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A REVIEW OF MEDULLATION IN WOOL

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Introduction

Wool fibres may be made up of three types of cells: cuticle, cortical and medulla. Most wool fibres have only cuticle and cortical cells and it is the coarser carpet types of hairy wools which are medullated. Medullated fibres are often called hairy fibres because of their resemblance with hair, in coarseness and medullation.

A carpet wool usually consists of true and medullated fibres; fibre length varies between 1–10 in and dia 20–70μ. Such wools are usually associated with a wide range of lustre, elasticity, lower density and good resistance to wearing and soiling. The presence of medullated fibre in a carpet wool lends necessary strength, in the manufacture of carpets where the true fibres intertwine and entangle themselves giving further support to the structure. Moreover, the coarse fibres are more springy and have the ability to restore to their original position after being compressed. Thus the value of woollen carpet would largely depend on the resilience characteristics.

The following discussion relates to carpet wool in general, but frequent references have been made to the work being done in Pakistan on medullation.

Medullation in Carpet Wool

Pakistani wool is considered as one of the best wools for carpet manufacture and the bulk is exported for this purpose. In Pakistan, there are about 22 breeds of sheep which inhabit the various district.[1] These breeds produce carpet wool which contains medullated fibres in various degrees. However, due to cross-breeding with imported Rambouillet in north-west region of Pakistan, Kaghani (cross), Kail and country cross (Azad Kashmir) approximately comprise 100% true wool. The fine wool so produced, which is of about 64's quality, is of limited quantity and it is not properly utilized due to lack of a systematic classing system in the country. This fine wool is often mixed with carpet wool and is utilized by the local people for making blankets. Except the three breeds mentioned above, the rest of the breeds contain medullated fibres which vary from small proportions to about 80%.[2–4] It may be mentioned that a specific percentage of medullated fibre in a breed cannot be given as large variations do occur within as well as between the various parts of even the same sheep.[5,6]

The pace of research work on medullation is rather slow as most of the wool produced in the developed countries is free from medullation. However, in New Zealand and in the U.K. some work on medullation is being done as some of their wools contain medulla. For this reason no specific standards for carpet wool have been established in the recent past. It may be mentioned that different types of wool are required for the various types of carpets. For instance Pakistani wool is very suitable for the cut pile, hand or woven carpet which are made throughout Asia. On the other hand such yarns are not suitable for loop-pile tufted carpets which are made from wool raised in the U.S.A., Europe or New Zealand. It is, therefore, important that for making any specific carpet standard, the type of carpet and the manufacturing system may clearly be defined. The only standards for an ideal carpet wool proposed by Burns, Johnston and Chen[7] in 1940 include:

(a) An ideal carpet wool should not contain more than 85% by count of true wool fibres. These fibres should have an average thickness not exceeding 25.4μ and length of at least 4 in; the variation not exceeding 25% in both the cases.

(b) An ideal carpet wool should contain at least 15% by count of heterotypical fibres. These fibres should have an average thickness of at least 30μ and length of at least 4 in and variation should not be more than 15% and 20% respectively.

(c) An ideal carpet wool should contain not more than 2% by count of kemp fibres. The characteristics of these fibres are not important.

The term heterotypical in the above standard has been interpreted to include all the medullated fibres irrespective of the type of medulla. The above definition does not specify the maximum limit of heterotypical fibres and the minimum limit of true fibres. Yet we may take these limits to be 59% and 40% respectively.

Type of Medulla

Medulla is of two types, latticed and nonlatticed.[8] The nonlatticed medulla is further subdivided into continuous, interrupted and fragmental. In the first case, the medulla continues along the length of the fibre and most of the medullated fibres have this type of medulla. Interrupted and fragmental medulla are practically the same but in the latter case the medulla is narrower than the interrupted. These two types are present in heterotypical fibres.[9] In recent studies[10] it has been shown that medulla appears in a fragmental form beyond 32 $\pm\mu$ and becomes continuous at about 51 ± 15 μ. It is further stated that with the increase of diameter in heterotypical fibres, the diameter of the medullated fragments would go on increasing almost consistently till medulla becomes continuous. For fully medullated fibre, the medulla diameter increases rapidly till when the fibre diameter is about 100 μ, medulla occupies more than 85% of the fibre diameter.

