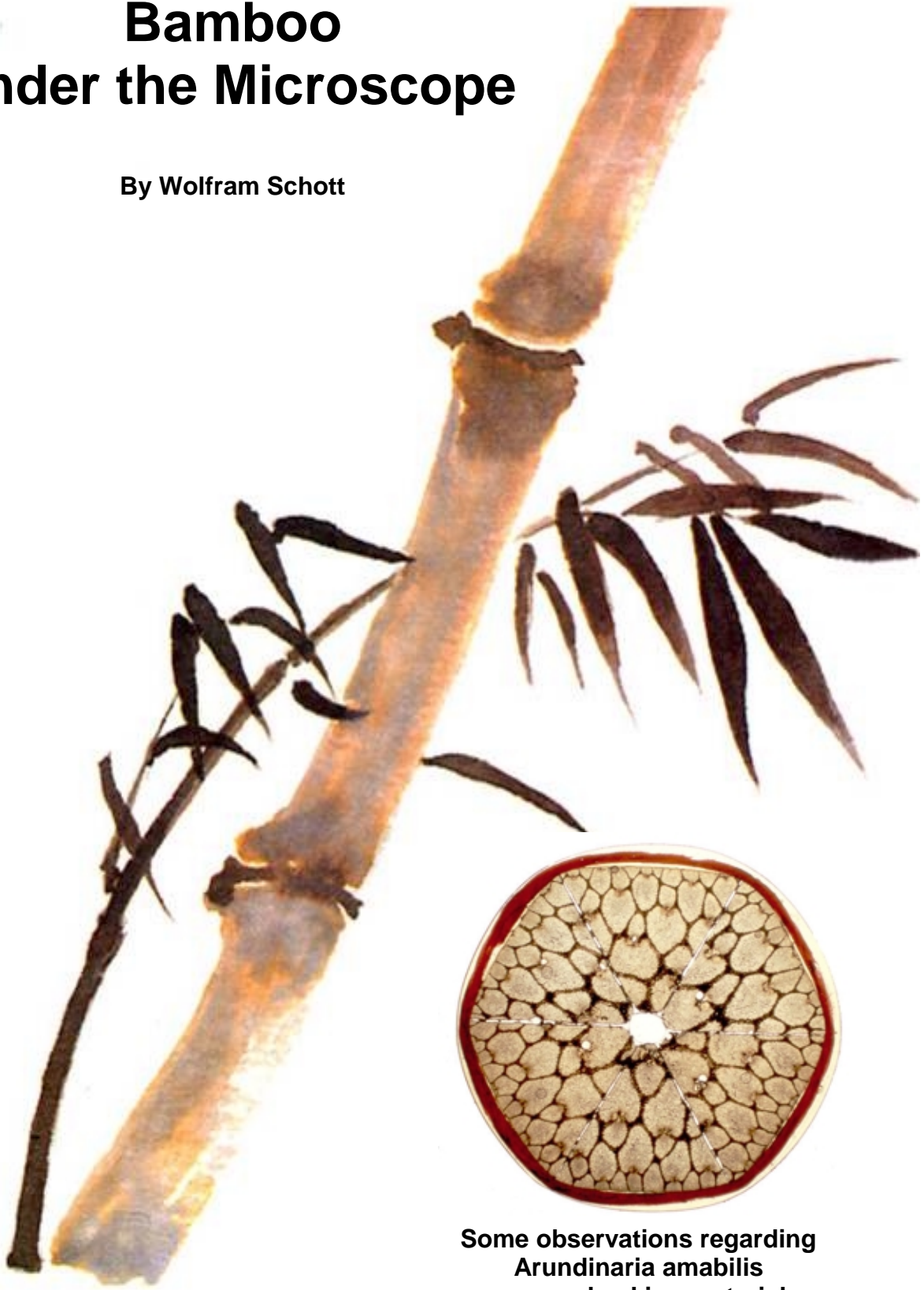# Bamboo
under the Microscope

By Wolfram Schott

**Some observations regarding
Arundinaria amabilis
as a rodmaking material**

Bamboo under the Microscope

<u>Introduction</u>

Back in 1981, I finished my first bamboo fly rod from a blank. It was a Norwegian "Hørgård", of 7' 6". ("ø" is pronounced like "i" in "Sir", "å" is pronounced like "a" in "wall"). Later in the same year I bought a HLL "Tournament", 7' # 5, 3-piece (Maxwell) at Rudolf Reichel's († Nov 2003) unforgettable shop in Münchberg/Germany.

Ever since then I have been fascinated with bamboo fly rods and I badly wanted to know how such rods were constructed, i.e., how they were designed, planed or milled, glued, assembled and varnished. In short, I wanted to discover the secret of what it was all about.

To further my research I bought all the books on rod making I could find: T. Norris, J.H. Keene, H.P. Wells, P. Frazer, G.P. Holden, G.L. Herter, C. Kreider, L. Lambuth, E. Garrison, only to name the well-known ones. Others in my library are Danish, Dutch, English, French, German and Norwegian, and now all the "post"-Garrison ones, of course. These I studied at length and eventually the time came for me to convert the theory into reality. I wanted to see how it all worked.

At that time, I was associated with a German university, at their Mineralogical Institute to be precise. (I am a mineralogist by profession) and had all their facilities to hand: both chemical and physical laboratories, microscopes, and the like. It was here that I did my investigations into the physical nature of the bamboo and its subsequent conversion to the finished rod.

One of the most important elements in the preparation of the bamboo prior to its assembly as a recognisable rod is its exposure to an elevated temperature for a pre-determined period of time. This process has the effect of removing most of the free moisture and some of the volatile oils. At elevated temperatures, it also alters the chemical structure of various constituents of the bamboo to some degree. The result of this treatment is a dramatic improvement in its stiffness and ability to absorb shock and stress without permanent distortion.

Rod making friends provided me with bamboo, both pieces of culms and parallel-planed triangular internode sections. Using my samples, I embarked upon a series of controlled experiments during which I subjected them to a number of time/temperature regimes.

The effects of heat-treating were recorded e.g. as loss of weight versus change of MOE (modulus of elasticity). So-called Thermo Scales recorded continuously the weight-change of a given sample, while this was heated with a constant and predetermined ratio of x degrees/minute. A number of such records helped finding out the time and temperature required to dry/heat treat bamboo properly (after my understanding). DTA (Differential Thermo Analysis) was employed to study further effects of heat-treating. This instrument records both exothermal (energy producing) and endothermal (energy consuming) chemical reactions, which gives one the possibility to find e.g. the breakdown-temperature of cellulose molecules, or monomerising of polymers. But this is another subject.

In mineralogy and geology, one means of investigating rock samples is by what is known as "thin section microscopy". This is, in short, a piece of rock, cut out with a diamond saw, ground perfectly flat on one side and mounted onto a thin glass-plate (28 x 48 mm, 1.3 mm thick) with a special low-viscosity epoxy (before that colophony resin was used). Then the sample is ground thin to a thickness of 25 µm (micrometers), or one thou (1/1000 inch), and covered with another glass-plate of 0.18 mm thickness. At 25 micrometers, the sample becomes transparent and can be studied under the microscope. Polarised light travels through it from underneath, and the individual components of a rock can be identified, e.g. by their characteristic colours, and their properties studied. With a built-in camera, pictures can be taken from the samples.

Having all the laboratory facilities available, I made thin sections of bamboo. Both in its natural state (from the culm), heat treated, and in its "hexagonal state", as samples taken from leeway cut-offs, or from rods broken beyond repair, which I also collected. And from all of these thin sections I made pictures (slides) on high resolution film (AGFA Professional 50 L). I have in my collection samples from many of the larger producers of bamboo rods, like Hardy, Farlow, Foster, Pezon, Hørgård, Leonard, just to name a few, and from smaller companies and individuals, like Bjarne Fries from Denmark, Walter Brunner from Austria, Tom Moran from England, and many others. Also some of my own, of course. I have some 200 slides, covering the major aspects of rod mak-

ing, like planing/milling, heat-treating, gluing, varnishing, and their (possible) problems. A selection of these is presented in this paper.

I gradually amassed and interpreted a lot of data and finally began to draw some definite conclusions. This was in 1984 and by then I was getting to know pretty much how a well-made bamboo rod should look from the inside as well as the outside. I had also gained an insight into many of the problems, which various makers had suffered from. The time had come when I simply had to give it a try myself. I have been a rod maker ever since.

From time to time, I have shown selections of my research slides to fellow rod makers, or at gatherings in Europe. In September 2003, I visited rod maker Harald Langer, of Austria, also to learn something about his hexagonal ferrules. I showed him a selection of my slides. He insisted on and finally talked me into scanning them and writing some comments to every picture. He put the material, together with some of his own comments, as a PDF-file onto his homepage. Sadly, for the English speaking nations, it is in German, but I am under pressure from many requests to prepare a translation. Here is my attempt to do so.

