JOURNAL OF MATERIALS SCIENCE 10 (1975) 525–538

Review
The anatomy of leather

B. M. HAINES, J. R. BARLOW
British Leather Manufacturers' Research Association, Milton Park, Egham, Surrey, UK

Leather is prepared from vertebrate skin by the chemical stabilization of the fibrous protein collagen, the main solid constituent of skin. The natural three-dimensional fibrous weave of the collagen fibrils is retained intact in the leather, and this paper describes in detail the relation between the fibrous weave as seen under the light and scanning electron microscopes and the physical properties of the leather.

In the main, skins of cattle, sheep and goats are used. These differ in total thickness, fibre bundle size and weave pattern, but offer a variety of raw material from which the tanner can select the skin type best suited for a particular end use. The tanning process can also modify the natural weave in order to achieve the required physical properties. For example the processing can allow fine spaces to remain between the fibrils, so that they are free to move over each other within the fibre bundle. Such a bundle will be highly flexible as will be the leather as a whole. Conversely, if fibrils adhere to each other and are not free to move the leather will be firm. Such fine spaces can be recognized under the microscope as longitudinal striations.

Another important feature which is influenced by the tanning process is the angle at which the fibres interweave in relation to the grain surface. A low angle of weave is required for high tensile strength as this allows the pull to be transferred along the fibre axis. A low angle of weave also allows more frequent interweaving of the fibres within a given thickness of leather, than if the angle is high. As frequent interweaving of the fibres is a prerequisite for strength the tear strength of leather is highly dependent on the angle of weave. This is particularly so in certain types of leather prepared from cattle skin, which is cut into layers to obtain the required leather thickness.

For leather to accommodate stretching, such as that occurring when lasting shoe uppers, or compression and creasing, the individual fibrils need to be free to move within the bundle, and the bundle within the weave as a whole. The changes in the fibre structure that occur under such conditions can be followed microscopically and are described in detail in this paper.

1. Mammalian skin characteristics and the structure of leather*

Although any vertebrate skin can be converted into leather the most commonly used skins are those of cattle, sheep, goats and to a lesser extent pigs. These have a similar basic skin structure consisting of innumerable bundles of collagen fibrils interweaving in a three-dimensional manner. The characteristic layers of tanned cattle skin are seen in the cross-section in Fig. 1.

The collagen molecules are extremely long, in relation to their cross-section, (the triple helix being 280 nm long, and 1.4 nm wide) and are naturally orientated during their formation into fibres and bundles of fibres as shown in Fig. 2. These bundles vary in dimension at different

*The terms used in this paper are those in common use in the leather industry but differ in some instances from the terms used by the histologist, and so the following definitions are given:

The fibrous portion of the skin below the epidermis is termed the *dermis*. The region of the dermis in which the hairs are found is termed the *grain layer* (marked A in figures). The region of the dermis below the hair roots is termed the *corium*, and the limiting layer of the skin, where the collagen fibres run in a horizontal manner to form a boundary to the skin where it is adjacent to the muscle of the animal, is termed the *flesh layer*.

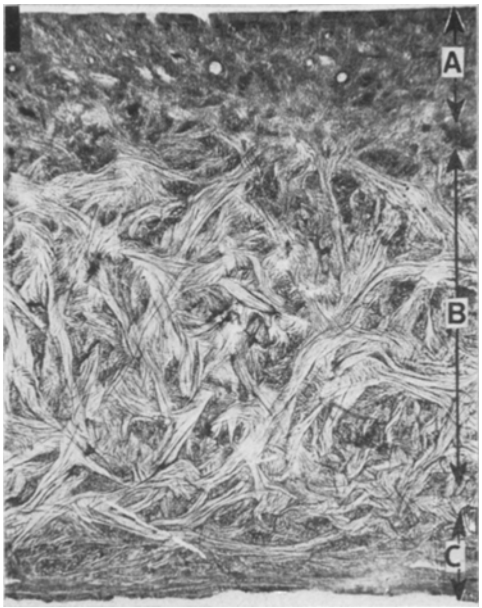

Figure 1 Vertical section through cattle skin made into vegetable tanned sole leather, × 14. A: grain layer, B: corium, C: flesh layer.

Figure 2 Corium fibre bundles, × 4500.

levels within the skin. The largest are to be found in the central region of the dermis or corium, marked B in Fig. 1. In cattle skin these large corium bundles are about 0.1 mm in diameter

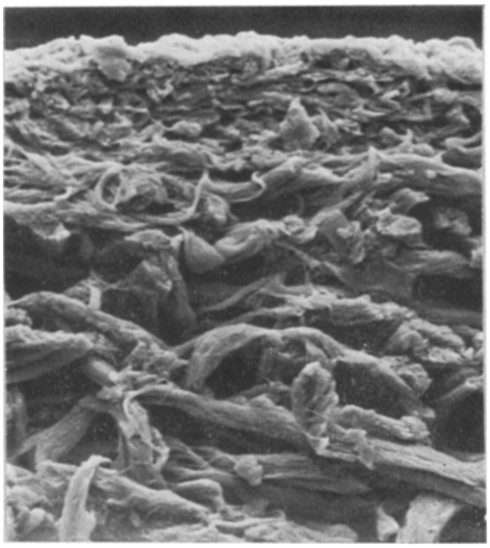

Figure 3 Fibres within the grain layer of a full grain leather, × 1200.

but these subdivide and become finer (~0.001 mm) as they approach the skin surface.