Latticed medulla occupies a very large proportion of the width of the fibre and usually occurs in kempy fibres and some medullated fibres. The latticed structure consists of rod-like trabeculae of solid keratin separating hollow spaces that are polyhedral in shape. The rods are formed from collapsed cells so that the spaces result between the cells and not inside them.[8]

The occurence of more than one medulla viz multiple medulla in a fibre was first reported by Brown and Onions.[11] Double and even triple medulla was also found in Lincoln wool.[12] It was reported that Scottish Blackface wool contains 10% of the medullated fibres with double medulla.[13] In Pakistani wool, double medulla was found in Michni and Hashtnagri wool.[14,10]

Measurement of Medullation

For visual determination of medullation, the Elphick's[15] method is applied which is based on the fact that the refractive index of wool fibres (1.548) is approximately the same as that of benzene (1.500). Therefore, when the wool fibres are immersed in liquid benzene, the nonmedullated fibres are invisible, heterotypical partly visible and medullated visible throughout the length of the fibre. Bray[16] has suggested o-dichlorobezene which has almost equal refractive index (1.549) as that of wool. It wets the fibres well and also evaporates more slowly than benzene.

McMahon[17] devised a medullometer in which the visual judgement of whiteness is replaced by measurement with electric cell of the amount of light replaced by the medulla of the wool. The instrument was improved by Belin and Goldstone[18] by incorporating a direct current amplifier for increased sensitivity and a constant voltage transformer to minimise fluctuation in the light intensity of the lamp. The medullometer was widely used throughout New Zealand over a large number of years for flock testing. The machine, however, was burnt and for this reason it is no longer recommended that benzene or benzol be used as a refractive media.

Another method[19] for measurement of medullation is based on the assumption that if the whole of the medulla is occupied by air, there is a direct relationship between the percentage volume occupied by the medulla, the specific gravity of the sample (m) and the specific gravity of the solid keratin (k) which may be expressed as follows:

Fibre volume (%) occupied by the medulla $= 100\,(k-m)/m$

One of the disadvantages of this method is that it is impossible to determined correctly the specific gravity of the sample. Moreover, the specific gravity of the sample varies with medullation.

Ross and Speakman[20] have shown that medulla may be isolated from the cortex by treatment with 0.75N NaOH at 25°C for 5 days. The authors have also assessed it quantitatively by treatment with 1.6% per acetic acid at 25°C for 48 hr followed by dissolution of an alkali-soluble portion in 1.0N ammonia at 25°C. The residues left at the end of this test, expressed as a percentage of the initial weight, were highly correlated with the benzole test.

For practical purposes the microscopic method is used for measurement of medullation[19] in individual fibre. This method is devised by Bray[16] and the different factors necessary for estimating the percentage volume occupied by the medulla are measured with a projection microscope. The factors are percentage length of the medullated fibre ($1m$), the mean cross-sectional area of the medulla (Πr^2) and the mean cross-sectional area of the fibre (ΠR^2). The volume of fibre occupied by medulla then equals $Im = (\Pi r^2)/(\Pi\ R^2)$.

Although the microscopic method is laborious and time-consuming, yet it gives a better quantitative index of medullation than any other method.

Medullation and Mechanical Properties

Many papers have appeared on the strength characteristics of Pakistan wools.[21–24] The general conclusion is that in the case of true wool, with the increase of fibre diameter, the fibre strength also increases. However, as regards heterotypical and medullated fibres, the situation is not clear. These authors have not taken into consideration the actual volume occupied by the medulla. In a recent paper[14] the various correlations among fibre diameter, medulla diameter, volume and strength characteristics were determined employing seven heavily medullated wools. It was found that no significant correlation exists between volume occupied by the medulla and strength in individual wools, but taking all the wools as forming a composite sample, a significant correlation was found between fibre diameter and strength in individual as well as in composite samples. It is thus clear that for investigating such correlations in medullated wools, volume of the medulla must be taken into consideration.