I have re-evaluated the selection and added a few more photos and some other material. The originals are, as I indicated, photographed on high-resolution positive film, 36 x 24 mm (this was long before digital cameras were ever thought of). I have scanned the slides using 600 dpi resolution. For internet distribution, the pictures have been resized to approximately 600 x 400 pixels.

I have grouped the pictures into chapters. First, the bamboo in its natural state is shown and its structure explained. Then the same material, heavily heat treated, and the results thereof. The pictures of rods deal with the processing, that is the shaping of the strips into equilateral triangles and into glued-up rod sections, with gluing, varnishing and a few other points of interest following.

The scale of the pictures is given as "Long side of picture equals x mm (y in)" and varies, of course, with the objectives used in the microscope. I am not referring to a scale like "Magnification x 50" for example, because this is dependent on the size you actually have the picture printed, or on your screen, the size of the screen, which can be anything from 15" to 21" diameter, and the inherent resolution thereof.

Not all pictures show the same yellowish colour of the bamboo fibers, and sometimes the background is blue. This is due to using polarized light to enhance difficult-to-see features in some photos. Varnish versus embedding epoxy, both 25 micrometers, or one thou thick, are such tricky objects. A few of the pictures show trapped air-bubbles in the epoxy mounting medium as small round circles, and very occasionally some tiny debris grains from the grinding process.

Any questions or suggestions related to this paper are welcome.

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e-mail: w-schott@t-online.de
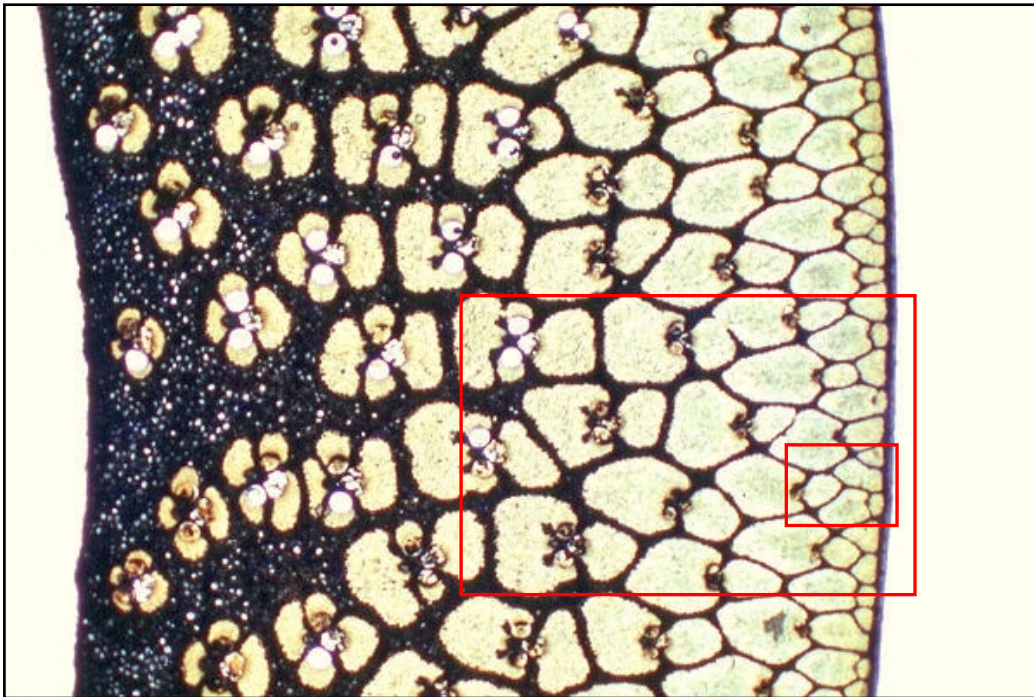
The Bamboo

Fig. 1
Long side of picture: 6.6 mm (0.26 in) Cross section through wall of culm. Yellow: "powerfibers", black "pith". The fibers conduct the light, which is coming from underneath, much like glass-fibers, appearing bright (yellow). The "pith" cells reflect the light back down and appear dark. This is opposed to what the naked eye sees: light falling onto the long-ish powerfibers from above will disappear "down into the depth", the fibers appearing dark brown. "Pith" cells will reflect the light, appearing white or buff-coloured. The "power fibers" are actually what is called vascular bundles, consisting of thousands of individual cells each, tightly packed together. The black areas represent the "pith", or basic tissue, between the vascular bundles which is botanically called parenchyma and is built up of elongated cells, which become more and more roundish towards the inner part of the culm (at left). White round holes in the left half of the section are large vessels (metaxylem), which serve as water conducting pipes. Red rectangles show approximate positions of Figs. 2 and 3.

vessels   vascular bundle   vascular bundle   skin
                 Xylem   Phloem
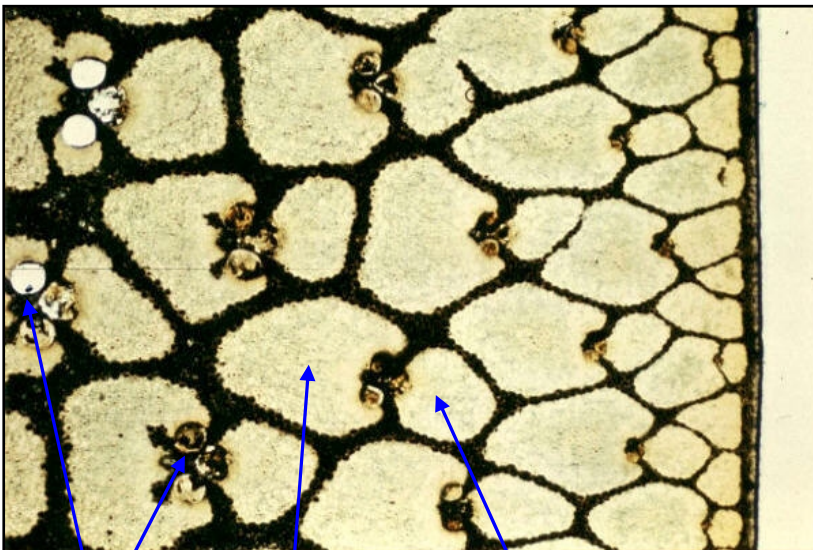
Fig. 2
Long side of picture: 3.2 mm (0.126 in)
More details can be seen: the "powerfi-bers", or vascular bundles, are grouped in pairs (phloem and xylem) on either side of a set of vessels. They are small-est near the outside of the culm, where also the surrounding basic tissue is very narrow. The relation between vascular bundles and basic tissue is, dependent of the quality of the culm, something like 50/50%. This sample (Fig.1) was measured to 56% "powerfibers". The outer half of the culm consists of 75% "powerfibers". This is the part of a culm which is usually used for rod making.

Note: In all of these images, the bamboo is illuminated by transmitted light, not light reflected from the surface.

Fig. 3
Long side of picture: 1.3 mm (0.051 in)
Fine structures within the vascular bundles become visible. These are tightly packed cells. The skin can be subdivided into a black outermost layer (epidermis), followed by a light (yellowish-brown) layer, and another, somewhat thicker, black layer (cortex).

The inner wall zone of bamboo contains some 1.5%, the outer wall zone in excess of 3%, and the node (diaphragm) about 4.5% silicon (SiO_2). Variations by a factor of 3 are known [1]. It is reported [2] that one can strike sparks from the species *Bambusa tabacaria* with steel...

