The structure of bow-hair fibres

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ABSTRACT

In previous papers concerned with the structure of bow-hair [1,2,3] the external surface of horse hair was a major object of controversy. The purpose of this paper is to introduce a series of photographs of horse hair obtained with a JEOL JSM-35 Scanning Electron Microscope. These micrographs come in support of the flat scale structure theory [2,3] and give further insight of the structural organization of the material. The histological structure of horse hair is finally discussed in relation to bow-hairing.

PRESENTATION OF BOW-HAIR MICROGRAPHS

The samples presented in this series of micrographs were fibres of natural white unbleached Chinese-Mongolian horse hair of length 30″ and diameter ranging from .006″ to .013″ (.165 mm to .330 mm). These fibres correspond to good quality violin bow hair.

The first step when investigating a fibre consists in marking the distinction between its chemical structure - as determined by its chemical constitution and molecular arrangement - from its histological structure, a result of growth factors.

In chemical terms horse hair is a proteinic fibre like wool and silk. Its protein is keratin, a polymer built-up from 16 different amino-acids and therefore much more complex than wood cellulose. Keratin is a long-chain molecule with a linear structure; fibrils are formed and will be seen in the components of the core and surface of horse hair. The keratin molecule can exist in two different forms: a folded form and a stretched one. Stretching and releasing wet fibres produces the transition from one form to the other, which explains why bow-hairers sometimes experience fiber shrinkage when washing stretched hair.

From an histological viewpoint human and animal hair fibres have a characteristic scale surface. The scales overlap from the root end to the tip in an arrangement recalling that of slates on a roof.

The core or cortex of horse hair consists in tightly packed fibrillar tapered plates built-up from keratin. This fibrillar system runs along the hair length as depicted in (Fig.1) and (Fig.2) and contains the color pigment. The cortex is enveloped in the cuticle, made up of 3 concentric layers, one of which - the epicuticle - resists chemical degradation. In new-grown hair the cuticle is covered with scales as shown in (Fig.1).

The growth processes that characterize hair fibres result in the tip and root ends showing a different external envelope. The scales characterizing the root degrade as the hair grows further and undergoes attacks from external factors. The scales thus disappear as one moves toward the tip where the external envelope often consists in the bared cuticle; horse hair fibres typically show a tapered tip end. (Fig.3) and (Fig.4) illustrate this degradation. Both were obtained from the same hair fibre but (Fig.3) is representative of new-grown hair with a well-developed scale structure whereas (Fig.4) shows the bared cuticle at the tip end. The scale degradation process is on its way in (Fig.1) and can be observed at a higher magnification level in (Fig.5). The degrading scales show cracks, eroded and split ends. New-grown healthy scales are shown by comparison in (Fig.6).

At levels of magnification beyond 4000 the fibrillar structure of the scales can be appreciated. From a close examination of (Fig.5) the "barbs" that have been conjectured to cover horse hair can probably be attributed to keratin fibrils which have torn themselves free from degrading scales.

DISCUSSION

To a large extent the purely physical properties of horse hair fibres are determined by their histological structure. At the tip end the degraded envelope of the hair fibres offers less resistance to external forces; so that the strength and elasticity of the fibre are lessened at the tip end. To put up with these histological features bow-hairers start fastening the new-grown root end at the bow tip; the degraded hair tips are thus found at the frog and are removed if the hair is sufficiently long. Ideally one or two inches ought to be removed at the very tip end. Unfortunately white horse hair fibres beyond 31″ in length are now scarce and sell for very high prices.

Horse hair chemical structure relates to the musical use of the material. It also affects its physical plasticity. Under certain conditions the extension of fibres is not fully recovered upon release of the stretching force owing to the properties of the keratin molecule. Simultaneous stretching and steaming of horse hair is particularly effective in generating such plastic deformation. This additional stretch can be removed through washing. This ability to shrink hair is sometimes used by bow-hairers to obtain straight and uniform fibres.