Towards the flesh surface, which in life was adjacent to the muscles of the animal, the fibres tend to run in a horizontal plane to form a limiting or flesh layer, C in Fig. 1. Towards the outer or grain surface the fibre weave has to accommodate other structures such as hairs, which are found in one distinct layer, the grain layer. This layer, marked A in Fig. 1, extends from the hair roots to the outer surface, which in the untreated skin is composed of the epidermis. The collagen fibres become increasingly fine as they pass through the grain layer, so fine as to be more readily studied by the scanning electron microscope. Fig. 3 shows fibres towards the grain surface 0.001 mm in diameter. At the extreme outer surface of the dermis the fine fibres are only resolved under the light microscope if specifically stained. In Fig. 4 the dermal surface fibres are stained black by silver and are seen lying immediately below the epidermis in the raw skin. The epidermis, together with the hairs, is removed chemically during the early stages of leather processing, and it is then that these fine fibres form the outer surface of the leather. It is the compact interweaving of these fibres which creates the smooth aesthetically pleasing surface of the leather.

The natural weave of the collagen bundles not only varies through the thickness of the leather,

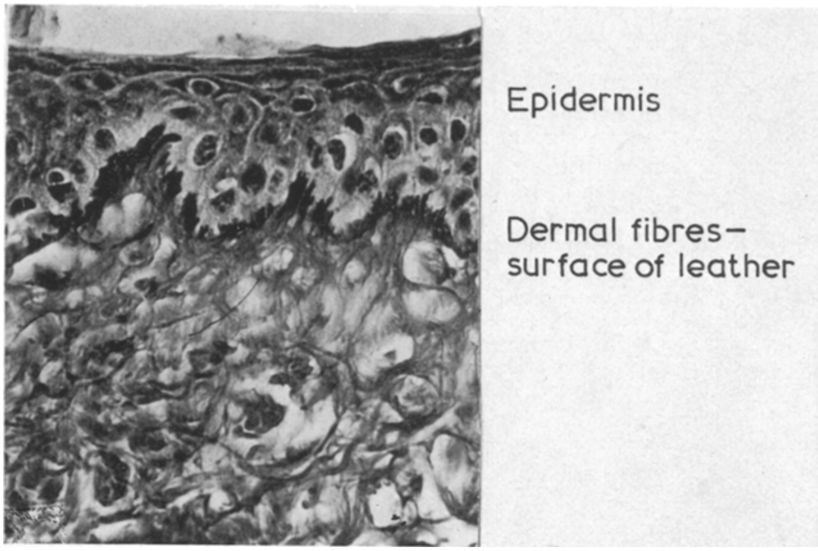

Figure 4 Section through a raw cattle skin, surface dermal fibre stained black below epidermis, × 100.

Figure 5 Vertical section through leather from cattle skin at the back of the animal, × 20.

Figure 6 Vertical section at the belly, × 20.

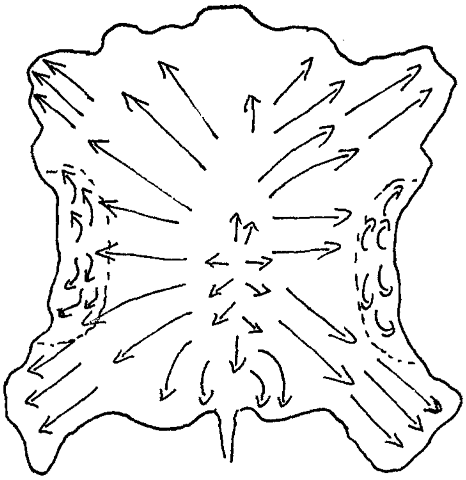

Figure 7 Diagram showing direction of main run of fibres through the skin.

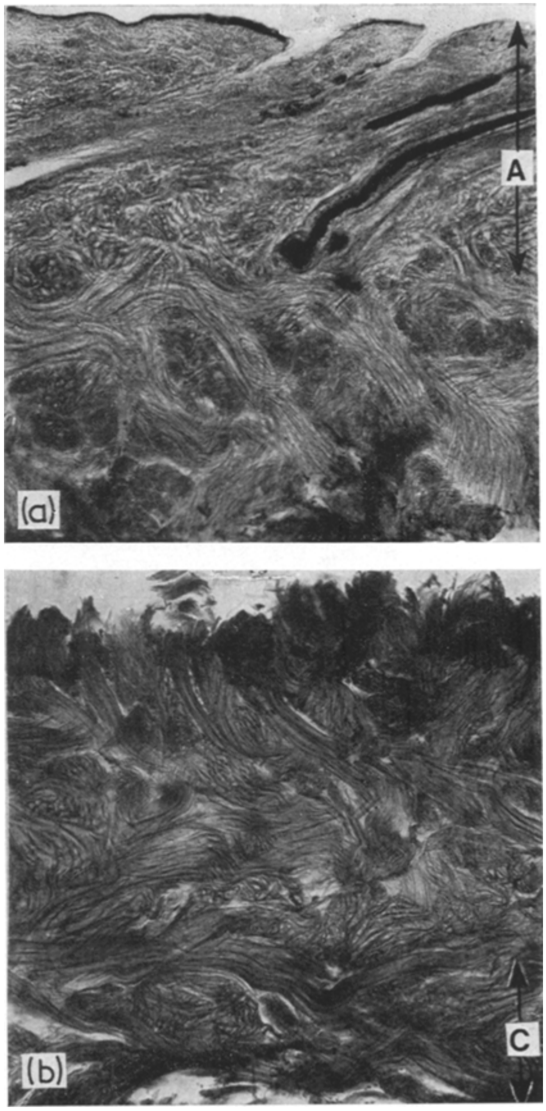

Figure 8(a) Grain split and (b) flesh split from cattle skin, × 55. A: grain layer, C: flesh layers.

but varies according to its location on the original animal. For example the skin which originally covered the back of the animal has a more compact weave, with the fibres interweaving at a higher angle in relation to the grain surface than has that of the belly region. This difference is clearly shown in Figs. 5 and 6.