Medullation and Felting

Felting as defined by Makinson[25] is the process of progressive entanglement of the fibres in an assembly, occurring as a direct result of agitation by undirected external forces,. A lot of work has been done in foreign countries on felting of true wool fibres which has been reviewed by Moncrieff.[26] So far the following points have been established: (i) The fibre must have a directional frictional effect (D.F.E) or scaliness in order to allow felting to take place. (ii) The migration of the fibres occurs during felting.[27,28] (iii) The crimp structure plays an important part in felting, i.e. the fibres with helical configuration do not felt while that of sine configuration felt easily.[29–31] (iv) Fibre diameter, length, D.F.E. have little or no effect on felting.[32,33]

The felting potential of Pakistani wool employing Blankenburg and Zahn, and Faur's methods[34–37] have been reported. The methods differ in the techniques adopted for measuring the volume of the felted ball, which gives an indication of the feltability of the wool; lower diameter of the ball signifies higher felting and vice versa. It was found that except cross-breed kaghani wool, all other wools were good felting. The reason for the poor felting has been given to be the helical configuration of crimp structure of cross-breed kaghani wool which also confirms the earlier work.[29,30,33] Other fibre characteristics such as diameter, length, D.F.E. have been shown to have little or no effect on felting.

It may be mentioned that high felting wool is keenly sought by the manufacturers of non-woven commercial felts. Besides tightly structured fabrics are obtained by milling after weaving, because the limitations of textile machinery do not warrant the production of garment by weaving alone. Poor felting wool is highly valuable in the production of suiting and hoisery so that these products do not lose their shape inspite of frequent washing while in service.

Kemp

Kemp fibres are the coarsest fibres of all and are usually short in length. Kemp fibres are undesirable as it fall out in carding and increase card waste. Due to the short period of growth their pointed tip remains unbroken and they have a tapering root. The main feature of a kempy fibre is a wide-latticed medulla occupying most of the width of the fibre and the cortex forms only a narrow ring around the fibre. Thus the absence of cortex makes the fibre brittle and minimises dye uptake. This effect is enhanced by the reflection of light from the surface of the medulla which makes undyed kemp appear chalky white. In fact, kempy fibres are often added to some wool to give fancy effect especially in tweeds. As kemp is genetic in origin, it should be possible to keep fleeces free from it by careful breeding.

Characteristics of Medullated Fibre

The carpet wool fleece is composed of a mixture of long hairy fibres forming the outer coat (medullated and heterotypical fibres) and a fine undercoat of true wool. It is thus evident that the fibre length of medullated fibres would be greater than true wool fibres. Heterotypical fibres occupy intermediate position. As regards crimp structure, in most of Pakistani carpet wools, the configuration of true fibres is sine and medullated fibres are of straight type.[38]

Medullation is generally rare in fibres of less than 35μ thickness. As far as diameter of medullated fibre is concerned, different breeds give different mean value. For example Hashtnagri wool gives highest value of mean dia (99.6μ) whereas Buchi wool gives lowest value of mean dia ($45.3\ \mu$). However, in the case of true and heterotypical fibres, the variations in the mean values are not so marked as in medullated fibres. Ali and Fatima[39] have shown that percentage medullation (p) in heterotypical fibres is positively correlated with $\sqrt{r^2{}_f}$ (where r_f is medullary radii fragment) and negatively correlated with toughness T. Most recent studies[40] on Pakistani carpet wool have found corelations between fibre fineness and the percentage of various types of fibres, showing that the percentage of true fibres is negatively related to the mean diameter of the sample and the relationship is significant at the 1% level, whereas the percentage of medullated fibres is positively related to the mean diameter, the coefficient being also significant at 1% level. The heterotypical fibres do not follow any regular trend. The diameter of the true fibres is approximately two-third of the mean diameter, that of heterotypical is almost equivalent to the mean diameter and that of medullated is almost one-and-a-half times of the mean diameter.