In the past the scale structure of horse hair has been discussed in relation to its influence on bowing [2,3]. It might be worth stressing the point that the scales are not protruding; in fact the scale projection was estimated to hardly exceed $.5\mu m$ [3]. New-grown hair thus shows a flat-scale surface rather than the saw-tooth surface sometimes conjectured to account for the sticking friction between the string and bow. The scales overlap in a given direction - from root to tip. This feature could be thought to produce a directional component in bowing. However experiments carried along this line have yielded very little result so far. Although the scales of horse hair probably contribute to fixing the rosin bits on the fibres it now seems highly probable that the musical use of horse hair is related to its chemical structure rather than to its scaly surface.

Investigations have shown that the sound-producing stick-slip driving force is a function of the adhesive action of rosin particles. The musical use of horse hair and other man-made fibres used in bow-hairing is therefore connected to their ability to fix rosin particles in a suitable way. As a high polymer, keratin is capable of exhibiting surface activity, a property common to all high-molecular substances. The numerous

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MICROPHOTOGRAPHS OF CHINESE NATURAL WHITE HORSE TAIL HAIR

Figure 1. Magnification: 600
Detail of the cortex showing the system of tightly packed keratin plates running along the hair length.

Figure 2. Magnification: 2400
Detail of the cortex and cuticle showing the fibrillar structure of the cortex cells.

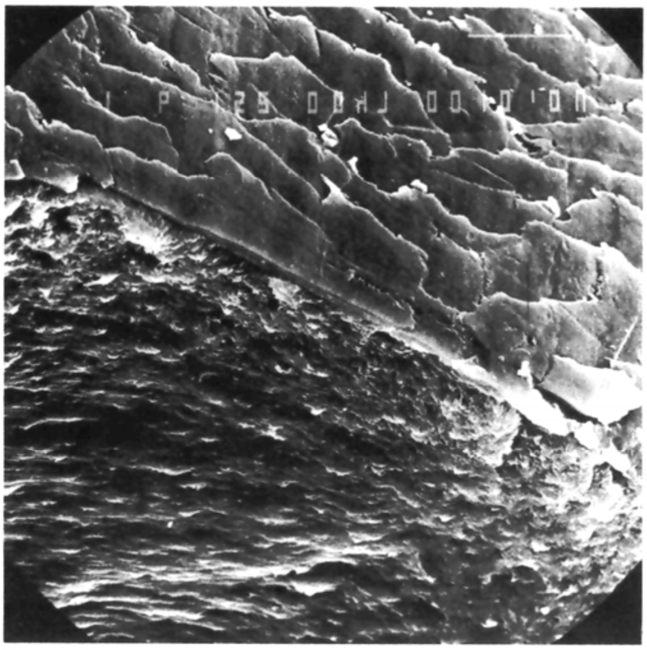

Figure 3. Magnification: 2400
Cortex, cuticle and scaled surface of new-grown hair at the root end showing the slate-like arrangement of the scales.

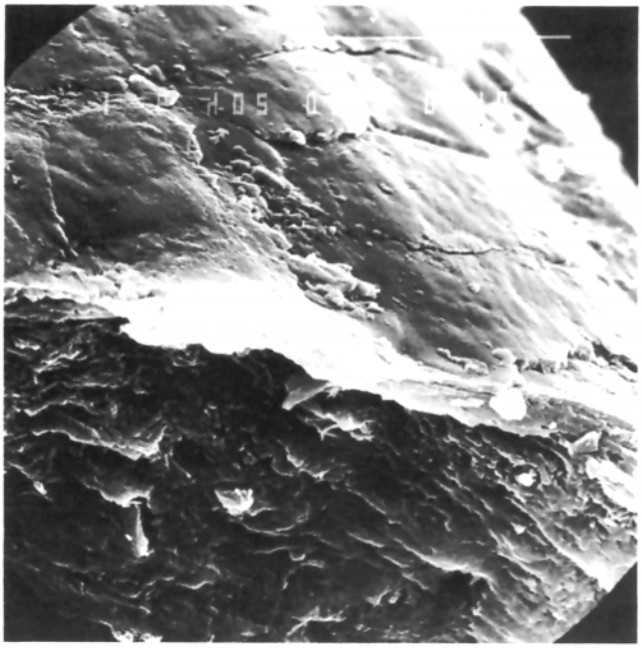

Figure 4. Magnification: 4000
Cortex, cuticle and eroded scales near the tip. Note the very flat scale structure.