The three-dimensional weave is not a random weave: there is, parallel to the skin surface a predominating direction in which the fibres run as shown in Fig. 7 [1]. This directional run is aligned with the line of the hair growth and the direction of the underlying muscles and it is reasonable to assume that the fibres in the skin become so aligned in response to the stresses that arise during the growth and development of the animal. This directional run of the fibres is the least marked in the compact area over the back of the animal, more marked in the looser belly regions and most pronounced in the legs. It can profoundly affect the physical properties of the leather. For example it is easier to bend leather parallel to the main run of the fibres [2] than across them. Tensile strength, and shrinkage that occurs with excessive heat [3] is greatest in line with the main run of the fibres, but tear strength has been found to be less dependent on direction of testing.

2. Variation of structure between animal types

Each species of animal has a distinctive weave pattern; the skins vary in thickness, dimension of the constituent fibrous bundles and in the proportion of the total thickness occupied by the grain layer, i.e. the layer in which the hairs are to be found. For example, cattle skins are generally between 4 and 6 mm thick; the corium fibres are relatively large and the grain layer occupies one-sixth of the total thickness of the skin (Figs. 1 and 8). In calfskin this proportion is similar but the total thickness of the skin and the fibre bundle size are dependent on the age of the animal (Fig. 9). Sheep- and goatskins range between 1 and 2 mm in thickness, the corium fibre bundles are relatively fine and the grain

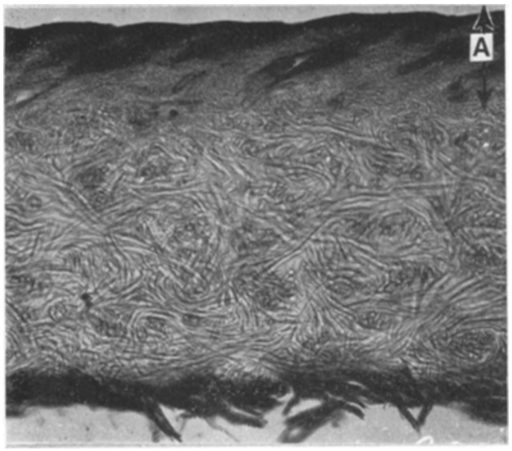

Figure 9 Calf leather 1.2 mm thick, × ~50.

Figure 10 Gloving leather from hair sheep, × ~50.

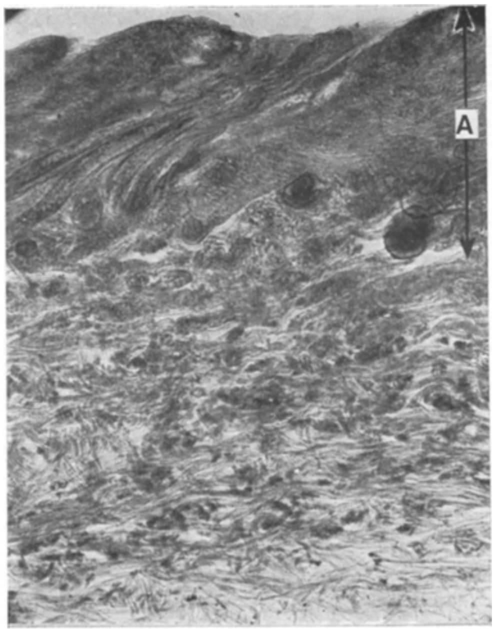

Figure 11 Clothing leather from woolled sheep, × ~50.

layer occupies half the total thickness (Figs. 10 and 11). In all these figures the bracket A indicates the depth of the grain layer.

This variety in skin structure offers a range of raw material to the tanner from which careful selection has to be made in order to achieve the combination of mechanical and aesthetic properties required for specific purposes. For example, the thickness of cattle skin and the size of its constituent fibres make it an ideal raw material for machinery belting leathers from which high tensile strength is required, or for sole leather from which high resistance to abrasion is expected. On the other hand, cattle skin is far too thick for shoe upper, upholstery or clothing unless it is cut into two layers, i.e. a grain split which consists of the grain layer and part of the underlying corium (Fig. 8a), and a flesh split consisting of the remainder of the corium and the flesh layers as shown in Fig. 8b. Even so the coarseness of the corium fibre bundles puts a limit on certain qualities desirable in clothing leather. For example the degree of drape is far less in clothing from cattle skin compared with that from the finer fibred sheepskin.

A suede leather is produced by abrading the leather, pulling the surface fibres up into a nap. The split surface of a cattle skin is abraded and the coarse corium fibres give rise to a coarse nap (Fig. 12) that is less pleasing than the fine nap (Fig. 13) produced by abrading the flesh surface of sheep or goat.

There are many types of sheep, each type with a different skin structure. The hair sheep indigenous in tropical countries is a relatively small animal with a hair growth more like a goat. The skin is small in area, thin with a compact fibre structure (Fig. 10) well suited to lightweight gloving leather. The woolled sheep of European origin is a larger animal with dense wool growth; the skin is thicker and larger in area, more suited to clothing leather, Fig. 11.

The tanner, therefore, has a wide variety of sources from which to select his raw material.