[1] Institut für leichte Flächentragwerke, Stuttgart: IL 31 Bambus Bamboo. ISBN 3-7828-2031-2
[2] David Farrelly: The Book of Bamboo. ISBN 0-87156-824-1
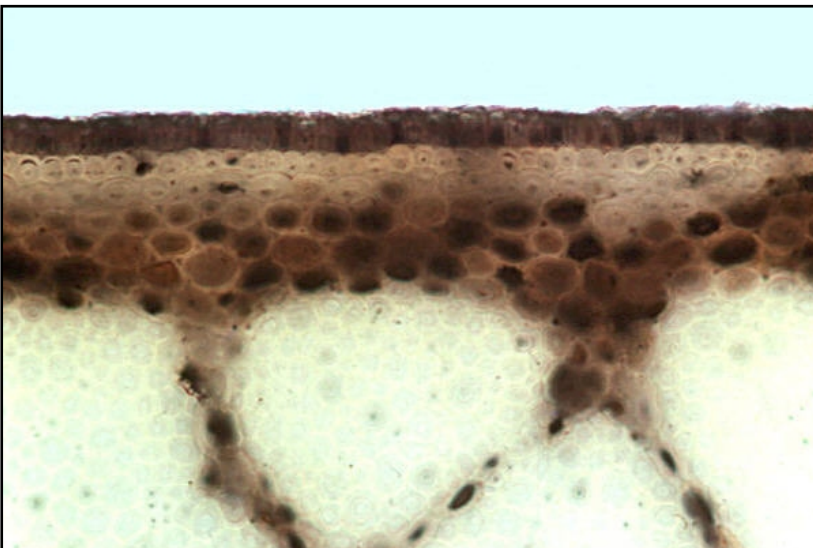
Fig. 4
Long side of picture: 0.23 mm (0.009 in)
Skin, or rind, in detail. The outermost layer is a one-cell-thick layer of 0.015 mm (0.00059 in), the rod maker's "enamel". Next comes a tan layer of even smaller cells, which is 0.025 mm (0.00098 in) thick, and finally a layer of coarser, dark brown/black cells, which is 0.03 mm (0.00118 in) thick. The last two layers are also called "under-enamel" by some rod makers. Sum total is 0.07 mm (0.00275 in). All of this must be carefully removed to expose the vascular bundles. But nothing more.
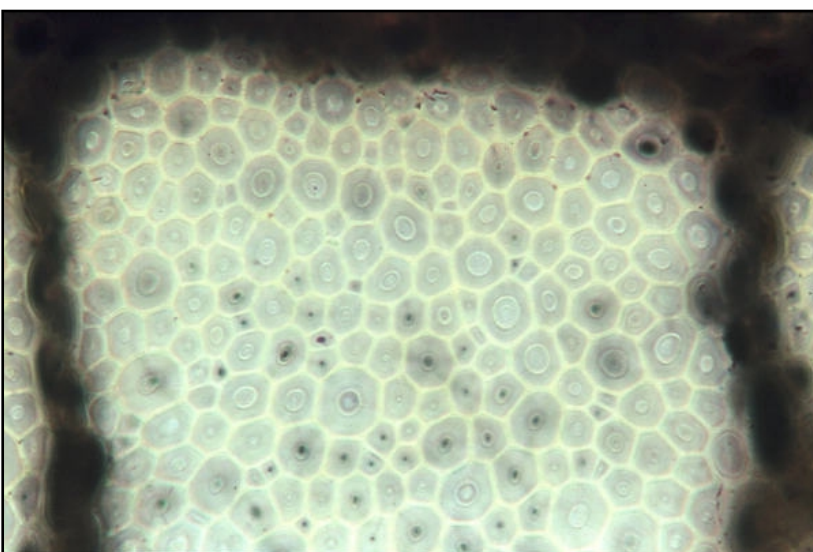The yellow vascular bundles are over exposed (too bright), to properly capture the dark skin structure.

Fig. 5
Long side of picture: 0.23 mm (0.009 in)
A vascular bundle from just under the skin. The individual cells are clearly visible. Their average diameter is approx. 0.01 mm (0.0004 in) with some smaller ones, possibly tapering ends of cells, and a few larger ones. Taking this average diameter of 0.01 mm (0.0004 in), this means a density of 100 x 100 = 10000 cells/mm^2, or 1 million cells/cm^2, or 6.45 million cells/inch^2. An impressing number indeed. They show polygonal outlines, most of them hexagonal. At very high magnifications, internal structures, like concentric rings, can be detected.

Fig. 6
Long side of picture: 0.23 mm (0.009 in)
Part of a vascular bundle from about the center of a wall (cf. Fig.1). Here the individual cells are much larger/coarser. Their diameters are two or three times as large as those in Fig. 5. The internal, or ultrastructure, is sharper visible, due to manipulation with the microscope. It shows the below described "polylamellate secondary walls". Visible also the yellow pectin, the bonding agent between the cells, and the lumen, or cell cavity, in the center of the cells.
The shape and distribution of the cells reminds me much of a honeycomb.
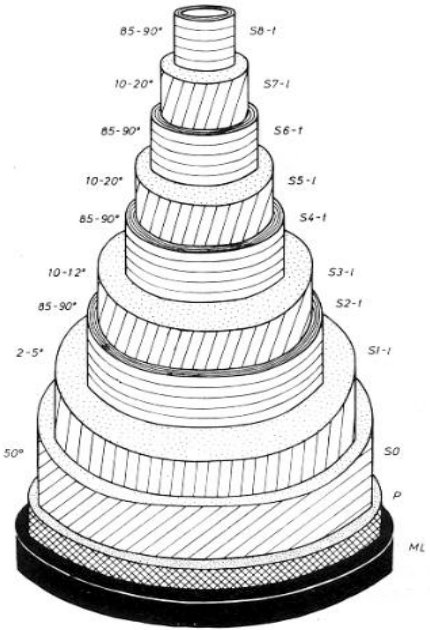
Fig. 7

The internal, or ultrastructure, of bamboo fibers is explained in: "Bamboos – biology, silvics, properties, utilisation", by Walter Liese, ISBN 3-88085-273-1, where the drawing on the left has been extracted and redrawn from. The text to it is as follows:

"The ultrastructure of most of the fibers is characterised by thick polylamellate secondary walls. This lamellation consists of alternating broad and narrow layers with differing fibrillar orientation. In the broad lamellae the fibrils are orientated at a small angle to the fiber axis, whereas the narrow ones mostly show a transverse orientation. The narrow lamellae exhibit a higher lignin content than the broader ones. ..... The polylamellate wall structure of the fibers especially at the periphery of the culm leads to an extremely high tensile strength, as demonstrated in engineering constructions with bamboo culms. Fig. 7 illustrates the fine structural make-up of a bamboo fiber. The polylamellate structure does not exist in the cell walls of fibers or tracheids of normal wood"

Fibers, or rather cells, in cross section are to some extent shown in the above pictures, and their average diameter has been measured. The length of the cells could not be ascertained. Literature gives values for a number of bamboo species (but I could not find *Arundinaria amabilis,* or *Pseudosasa amabili*, as it has been renamed by The American Bamboo Society*)* from 1.5 mm (0.06 in) near the nodes to 3 mm (0.12 in) and more along the internode sections. This gives a ratio of length/diameter of 60:1 up to 120:1. In literature values of 250:1 are given. Truly long cells, or fibers.

Going further into detail, like the chemistry of cellulose, hemicellulose, lignin and others and its behaviour when subjected to high temperatures, or the physical parameters of bamboo, is beyond the intended scope of this paper. R.E. Milward, in his excellent book: Bamboo – Fact, Fiction and Flyrods (ISBN 0-9688829-0-0) has dealt in depth with these aspects.
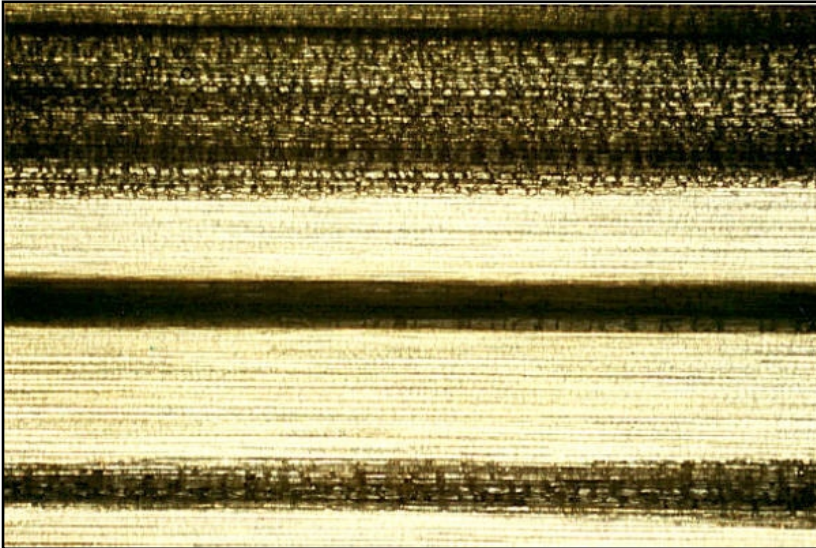
Fig. 8
Long side of picture: 1.3 mm (0.051 in)
Longitudinal cut through bamboo. Yellow: vascular bundles, with the individual long fibers (cells) clearly visible. Black and somewhat transparent the rod maker's "pith" (parenchyma). These are short, elongated cells of 0.03 to 0.05 mm (0.0012 to 0.002 in) diameter and two to four times that length.
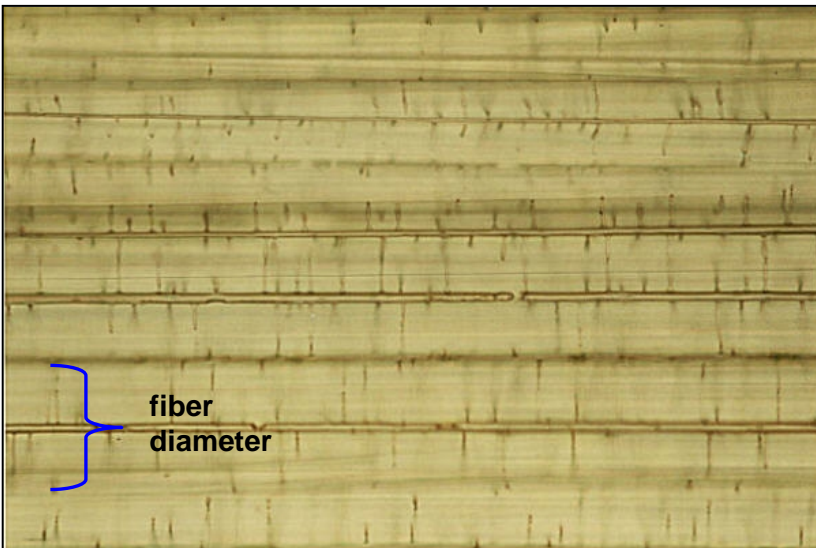

fiber diameter

Fig. 9
Long side of picture: 0.23 mm (0.009 in)
A few fibers, or cells, seen longitudinally. The center of the cells is easily recognised by its lumen, or cell cavity. From this lumen, radial structures, much like branches in a tree, reach perpendicular into the cell body. At close scrutinising of Fig. 6, one can faintly see some of these structures. The outer walls are not so easily seen in this picture, as several cells lie on top of each other, blurring the image somewhat.

