotted on the same graph, a strong negative relationship was revealed in both the cases. The coefficients of correlation were -0.910 and -0.728 in the cases of Hashtnagri and Lohi samples, respectively (Table 5). The absence of a relationship within the same type of fibres viz. true, heterotypical and medullated may well be attributed to a narrow range of fineness within the same type but the wider range for the composite sample allows the relationship to fully express itself.

For the purposes of between sample relationship, three plots were obtained (from the data of Table 2) for mean c.p.i. and fineness, separately for true, heterotypical and medullated fibres. Once again, no trend was revealed. When all these means were, however, plotted on the same graph, a negative relationship was revealed, with -0.582 as the coefficient of correlation, which was also found to be significant at the 1% level.

It appears, therefore, that although a negative relationship exists between fibre diameter and c.p.i. the range of fineness should be wide enough to allow the relationship to express itself. If this range is narrow, the relationship is likely to be masked by the high variation in the values of c.p.i.

Length and Crimp. Between sample plot of mean staple length against mean number of crimps per staple (Table 1) resulted in a scatter, with a non-significant negative coefficient of correlation.

Within sample plots of fibre length against number of crimps per fibre drawn separately for true, heterotypical and medullated fibres in the various wools (13 wools $\times$ 3 types $=39$ cases) revealed a scatter in the majority of the cases, but a positive relationship was indicated in some of the cases. However, when all the values for the three types of fibre were plotted on a composite graph for each wool, a complete scatter was obtained.

Between sample graphs of mean fibre length against mean number of crimps per fibre drawn separately for true, heterotypical and medullated fibres (3 cases only) revealed again a positive relationship which became weaker in the order true $\rightarrow$ heterotypical $\rightarrow$ medulatted. The coefficients of correlation were, respectively, 0.656, 0.214, and 0.130. A composite graph of fibre length and number of crimps per fibre for all these mean values, however, resulted in complete scatter (Table 5).

A positive relationship between fibre length and number of crimps per fibre as revealed in some of the cases mentioned above gives some indication that the longer fibres may well be associated with a higher level of crimp frequency. This is in contradistinction with some of the known reports[5-7] which suggest an independence of length and crimp. If a higher rate of growth of wool is associated with a higher rate of fibre crimping, in these cases, the fibre crimping, which has been suggested to be a periodic phenomenon of time, may well be enhanced with a higher rate of wool production. That the results in the case of staple crimp do not show the same trend, as indicated above, suggests that such an effect may not hold in the case of staple crimp, the causal basis for which may well be different from those for fibre crimp.

Amplitude. Mean results for the two wools studied are given in Table 6. The results indicate that while the amplitude for the primary fibre crimp ranges between 0.5–0.9 mm only in the various cases, that of the secondary ranges between 2.1–5.6 mm. It is also apparent that as we proceed from true through heterotypical to medullated fibres, the amplitude of the secondary crimp increases, on the average from 2.5 to 4.2 mm but that of the primary drops from 0.8 to 0.55 mm, in general, although the values for heterotypical are not always the intermediate ones. It is thus obvious that the primary fibre crimp has a larger amplitude in the case of true wool fibres, and is thus more pronounced. It has, however, a small amplitude in medullated fibres, giving rise to the feeling that the latter fibres are almost straight. This observation, when considered together with the fact discussed, would indicate a low crimping in the case of medullated fibres both in terms of c.p.i. and amplitude. However, as both the incidence and amplitude of the secondary crimp increase as we proceed from true to medullated fibres, the medullated fibres are obviously associated with a larger secondary crimping as compared to fine fibres.

It was also generally observed in these wools that the staple crimp was rather irregular towards the base in a number of cases but was more regular towards the tip (Fig 3), although this was not the case with the fibre crimp. It appears, therefore, that the formation of staple crimp may well be due largely to environmental factors which groom the initial irregular staple into a regular pattern as it grows. The fibre crimp frequency, almost uniform throughout the fibre, on the other hand, would appear to be a more fundamental phenomenon based largely on biological factors (e.g. an activity of the follicle) accompanied by certain changes in fibre substance (e.g. *ortho–para* cortex), as is generally suggested.