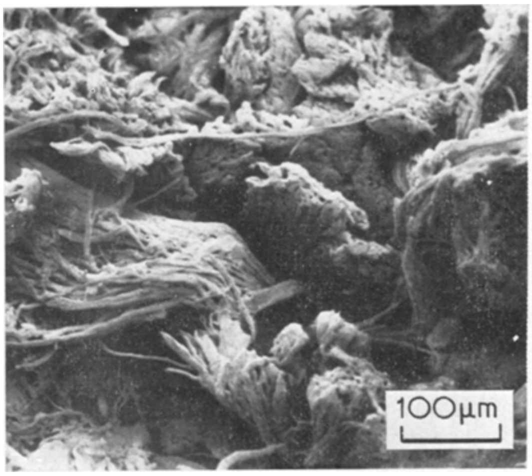

Figure 12 Suede surface of leather from cattle skin, × 135.

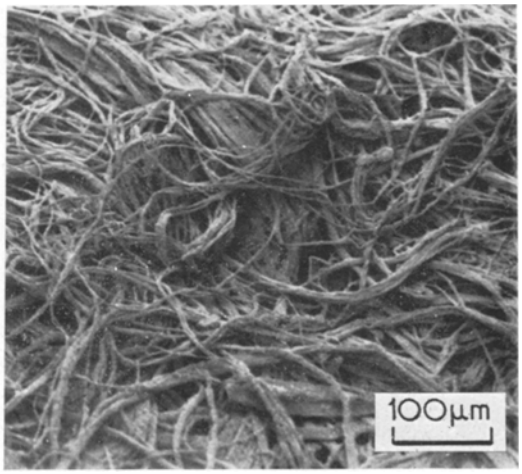

Figure 13 Suede surface of leather from sheep skin, × 135.

3. Variations in the fibre structure introduced by the tanner

The tanner is bound by the natural structure of the skin and the animal type but his skill lies in bringing about limited changes in the structure so as to produce leather of widely different physical properties. In transforming the collagen fibre to leather fibre the comparatively weak cross bonds between natural protein molecules have to be replaced by stronger ones built up by the tanning agent. However, before tanning, the skin is passed through strong alkaline and acidic liquors, which apart from removing the hair, epidermis and unwanted soluble proteins from the skin, cause the collagen fibre to swell. As it swells the fibres also contract and in doing so the angle at which the fibres run through the weave rises in relation to the grain surface. Other constituents of the liquors such as salt can influence the degree to which the fibrils are separated from each other within the bundle. By tanning the fibres in a changed state of being fully contracted, or fully extended or in an intermediate form, the tanner has a measure of control over the fibre structure.

His skill is most clearly demonstrated by comparing the properties of a sole, belting and picking band leather. A sole leather with a high resistance to abrasion will tend to be firm, a belting leather with high tensile strength will need to be flexible and a picking band leather, which is constantly flexed during its life on a weaving loom, will require a high degree of flexibility and flexural endurance. All three types can be produced from the one same type of raw material – cattle skin.

These different physical properties offer an interesting contrast in directly opposing requirements of structure. Figs. 14 to 16 illustrate the fibre structure of these three leathers, at the central corium region where the large corium fibre bundles are easily recognized. Two features of the fibre structure differ to a very marked degree, i.e. the degree of splitting up of the fibres and the angle at which the fibres interweave in relation to the grain.

Splitting up is recognized under the light microscope as longitudinal striations along the fibre bundles and as fine detail in the cross-sections. These striations are visible due to spaces between the fibres within the bundles. Such spaces permit the fibres to move over each other within the bundles. When numerous striations are apparent the fibre bundle is described as being finely split up.

Flexibility of a leather [4] has been shown to depend on the degree to which the fibre bundles are split up: the greater the splitting up the more flexible a leather. Conversely, resistance to abrasion demands a compact fibre bundle with little splitting up. Comparing Figs. 14 to 16, little splitting up is apparent in the firm sole leather (Fig. 14), more in the flexible belting (Fig. 15), and extremely fine splitting up in the picking band (Fig. 16).

Resistance to abrasion is greatest across the face of the fibre bundle, so the fibres in a hard wearing sole leather need to interweave at a high

Figure 14 Corium structure of firm sole leather, × 55.

Figure 15 Corium structure of flexible belting leather, × 55.

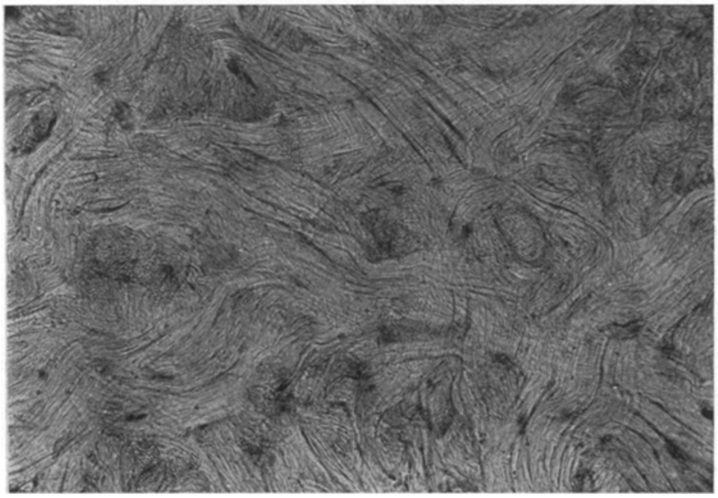

Figure 16 Corium structure of flexible picking band leather, × 55.

Figure 17 Strong upper leather 2 mm thick tearing at 22 kg load.

angle in relation to the grain surface, where abrasion will occur. Such a high angle of weave is seen in Fig. 14. In contrast for high tensile strength the load needs to be transferred along the fibre axis and so the angle of weave needs to be low as in the case of the belting leather in Fig. 15.