Fig. 10
Long side of picture: 0.23 mm (0.009 in)
Parenchyma cells in strong magnification. They seem to "swim" in a yellowish matrix, which actually is the embedding epoxy, and are connected with each other and held at distance by tiny hair-like "bridges". These cover all sides of the cells, of course (here the top ones are ground off). Obviously, such short cells contribute nothing to the bending strength of either culm or rod, opposed to the above very long fibers (like a chain versus a rod). Maybe they serve as some sort of "shock absorber", both in the plant and in the fishing rod.
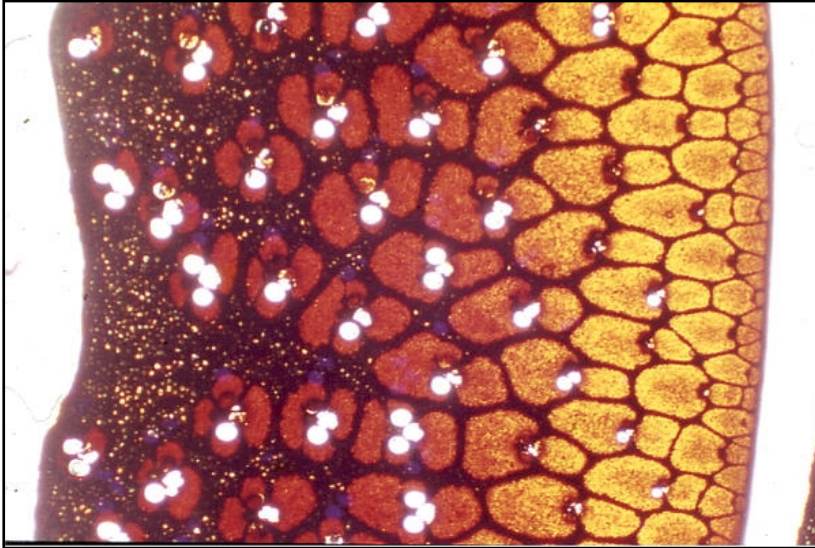
7

Heat Treating

Fig. 11

Long side of picture: 6.6 mm (0.26 in)
Cross section through wall of culm. Heat-treated 10 min at 250 °C (482 °F) in a large laboratory oven. The sample had a size of a few square cm, or about one square inch. The outer third or so of the vascular bundles with thin fibers is dark yellow/orange, to the naked eye this appears dark brown. The inner, coarser fibers have a much darker brown colour. To the naked eye, they appear all but black. In addition, the outermost vascular bundles, right under the skin, are considerably darker than the average outer third. This excessively heated sample is used to demonstrate the ill effects of heating much beyond the removal of water.

cracks along cell borders   crack within cell
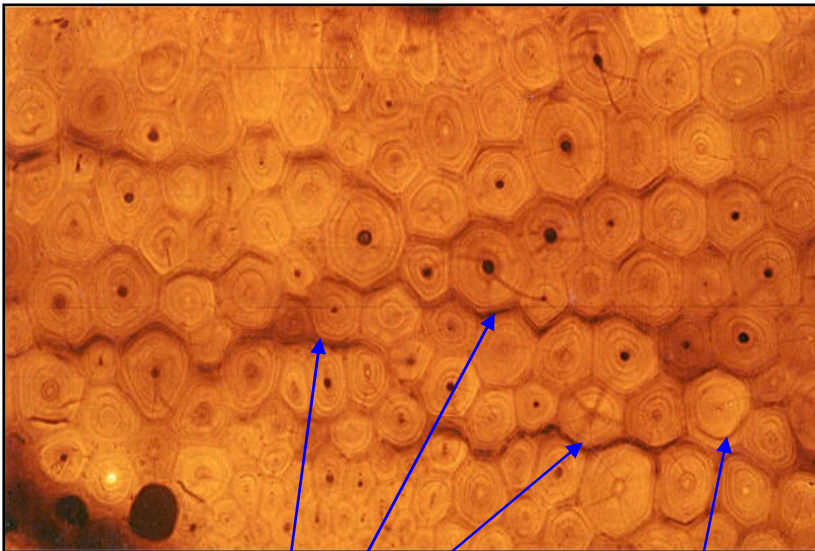
Fig. 12

Long side of picture: 0.32 mm (0.013 in)
A picture taken from the central part of Fig. 12. Desiccation cracks, or fissures, following the walls of the cells have appeared. These split up the vascular bundles into a large number of subunits. The cells are no longer snugly "glued" to each other. They have shrunk. The intercellular pectin is probably destroyed or cooked off. Some cells show circular cracks even within them, following the secondary walls (cf. Figs. 6 and 7). A bamboo treated such can no longer take up bending loads. The fibers will move along the cracks, shear strength is dramatically reduced.
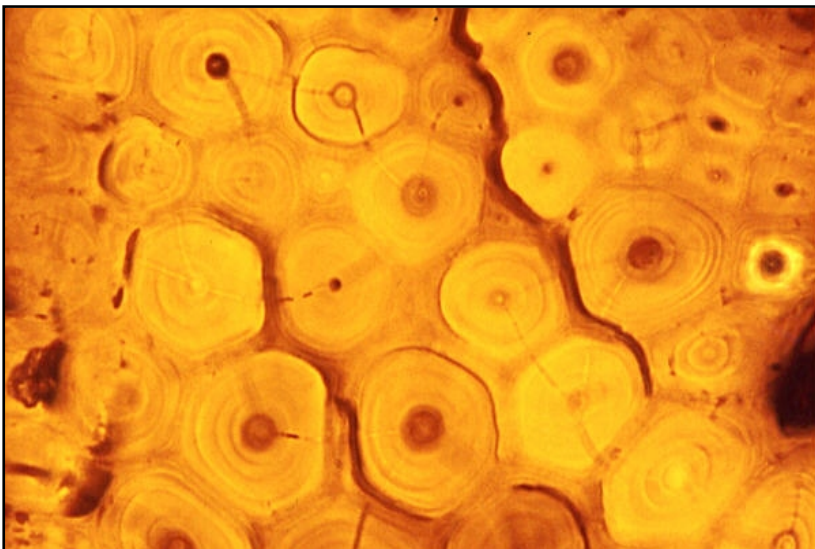

Fig. 13

Long side of picture: 0.23 mm (0.009 in)
A larger magnification of another part of Fig. 11 The "assembly of cells", the vascular bundle, is virtually destroyed: cracks along cell walls, many small cracks within the cells. The "polylamellate wall structure of the fibers" (cf. Fig. 7) seems partly destroyed, possibly due to breaking-up of the lignin-polymers into monomeric units. This sample had contained 6 % water (air-dried) and lost a total of 15 % (by weight) during heat-treating. Compare with Fig. 6.
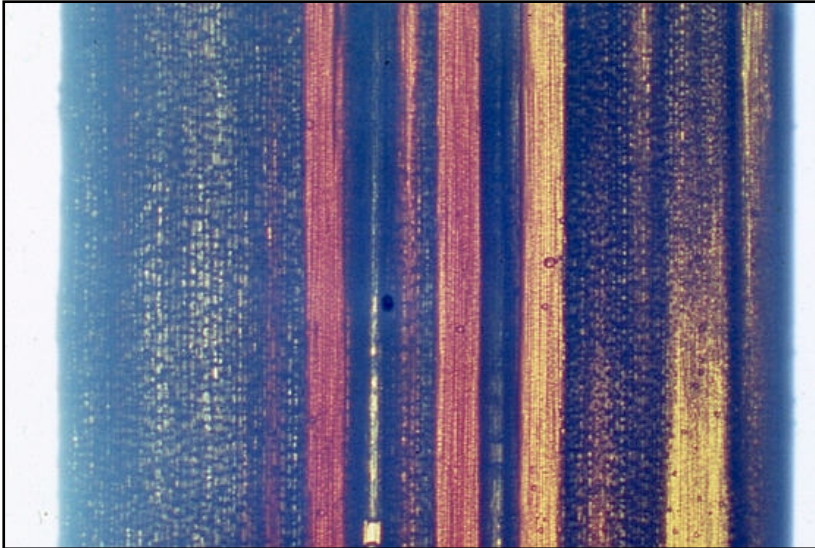
8