(continued)

secondary forces available in such large molecules are capable to attract and firmly hold together other substances such as rosin, thus making sound production possible.

CONCLUSION

In this description of horse hair emphasis is put on the histological structure of the material. The pictures were made at very high magnification and may be confusing inasmuch as they tend to overdo the importance of scales from a musical point of view. However the sole purpose of this paper is to present bow-hairers and others with a different image of horse hair.

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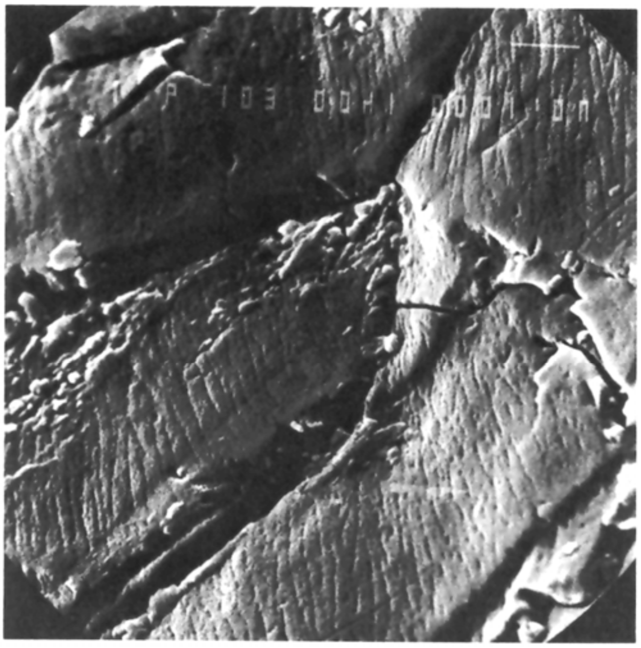

Figure 5. Magnification: 10.000
Detail of (Fig.1) showing cracks and splits in the degrading scales, half-length down the hair fibre.

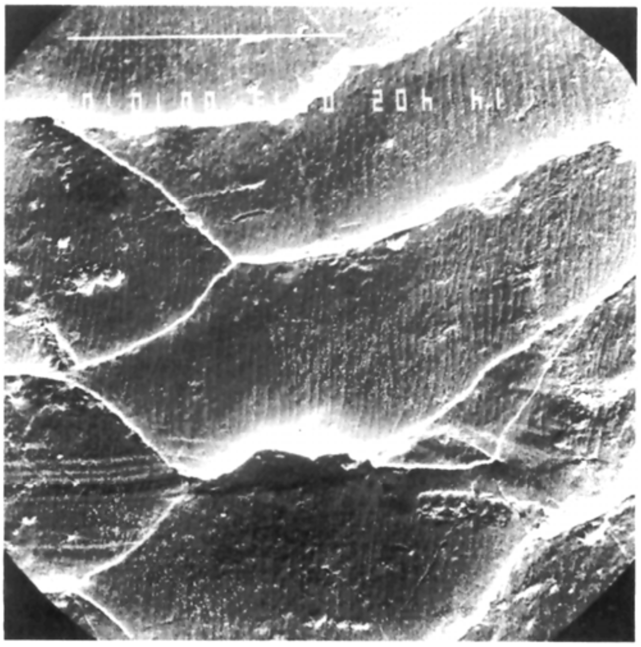

Figure 6. Magnification: 4000
Detail of the fibrillar scales at the root end.

Figure 7. Magnification: 10.000
Detail of (Fig.6) showing the keratin fibrils running along the hair length in the scales of new-grown hair.