4. Relation between fibre structure and tear strength

The angle at which the corium fibres interweave has a marked influence on the tear strength of a leather, particularly so, when, as in the production of shoe upper leather the natural weave of the cattle skin is disturbed by cutting it through to produce two layers, a grain and a flesh split (Fig. 8). A grain split will consist of the grain layer intact and part of the corium weave and its tear strength will be largely derived from the corium where the fibre bundles are so much larger than in the grain layer. The tear strength is dependent on the frequency with which these large corium fibres interweave and cross over each other, a prerequisite for strength. This is largely governed by the angle at which the fibres interweave: a low angle of weave permitting more frequent interweaving within a given thickness.

In an upper leather of 2 mm thickness as shown in Fig. 17 there is sufficient depth of corium for frequent interweaving of the corium fibres, and this leather tore at a load of 22 kg. As the thickness of the split decreases so the proportion of the corium decreases and it is in splits

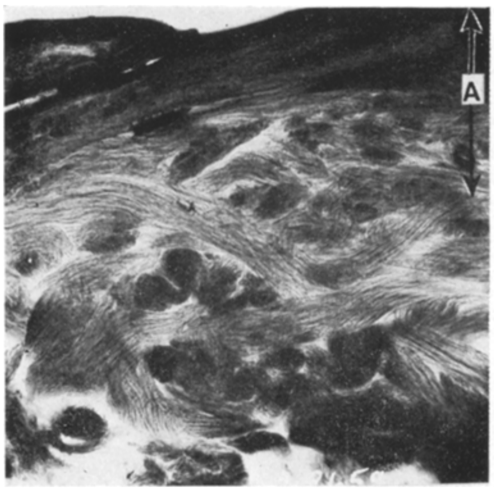

Figure 18 Grain split 1.0 mm thick tearing at 5 kg load.

Figure 19 Grain split 1.0 mm thick tearing at 2.5 kg load.

of 1.3 mm or less where the angle of weave has the most influence on strength. Figs. 18 and 19 illustrate the structure of two upper leathers 1.0 mm in thickness. In Fig. 18 the grain layer is relatively shallow, the corium fibres run at a low angle of weave to the grain and there is frequent interweaving of the corium fibres: this leather tore at a load of 5.0 kg. In Fig. 19 the grain layer is deeper and the corium fibres run at a high angle to the grain and so there is infrequent interweaving within the corium layer: this leather tore at 2.7 kg. Although the depth of grain layer can vary with the breed of cattle, it is also influenced, as is the angle of weave, by the tannery processing. A process that has minimum swelling action on the skin collagen produces shallow grain and a low angle of weave.

Figures 20-23 Shoe suedes made from flesh splits.
Figure 20 Strong flesh split – flesh layers (C) retained, × ~50.

4.1. Flesh splits

The principles of fibre structure just discussed apply equally well to the flesh splits cut from cattle skin. Whilst the corium fibres weave into and are anchored by the flatly running flesh layers as in Fig. 20, the split will have adequate strength. Once the flesh layers are cut away in processing, the strength of this now middle corium split is entirely dependent on the thickness of the split and the frequency with which the fibres interweave, which in turn depends on the angle of weave. Fig. 21 illustrates the structure of a strong middle split where the angle of weave is low: in contrast Fig. 22 shows the structure of a weak middle split where the angle of weave is high and the degree of interweaving is infrequent.

5. The reaction of the fibre weave to movement of leather

The three-dimensional fibrous weave allows considerable movement of fibres to occur within the weave when the leather is stretched, compressed or creased.

5.1. Stretching

Leather is stretched when it is dried at the last stage in tannery processing; it is stretched when a

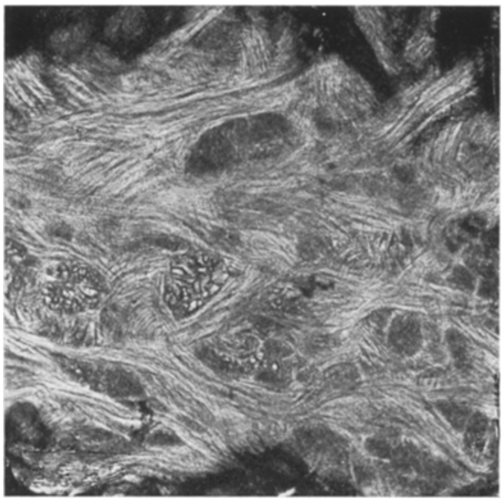

Figure 21 Strong middle split – low angle of weave frequent interweaving, × ~50.

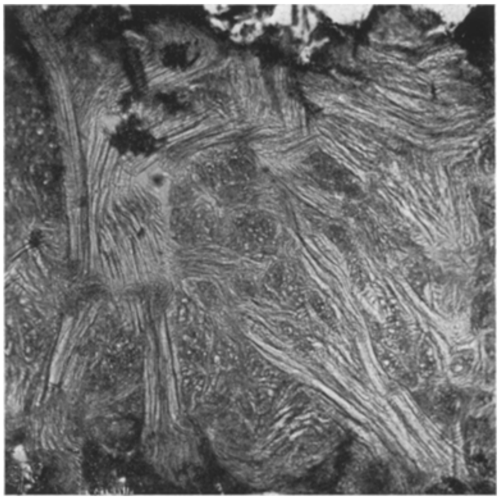

Figure 22 Weak middle split – high angle of weave insufficient interweaving, × ~50.