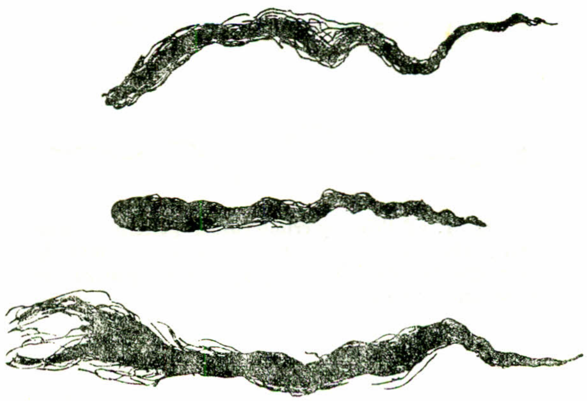

Fig. 3. Staples with a regular crimp towards the tip but a straight or irregular pattern towards the base.

Conclusion

1. The fibre c.p.i. is several times higher than the staple c.p.i. in Pakistani carpet wools. The mean frequency of staple crimp is as low as about 2.3 c.p.i., whereas that of fibre crimp is different in the three types of fibres viz. true wool, heterotypical and medullated, being 8.7, 5.7 and 4.5 c.p.i., respectively.

2. These wools are generally associated with two types of fibre crimp: a secondary fibre crimp of a larger amplitude and wavelength is superimposed over the usual primary fibre crimp. The incidence of the former crimp increases from true to heterotypical to medullated fibres. Whereas there is little or no correspondence between the primary fibre crimp and the staple crimp, as mentioned above, the parameters of secondary fibre crimp seem to coincide in varying degrees with those of the staple crimp, the coincidence being the highest in the case of medullated fibres. The incidence of a secondary crimp has also been reported in certain cases in Merino wool,[12] but as the incidence is low in true wool fibres, it may well have been generally overlooked. The common view that the staple crimp is due to a minority of the fibres may be modified so that the minority may be indentified as the fibres exhibiting secondary crimp, as is the case in these carpet wools, and the relationship may be reinvestigated in the case of other wools.

3. In view of the above lack of correspondence between the staple c.p.i. and the primary fibre c.p.i., it is difficult to comment whether one is due to the other. However, the said coincidence of staple crimp and the secondary fibre crimp would seem to suggest that the causal factors giving rise to the two must have much in common.

4. A significant negative relationship exists between fibre diameter and fibre c.p.i., but if the range of diameter of fibres under examination is not wide enough the ralationship is likely to be masked by the variations in c.p.i.

5. A positive relationship between fibre length and mean number of crimps per fibre has been indicated in the between sample case of true and heterotypical fibres. This seems to be at variance with the concept of crimp as a periodic function of time necessitating independence of length and crimp.[5-7]

Acknowledgements. The authors are thankful to Messrs M. Raziq and Ataullah for carrying out some of the routine measurements.

References

1. M.L. Ryder and S.K. Stephenson, *Wool Growth*

(Academic Press, London, 1968), first edition, pp. 246, 644.

2. W.J. Onions, *Wool* (Ernst Benn, London, 1962), first edition, pp. 26, 96.
3. S.M.A. Shah, A.H. Mohsin and M. Haq, Pakistan J. Sci. Ind. Res., **13,** 134 (1970).
4. Y.E. Goldsworthy and W.R. Lang, J. Textile Inst., **45,** T755 (1954).
5. M.H. Norris and P.J.J. Rensberg, J. Textile Inst., **21,** T481 (1930).
6. M.H. Norris and C.C. Classens, J. Textile Inst., **22,** T224 (1931).
7. J.C. Swart and J.J.J. Kotze, Empire J. Expl. Agr., **5,** 69 (1937).
8. B.L. Elphick, J. Textile Inst., **23,** T367 (1932).
9. S. Glowacka, Proc. Inst. Wlok., **28,** 13 (1958).
10. E. Balasubramanium and K.J. Whiteley, Aust. J. Appl. Sci., **15,** 41 (1964).
11. Ref. 1, p. 582.
12. W.R. Lang and W.K. Campbell, Nature, **211,** 257 (1966).