The frictional coefficients, particularly μ_1, for Pakistani wools are significantly higher than the values reported in the literature[41–43] and in the dry state, μ_2 D.F.E. and scaliness do not significantly differ either among the breeds studied or among the fibre types except μ_1. However, in the wet state (O.1N HCl)μ_1,μ_2 are significantly different among the breeds but not among the fibre types.

The incidence of low-grease content in the medullated wools has been discussed by Khan *et al.*[44] which showed that the grease content of Pakistani wool ranges from 1.3 to 4.5% as compared to Merino wool (15%). This low content renders recovery of grease uneconomical. There are, however, some advantages of this low-grease content. For instance, the clean fibre content (yield) is higher for carpet wool as compared to fine wools.[45] Another advantage is that quite a lot of these wools are used for carpet manufacture without scouring before processing. A comprehensive recent study of Pakistani wool carried out by Mohsin and Shah[46] shows that the percentage suint content of carpet wool (range 5.1–7.8%) is the same as that of Merino wool. Thus whereas in Australian wools, the ratio of grease to suint content is about 2:1, it is about 1:3 in the case of Pakistani wools. They have further pointed out that the high content does not appear to be necessarily a consequence of the hot climatic conditions as the suint is probably not sweat or perspiration produced to reduce temperature.

As regards cortical segmentation of Pakistani wool, Ahmad and Lang[47] had noted that in medullated wool, the cross-sections showed a typical *ortho*-cortical annulus around the medulla and true fibre showed bilateral segmentation. This is in contrast to Burmese medullated wool[48] which showed no indication of any cortical differentiation and is in accordance with the earlier work as reported by Dusembury and Menkart[49] who had noted that in a B–A fleece wool (mean dia 50μ) there was no indication of cortical asymmetry and suggested that the two components, if present, may be randomly distributed.

It has been reported that the sulphur-content of medullated fibre is less than that of true fibres, for it is claimed that the medulla is completely free from sulphur.[50]

As far as chemical composition is concerned, Ross[51] had found that the amino acid-content of the medulla depended to quite some extent on how the medulla was isolated but that the most consistent feature of amino acid composition of the medulla preparations was the predominance of glutamic acid and the high proportion of basic amino acids and their derivatives, together with the almost complete absence of cystine.

He had further found that leucine is present in similar proportions in both untreated wool and the isolated medulla, the other amino acids are usually present in smaller quantities in the medulla although the proportions vary between preparations. Citralline was found in the medulla together, in some instances, with traces of lanthionine and proline. While working on Pakistani wool Khan and Siddiqi[52] have shown that amino acid such as aspartic acid, cystine, glutamic acid, methionine, proline, serine, threonine, tryptophane and tyrosine occur in lower percentage in medullated fibres as compared to true wool, whereas in the case of the rest of the amino acids the proportion is higher in medullated fibres than in true wool. Heterotypical fibres occupy intermediate values.

As far as processing is concerned, medulla up to the extent of 6% does not affect the processing properties of wool and there is no marked difference in the appearance and handle of either woven or knitted fabrics.[53] However, Lang[54] has found that when medullation is over 15%, the disparity of fibre thickness might become important. Moreover, medullated fibres appear lighter in colour when dyed because there is less cortex to take up the dye; in addition the enclosed air in medulla increases the amount of light reflected.

Control of Medullation

The production of medulla by sheep is strongly inherited but is also affected by climate and food.[55,56] For elimination of medullation, the long range programme would be to cross the indigenous breeds with fine wool breeds. In Pakistan, experiments have already been done by Animal Husbandry Department in Hazara, Kaghan and Azad Kashmir where the local breed is crossed with imported Ramboullet. The climatic conditions of these areas are suitable for such breeding and some success seems to have been achieved in this respect.