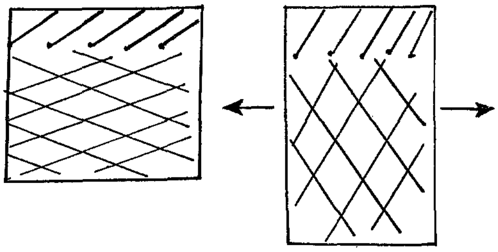

Figure 23 Diagram to illustrate changes in weave due to stretching the leather.

shoe upper is shaped on a last. The fibre structure has been found to adjust to stretching by a drop in the angle at which the fibres interweave and an increase in the compactness of the weave, as illustrated by the diagram in Fig. 23. Figs. 24 and 25 show the structure of a shoe upper, at the toe cap where considerable stretch is applied in lasting (Fig. 24) and at the top of the upper where stretch is minimal (Fig. 25). The drop in angle of weave due to stretching is apparent not only in the lower angle of the large corium fibre bundles, but in the lower slope of the hair follicles in the grain layer. The increase in compactness is most marked in the more finely split, more loosely interwoven region immediately below the hair roots (region A).

These changes in the weave occur more readily and to a greater extent if the leather fibres are lubricated by water: it is general practice to raise the moisture content of a shoe upper before lasting. However, these changes are

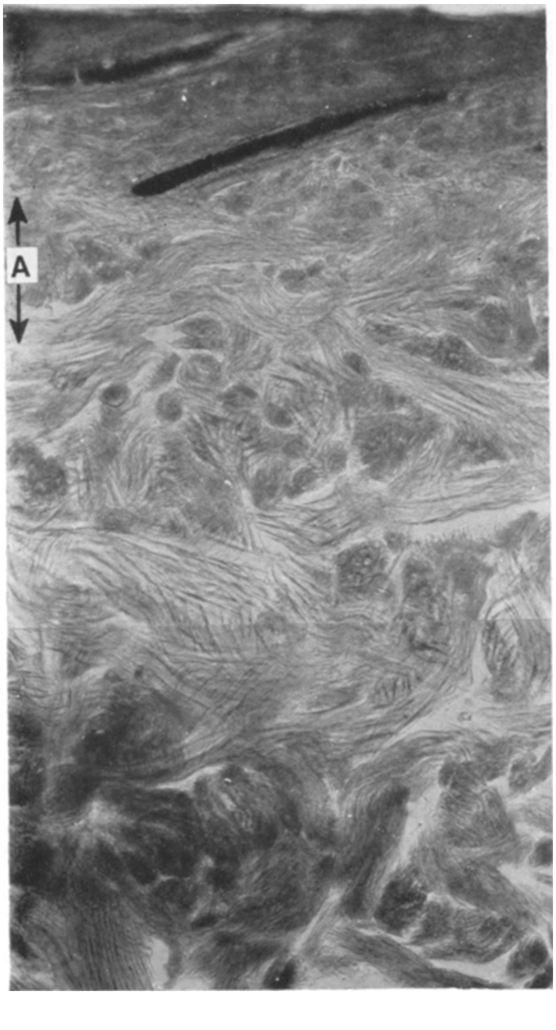

Figure 24 Upper leather at the toe cap, × 55.

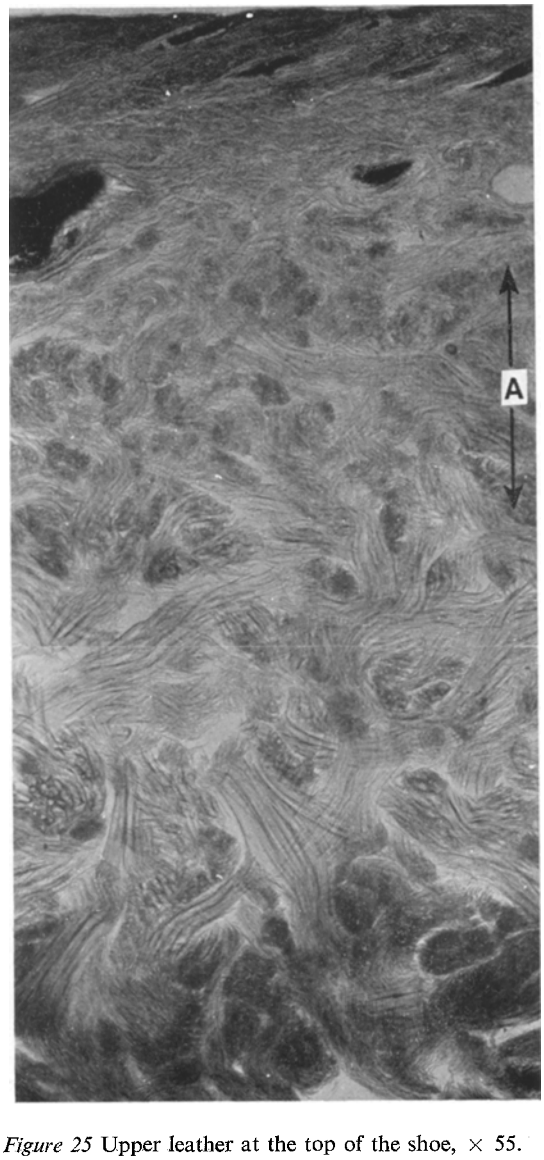

Figure 25 Upper leather at the top of the shoe, × 55.

Figure 26 Upper leather before compression, × 55.

Figure 27 Upper leather after compression × 55.

Figure 28 Upper leather with too compact a fibre structure to allow extension in lasting or compression in the moulded sole process.

only retained in the dry leather, if the leather is held in the stretched condition during the drying operation. When a collagen fibre dries it shortens, consequently on drying the leather loses area and becomes thicker unless it is dried under tension. It is usual in tannery processing to dry leather under tension to retain area and to dry a shoe upper on the last to retain shape.