Fig. 14
Long side of picture: 6.6 mm (0.26 in)
Longitudinal cut through wall of culm. Also in this view the outer vascular bundles (at right) are less brown than the inner ones (at left), cf. Fig. 11. Black "pith" overlying parts of some vascular bundles, especially the two rightmost ones, due to the cross-section not being perfectly parallel to the direction of the fibers. Strong light had to be used to penetrate the dark brown fibers perpendicular to their orientation. This is why the left side of the image is a bit blurred due to stray light.
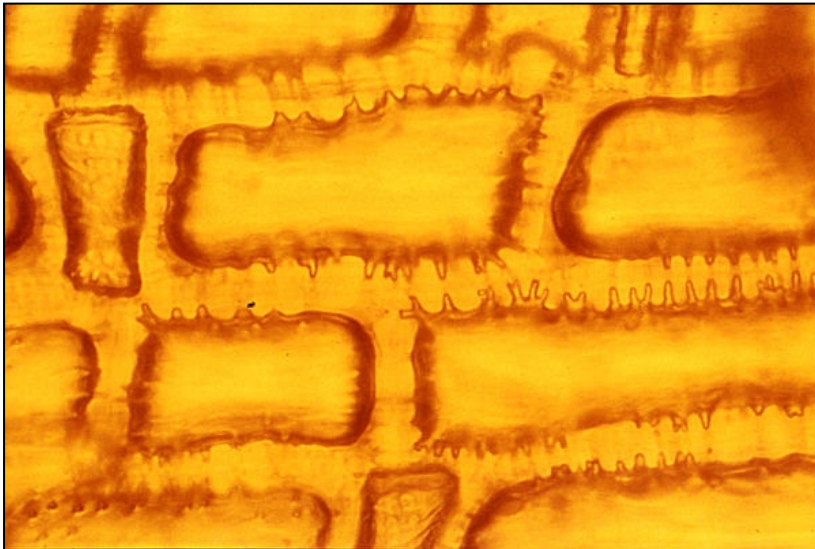
Fig. 15
Long side of picture: 0.23 mm (0.009 in)
Parenchyma cells ("pith") after heavy heat-treating. The hair-like interconnections ("bridges"), as seen in Fig. 10, seem to have been burned, or scorched, off. Only stumps remain. This is a sample from the inner part of the culm wall.

W. Liese (see Fig. 7) observes:
"The ground tissue consists of parenchyma cells, which are mostly vertically elongated (100 x 20 µm), with short, cubelike cells interspersed in between. The former ... become lignified in early stages of shoot growth. ... The function of these two different types of parenchyma cells is still unknown."

I have conducted experiments, and made thin sections, at temperatures of 150, 175, 200, 225 and 250° Celsius, or 302, 347, 392, 437 and 482° Fahrenheit, and with varying times of exposition.

Some people like blonde rods, others dark brown ones. A matter of taste, maybe. A number of manufacturers have produced dark rods, to meet their customers' demands, or fancies, by treating the rods with potassium permanganate instead of abusing the bamboo with too much heat. Hardy's, of England, e.g., called such rods "dark cane".

Processing

A rod making friend of mine once said, with a twinkle in his eye: "Anything thick in one end and thinner in the other, will throw a line and catch you fish". Which is true. However, here we are going to look a bit closer to thick and thin ends now. For me the way is the goal, to some extent. I always strive to improve my craft. And that is why I made these investigations. There are no good or bad ways to make a rod blank, only exact and lesser exact ones. Both milling and hand planing can produce excellent or mediocre results. The following examples present some cross sections of rods of both genres. Fairness commands that names of manufacturers remain anonymous. I am also very reluctant to give any advice in this paper, regarding the conclusions drawn from the observations. Every rod maker with some experience has developed his own ways of doing things.

Maybe some will nod their heads while browsing through the pictures in recognition of own experiences. I hope that others will see something new, which will improve their craft.
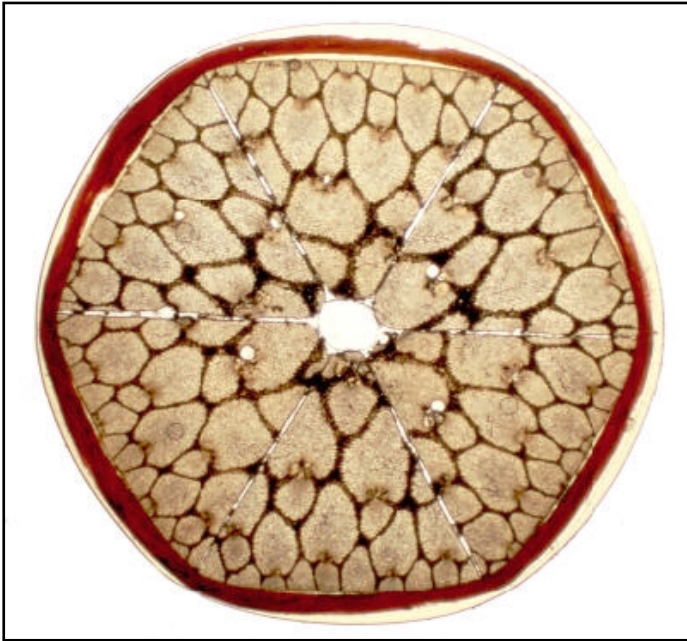
Fig. 16
Cross section from the tip joint of a rod. Flat-to-flat diameter (bamboo) 3.9 mm (0.153 in). The strips are milled to 60°, the centers, or apexes, are rounded, leaving a tiny hole in the center. Thin and even glue-lines. The outer flats are slightly rounded, following the curvature of the culm. The overall outside geometry shows a slight "off-hexagon" with the flats not exactly parallel to each other (see top versus bottom flat), which indicates some surface sanding. The strips show small vascular bundles, little more than the rind, or skin, is removed. This sample is a cut through an intermediate winding (red). On the left upper flat, the drawn-under threads of the invisible knot are seen. Between the bamboo surface and the thread a thin layer of varnish: the rod blank was varnished prior to winding. A good example of a commercially produced rod.
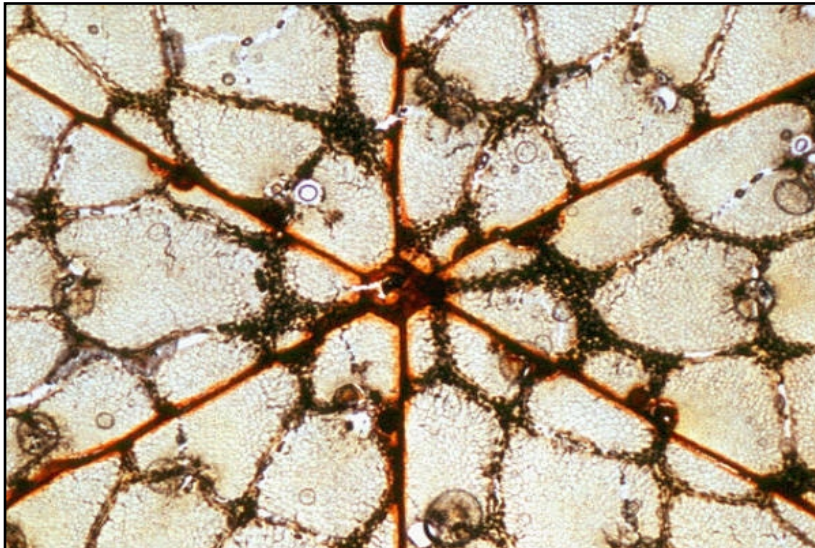
Fig. 17
Long side of picture: 3.2 mm (0.126 in)
Center of a rod, butt joint. This is a hand-planed rod. Perfectly planed strips, precise 60° angles. The innermost tip (apex) has been planed off. Red resorcinol glue is used, diluted with alcohol. The glue penetrates slightly into the fibers, making for a good hold.