As regards the climatic effect on wool, Hutchinson and Wodzicka-Tomaszewska[57] reviewed work showing that the lack of uniformity in wool growth throughout the year was recognised as early as nineteenth century and the narrowing and the loss of medulla in double coated British mountain breeds during winter is well known. This is also confirmed by Doney and Smith,[58] who have shown that primary fibres narrow proportionally more than the secondaries in the Scottish Blackface in the winter, mainly because of the loss of medulla. Hardy[59] has found that wool grows faster in summer and early autumn, however, the rate of growth of Merino (fine wool) was less as compared to Lincoln wool (coarse wool). Slee and Carter[60] found that some breed, for example, Merino showed far less seasonal variation than others. They found that whereas Merino sheep had a fibre diameter close to 20μ throughout the year and grew wool at about 7.5 mm/month, Wiltshire sheep showed a fibre diameter variation from 40μ in winter to 80μ in summer and varied in growth rate from 3 to 12 mm/month. For a year 1952–53, Ryder[61] kept some Musham sheep on a constant diet in England. He found that more wool was produced in summer than in winter and while this difference was being considered, Coop[62] published his findings from a greater number of Corridale sheep over a period of 3 years. Coop's graphs of seasonal fluctuation in wool growth were of the same pattern as those of Ryder. He dicussed the possible causes of these variations as lower winter temperature causing decreased blood flow to the skin and the effect of changes in the number of hours of day light. Story and Ross[63] have measured the changes that occur during the year in fibre diameter and the growth rate of wool fibre of New Zealand Romney sheep. They have shown that wool growth is more than three times as rapid in summer as in winter. Fibre diameter was at minimum in July and August and reached a maximum during the summer months of December to February. The minimum mean diameter was about 30μ and the maximum mean diameter about 40μ. But it must be emphasized that these seasonal variations in wool growth include more than variations due to changes of nutritions.

As far as the effect of nutrition on wool is concerned it has been shown that under drought condition in Australian Merinos[64] there is a reduction in fibre diameter and the same effect is obtained during winter in Britain and New Zealand when fibres often narrow so much that they break or the follicle may cease production altogather. Stewart *et al.*[65] have given an account of variations in wool growth during different seasons of the year by Merinos kept in Western Australia. Here the periods of poor nutrition occur during summer and this was also the season in which the wool growth rate was low. Conversely, wool growth was most rapid in the winter months of June and July. As this pattern is the reverse of that found in Britain and New Zealand, it was apparent that fluctuations in temperature and day light were not responsible and the obvious explanation was that nitritional conditions were the direct cause of the variations in wool growth.

It has been shown[66] that shearing stimulated medulla formation which was probably due to the effect of exposure, because medulla production was retarded if the shorn area was covered with wool pads. On the basis of observations, it has been claimed that tippiness owing to medulla can be prevented by leaving an inch of wool on the sheep to prevent exposure. However, most recent studies on Indian wools[67] reveal that medullation and fibre diameter increase from root to tip of the fibre. The differences between medullation and the diameter of root, middle and tip portions have been found to be statistically significant. The study points toward the possibility of deterioration in quality as sheep grow older and more shearings take place.

Conclusion

Apart from the early work on medullation, a number of studies have been undertaken on the subject recently in New Zealand, Great Britain and in Pakistan. In New Zealand work is being carried out on the effect of medullation on processing and on the performance of carpets. Some trials were also done on such work by Wool Industries Research Association in England. In Pakistan some work has been recently undertaken on medullation in Wool Research Division of these Laboratories. This work includes determination of extent of medullation in various wools and their correlation with diameter, mechanical properties, friction felting, amino acid, wax and suint content. Keeping in view the overall situation it is suggestted that future work on medullation should be carried out on the following lines.

(a) Different wools should be blended to get the most desirable blend for carpets for obtaining standard for an ideal carpet. The type of machinery and carpet type should be clearly mentioned.

(b) Different wools containing various degree of medullation should be blended and processed for making standard woollen fabrics for apparel use especially overcoats and tweeds. This will be an economic use of medullated wool found in most of the Asian countries where fine wool is not available.

(c) The existing methods for the estimation of medullation are laborious and time-consuming; efforts should be made to find out a quick method.

(d) There are a few complicated expensive machines available which separate medullated fibre from the fine undercoat of the expensive fibre types. Efforts should be made to develop simple machine which could separate medullated fibre from true fibres on a large scale.

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