5.2. Compression

The fibre weave adjusts to compression in a similar way, a drop in the angle and an increase in the compactness of the weave (Figs. 26 and 27). Leather is compressed when in shoe production the sole is moulded on to the upper. The periphery of the mould compresses the leather to about 40% of its original thickness in order to prevent the escape of molten soling material. In adjusting to this compression the spaces between the fibre bundles are reduced and the spaces

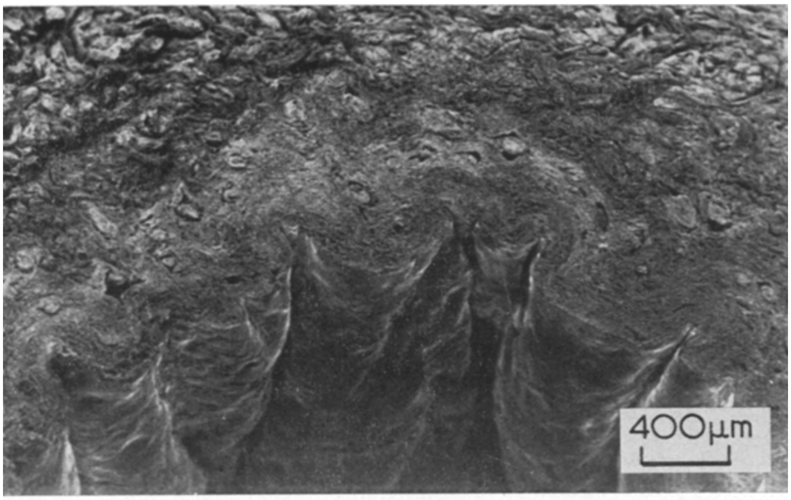

Figure 29 Shoe upper leather with light resin finish curved grain inwards, × 30.

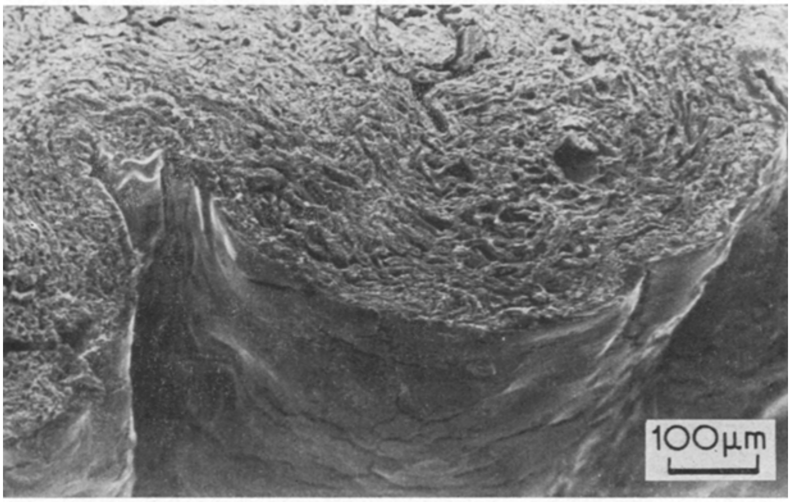

Figure 30 Grain layer in the adjoining creases, × 120.

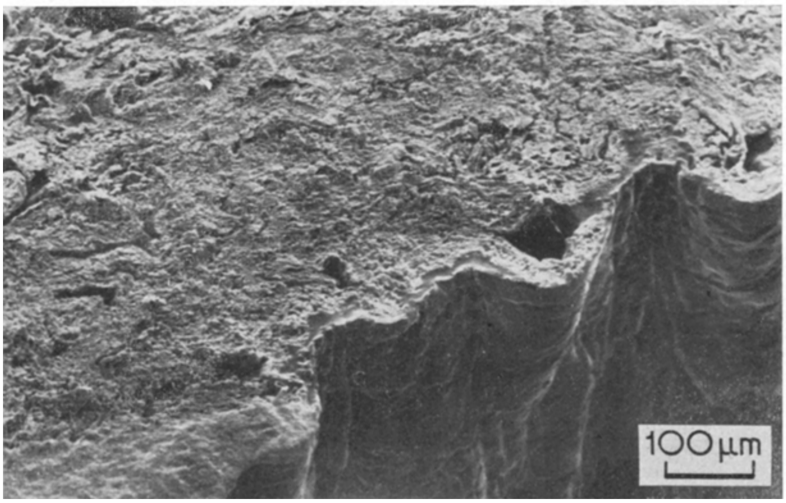

Figure 31 The same leather after impregnation with a flexible polymer, × 120.

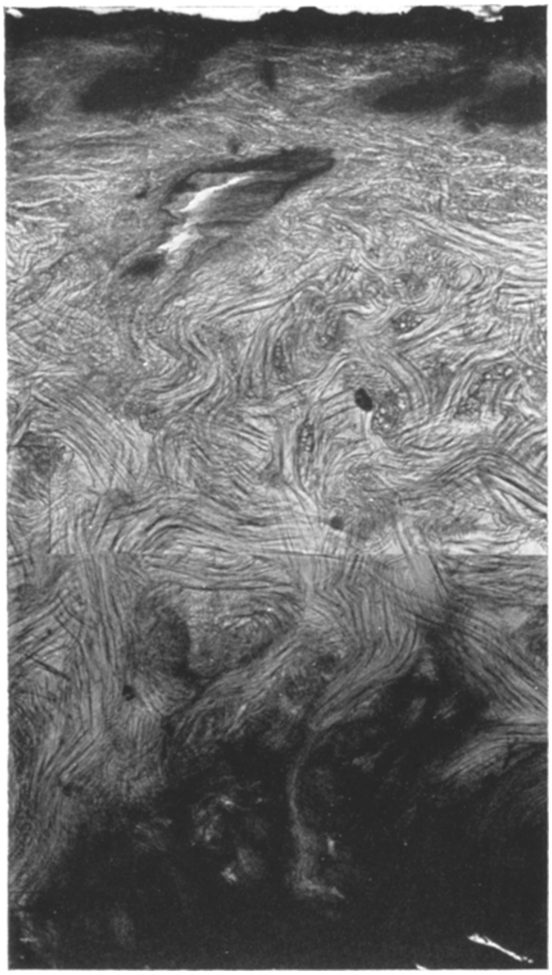

Figure 32 Upper leather with fine break, even fibre structure throughout, × 55.