Such properties as penetration are best seen with red resorcinol glue. Other (white, or transparent), glues may or may not have similar qualities, which can be studied under the microscope. However, they are not easily photographed, due to low contrast.
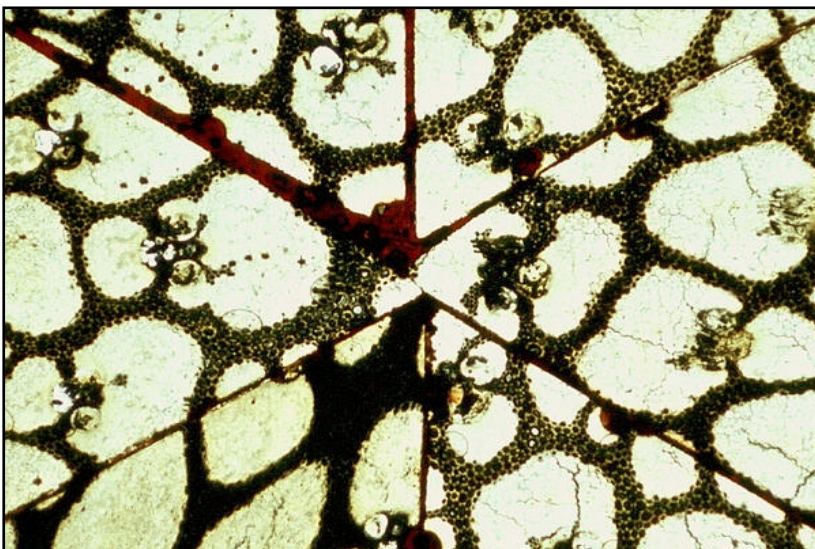

Fig. 18
Long side of picture: 3.2 mm (0.126 in)
Center of a rod, butt joint. Another hand-planed rod. Perfectly planed strips, precise 60° angle. The inner apexes are **not** planed (or sanded) off. The result is seen: the two horizontal strips (left and right) overlap each other, wedging the top-left one outwards, hence a thicker glue line. The whole center is disturbed, with uneven glue lines as another result. The outside geometry of this rod will be asymmetrical, with the three pairs of flats producing different values when measured. Resorcinol glue, undiluted.
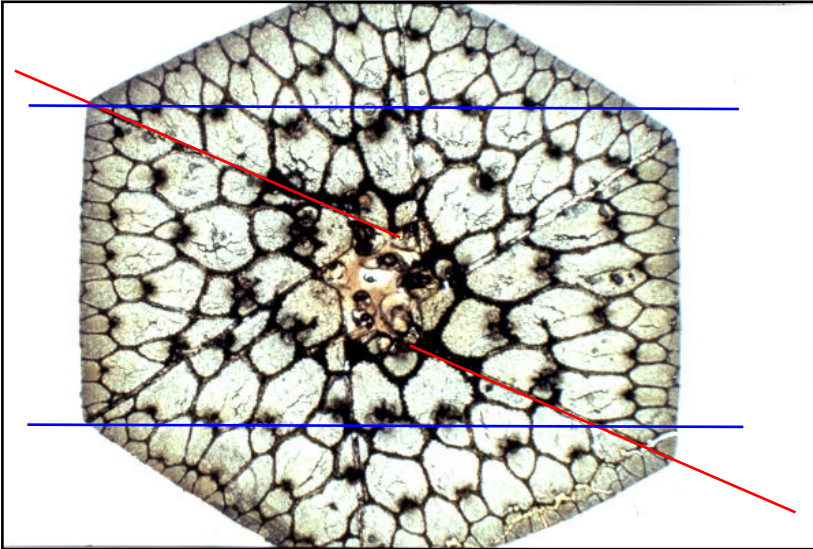
Fig. 19
Long side of picture: 6.6 mm (0.26 in)
A unique rod, hand planed. Six sided, but not really hexagonal (see blue lines). All six strips are off-shape (no equilateral triangle) by the same amount/angle. How this could be made, repeatedly and with some great degree of precision, I do not know. Maybe the planing form was made this way; more likely, the maker held the plane at an angle, not parallel to the surface of the planing form, with a locked wrist....
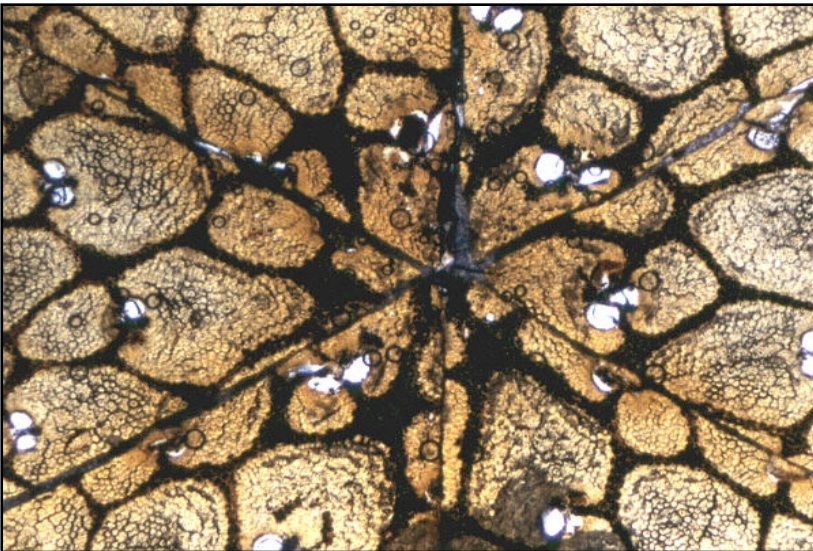

Fig. 20
Long side of picture: 3.2 mm (0.126 in)
Center of a milled rod. Perfect 60° angles, very thin glue lines. The cutters of the mill were bearing pretty hard on the bamboo, or they needed resharpening badly, or they had a wrong cutting edge geometry: Along the inner (milled) surfaces, the cane has been burned to a rather brown colour, due to friction. Very sharp and pointed apexes.

This "scorching" of milled strips along their inner surfaces is frequently observed.
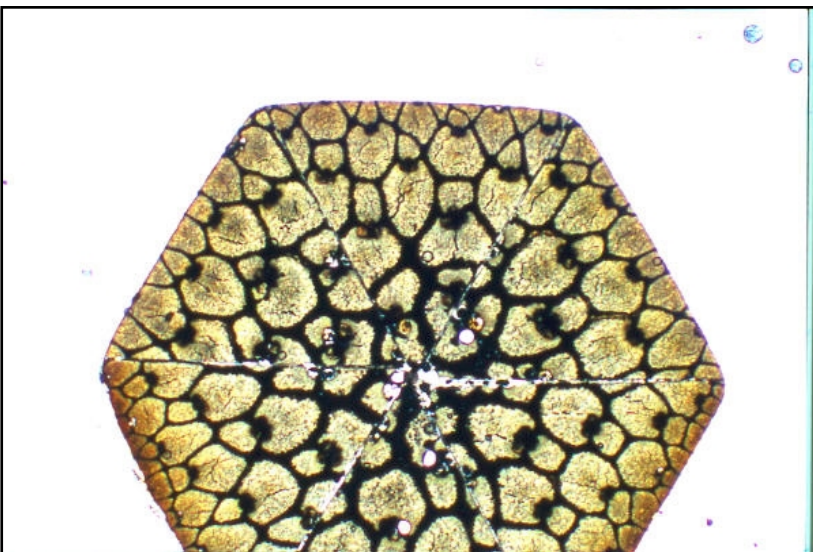
Fig. 21
Long side of picture: 6.6 mm (0.26 in)
Cross section through tip section of a hand planed rod. The inner apexes could have been removed. This is a flamed rod. The outer, or surface, areas of the strips are brown (to the naked eye really dark brown). This is best seen at bottom left and right strips. The high temperature of the flame reaches approx. 0.3 – 0.5 mm (0.012 – 0.019 in) deep into the bamboo. This means for the last 5 or 10 inches or so of the tip that most or the entire tip diameter has been scorched, making it brittle.
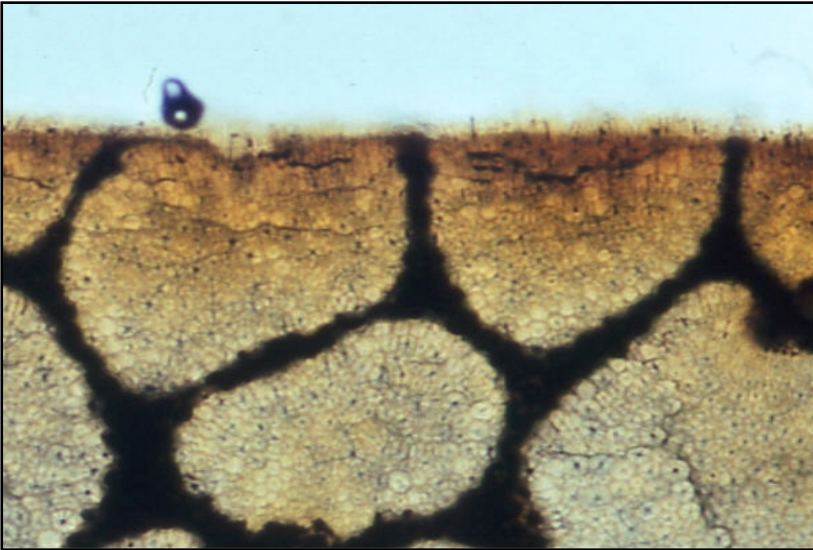See Figs. 11 – 13.

Fig. 22
Long side of picture: 0.41 mm (0.016 in)
Detailed view from above rod, Fig. 21. Under strong magnification, shrinking-cracks can be observed in the outermost vascular bundles. They run parallel to the surface. The largest cracks right under the surface, where heat was strongest, thinner ones deeper down. The individual cells begin to separate from each other, shear strength is reduced, and it is liable to break. And this is precisely why I got this rod in the first place. It had been stressed and the surface fibers had split into what looked like small brushes in several places.
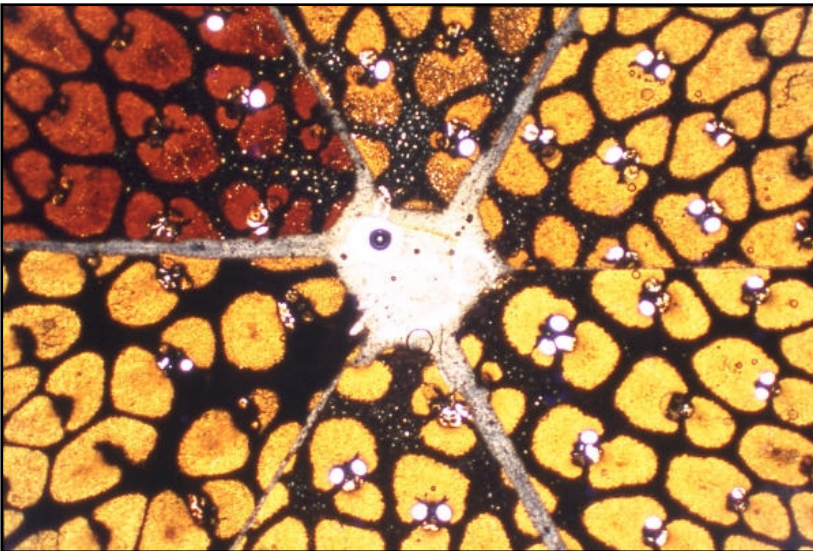
Fig. 23
Long side of picture: 6.6 mm (0.26 in)
Rod center, about middle of butt. This is an impregnated rod, milled. Three different colours can be distinguished. Top left: dark brown. Top, top right and bottom left: medium brown/orange. Bottom and bottom right: dark yellow. This indicates three different batches of strips, each treated separately with somewhat variable results. Center angle 62 degrees, apexes trimmed off. Glue lines near center 0.3 – 0.6 mm (0.0118 - 0.0236 in) wide. Rather coarse vascular bundles, with much parenchyma in between.
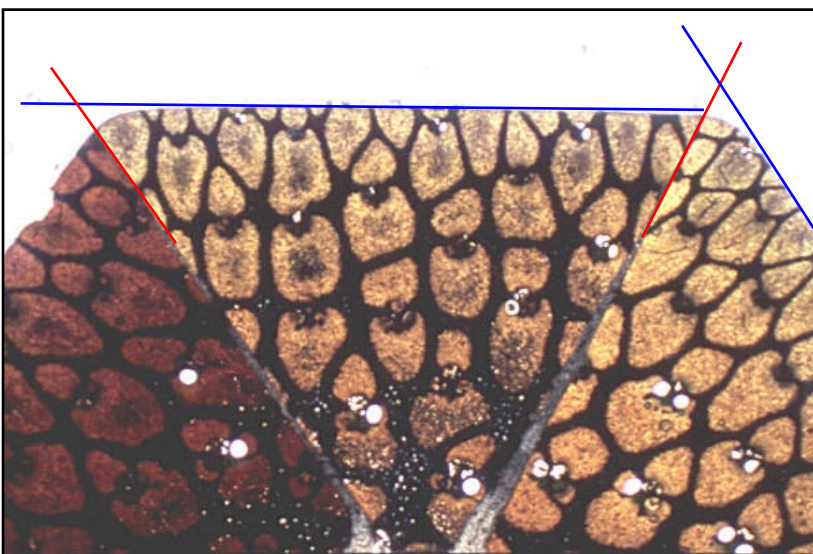

Fig. 24
Long side of picture: 6.6 mm (0.26 in)
Same rod as Fig. 23, top half. Surfaces have been sanded flat and polished, corners rounded. Glue lines not ending at the corners (see red lines). The vascular bundles are rather large near the outside of the rod, indicating that a good deal of the best material has been removed. Compare with Fig. 1 or Fig. 2. The rod appears much darker to the naked eye than the sections might suggest. The strip at top left is almost black, the others dark brown.
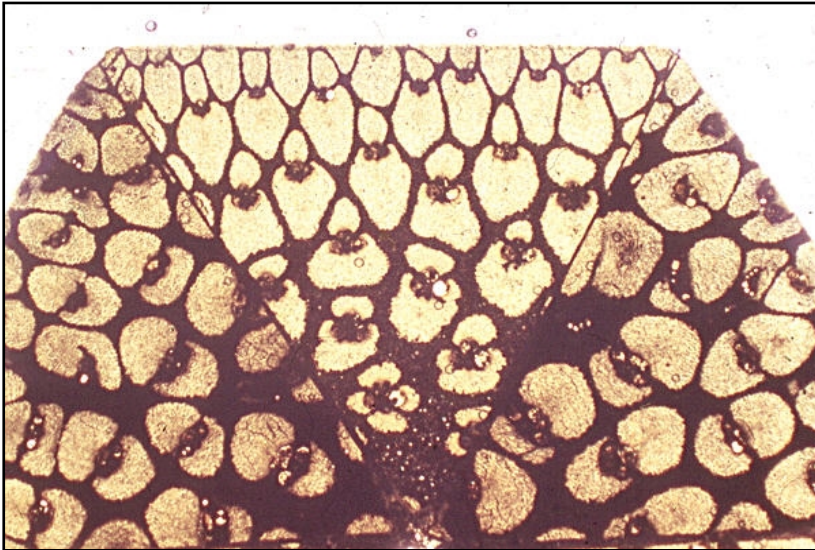
**Fig. 25**

Long side of picture: 6.6 mm (0.26 in)
Cross section through butt piece. Milled rod, 60° center angle. This had also the surfaces sanded flat, the glue line at left top is a little off the corner. The two left and right strips are cut through nodes (a 3-and-3 configuration). In the nodes, the vascular bundles are generally coarser, with much parenchyma cells in between. So, if the protruding "hump" of the node is sanded off (not pressed down) to provide for a flat milling surface, one is left with inferior material. As often as not rods break just at these weak node stations, especially at tips.
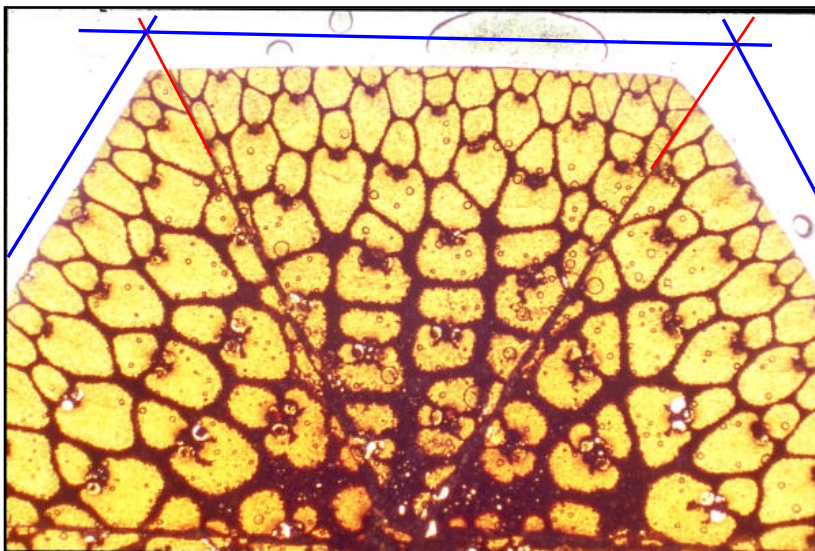
Fig. 26

Long side of picture: 6.6 mm (0.26 in)
Cross section through butt piece. Milled rod, 60.5 degrees center angle. Another example of rather heavy surface sanding. I have attempted to reconstruct the original outlines by lengthening the glue lines (red) and adding the possible original surface (blue). Compare the last three pictures with respect to geometry, and size/distribution/density of vascular bundles with Fig. 27.
Some larger trapped air-bubbles at top, and many tiny ones within the rod section.
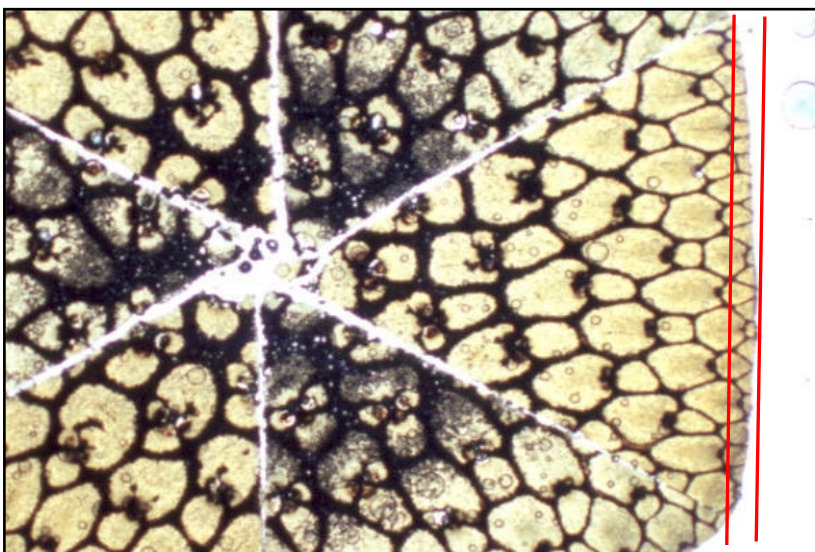

Fig. 27

Long side of picture: 6.6 mm (0.26 in)
Cross section through butt piece. The strips are milled with 61.5° angle. During glue-up in the binding machine the strips had room enough to rotate a little (clockwise), but they are still symmetrical around the center. Black: three rather bad strips, with inner vascular bundles being destroyed (possibly the result of fungus attack). The outer surface follows the culm-curvature. Had it been sanded or scraped flat, this would have removed a considerable amount of bamboo: 0.25 mm (0.01 in), see red lines. This problem is discussed in "Garrison", page 76.