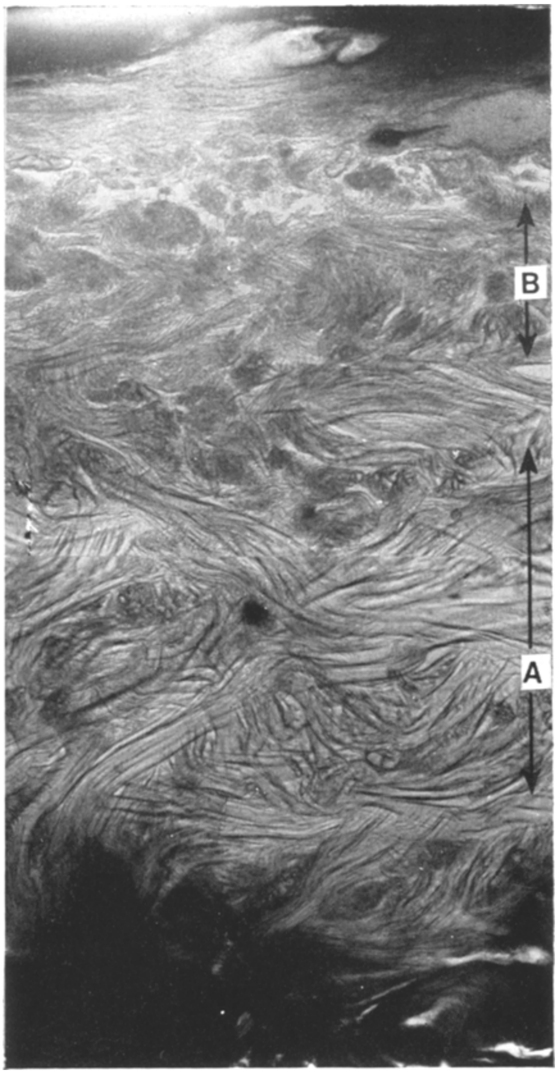

Figure 33 Upper leather with coarse break, compact corium A, loose finely split region, B, below grain, × 55.

between the fibres within the bundles reduced. Under the light microscope the reduction in spaces is apparent as a loss in splitting up. Fig. 27 also shows a marked reduction in the angle of weave.

For these adjustments to occur within the weave in response to stretching and compression there needs to be freedom of movement within the weave; when this is absent the leather is defective. Fig. 28 shows the structure of a leather where, through faulty processing there was so little splitting up of the fibres, and the weave was so compact that the leather could not be stretched satisfactorily in lasting. During the moulding operation this leather was cut by the mould as there was insufficient space within the weave to allow it to adjust to compression.

5.3. Creasing

One of the attractive features of leather is the fine creasing of the outer grain surface that occurs when leather is curved grain inwards. This is termed the break of the leather and a fine break gives to the grain surface character that is unobtainable in a homogeneous sheet material. The folds in the grain surface are formed by the fibre weave underlying the surface being able to open out and extend into the fold (Fig. 29), or to compress into the adjoining crease lines (Fig. 30). The only way in which this movement of the grain fibres can be followed is by means of the scanning electron microscope as in Figs. 29 and 30 where the grain has been held in a curved position.

The fineness of break depends on several factors. The finer the fibre dimension in the grain towards the surface, the finer the fold or break. Restricting the movement of the surface fibres by impregnating the region with a flexible polymer as in Fig. 31 can increase the fineness of break.

It is not merely the surface fibres but the weave throughout the leather that can influence the break. Fineness of break demands an even fibre structure through the thickness of the leather, i.e. a regular interweaving of the fibres and an even amount of splitting up of the fibres throughout as in Fig. 32. If there is an abrupt discontinuity in structure from a compact middle region to finely split fibres in a loose weave just below the grain layer as shown in Fig. 33, then the grain surface will form coarse folds from this looser region and the surface break will be unattractive.

The flesh surface can also influence break, for when leather is curved grain inwards, the flesh surface opens out and extends to accommodate to the curvature. If the fibre weave at the flesh surface is so compact as to restrict this movement, then the neutral axis moves away from the mid line to the flesh surface and the grain break becomes coarser.

6. Conclusion

The examples discussed in this paper serve to show the relationship that exists between the fibrous weave and the physical properties of leather. For the sake of brevity the examples have been restricted to leather prepared from cattle skin but many of the observations apply equally well to leather from other skin types. The chemical composition of leather can also profoundly affect its physical properties but discussion on this extensive subject does not fall within the scope of the title of this paper. It is possible by means of the microscope, to assess the quality of a given leather, and suitability for a specific purpose: it is also possible to detect the reason for failure in a faulty leather*.

References

1. G. O. CONABERS, *Journal of International Society of Leather Trades Chemists* **28** (1944) 270.
2. *Idem, ibid* **25** (1941) 305.
3. *Idem, ibid* **28** (1944) 3.
4. M. DEMPSEY, "Progress in Leather Science" (1920-1945) (British Leather Manufacturers' Research Association, London, 1948) p. 319.

Received 3 April and accepted 31 May 1974.

*A description of the sectioning and preparatory techniques for the microscopical study of leather is given in "Progress in Leather Science" 1920-1945, British Leather Manufacturers' Research Association, London 1948.