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Remark: Comparing Figs. 24, 25, 26 with Fig. 27, I would rather want to take off the enamel with sandpaper, carefully following the natural curvature of the culm. A true hexagonal shape, with perfectly flat outer surfaces and knife-sharp corners might look very "professional". However, it will also sacrifice a good deal of the most valuable outer powerfibers, especially in butts. Using hand-scrapers or the ubiquitous Stanley 212 scraper carelessly is liable to shave off not only the very thin skin, but also to dig into the topmost vascular bundles rather quickly. Using sandpaper one can actually watch the "uncovering" of the fibers through the "under enamel". Another negative aspect of sharp corners is shown further down, in the chapter on varnish.

In rod making literature, the importance of a 60° center angle is often stressed, with arguments like: Anything over 60° only makes for thicker glue lines in the center, and glue will contribute nothing to strength. A larger than 60° angle will invariably produce invisibly thin glue lines at the corners, and this is only disguising faulty workmanship, and is nothing but cosmetic. And so forth.

Here are three possible configurations of 62° strips:

Fig. 28
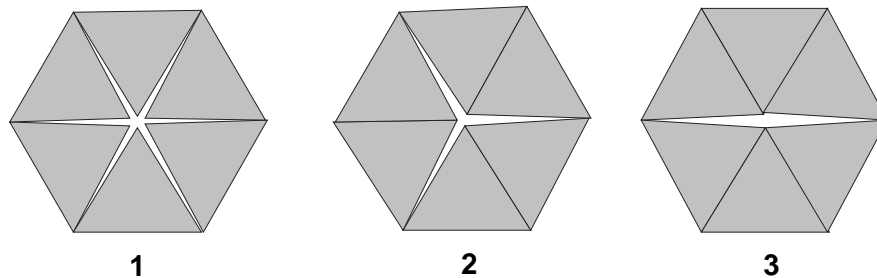
No. 1 is the most symmetrical one, and all pairs of flats are parallel to each other. No. 2 is also symmetrical around the center, but the three pairs of flats are not parallel to each other. No. 3 is symmetrical to a horizontal plane only, not to the center.

Fig. 27 is an example of No.1, and Fig. 23 is an example of No. 2. I have never observed No. 3.

Fig. 29
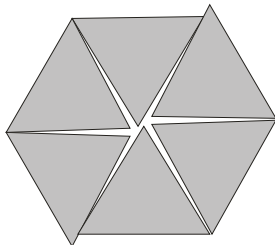
This is another, quite frequently seen, misplacement of strips under gluing. Two "halves" of a rod section have slipped along a glue line. This happens quite easily with strips of 60° center angle. The rod maker, anxious to get the rod section glued up before the glue begins to set and the rod full of glue and binding string, seldom realizes what has happened. After carefully cleaning the blank, he measures different values over the three pairs of flats, questioning his ability ...

Fig. 30
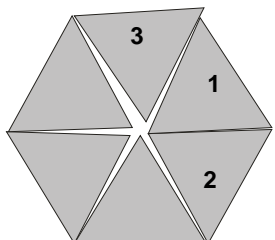
In this drawing, I have rotated triangle No.1 counter clockwise to close the gap to its bottom neighbour, No. 2. The top triangle, No. 3, is wedged outwards one way or the other. This may happen, when the torque applied by the binding-thread is too high on the first run through the binder (one-thread, or Garrison-type binder). However, it also happens with 2- or 4-thread binders. The strip will jam in this position, and the forces applied by the second run through the binder in the reverse direction, though often higher than the first, will not rectify this. After the glue has cured, the rod maker is left with one corner protruding outwards, over the flats. This is also seldom seen, the glued up blank being covered with both string and glue. Cleaning the surfaces, he will sand off this protruding corner, unaware of what has happened. This can, and does, happen with several or even all, strips at a time and sometimes even with hand planed, and milled strips, with 60° angles, see below. Such asymmetric cross sections may be one reason for a "weak" or a "strong" side in a rod.

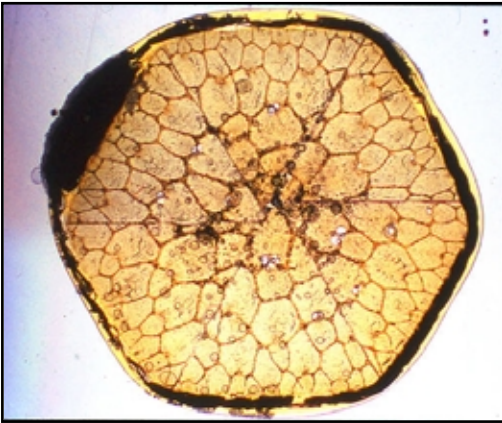Here are two examples of the above described phenomena.

Fig. 31
Cross section of milled rod, tip section. Flat-to-flat dimensions of bamboo 4.0 mm (0.157 in). Center angle 60°. Very thin glue lines. A cross cut through a guide winding (black thread). Guide foot at top left flat. A hand varnished rod.
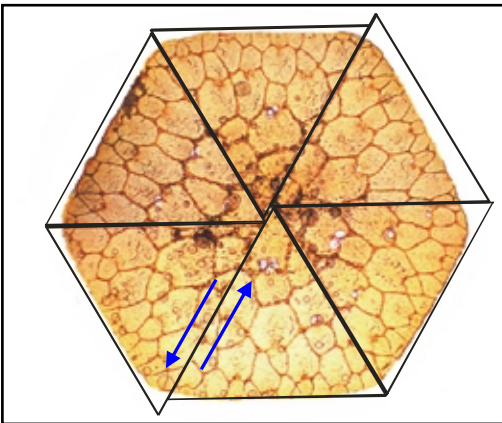

Fig. 32
Using Adobe Photoshop, I have removed the black threads of the guide winding in Fig. 31, plus the guide foot and the varnish. With Coral DRAW, I have constructed six equilateral triangles (with 60° angles) and of equal size. These are placed over the six strips of the rod section. The bottom strip determined the size (height) of the triangles The result shows the probable original outline of the glued-up strips, provided nothing has been removed from the flat of the bottom strip. It also shows that the two "halves" of the rod section have moved along a glue line in opposite directions, by approximately 0.2 mm (0.008 in). See blue arrows. Sanding off the glue and some powerfibers (most on top right strip), possibly followed by polishing with steel wool (well-rounded corners) prior to varnishing has rectified this mishap ...

Fig. 33
Cross section of milled rod tip. Heavily sanded flats and corners, the rod is more round than hexagonal. Flat-to-flat dimensions of bamboo somewhere between 1.6 and 1.9 mm (0.063 and 0.075 in). Sample prepared through an intermediate winding. The drawn-under ends of the thread located on top right flat. The strips are rotated counter clock-wise around the center.
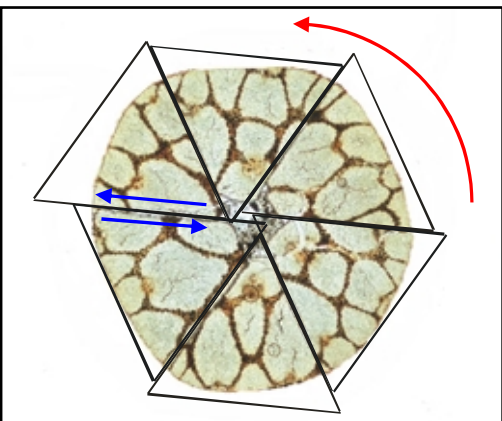

Fig. 34
Again, I have removed the red threads of the intermediate winding. Six equilateral triangles of equal size are placed over the six strips of the rod section. The bottom-left strip determined the size (height) of the triangles. The result shows the probable (minimum) original outline of the glued-up strips, provided nothing has been removed from the flat of the bottom-left strip. It also shows the rotation of the strips, the arrow indicating the direction of the binding thread on the first run through the binder. In addition, a displacement has happened, moving two halves of the rod in opposite directions along a glue line. See blue arrows. The rotation/lateral movement and hence the corners protruding over the flats are the result of too much torque first time through the binder with this delicate tip.
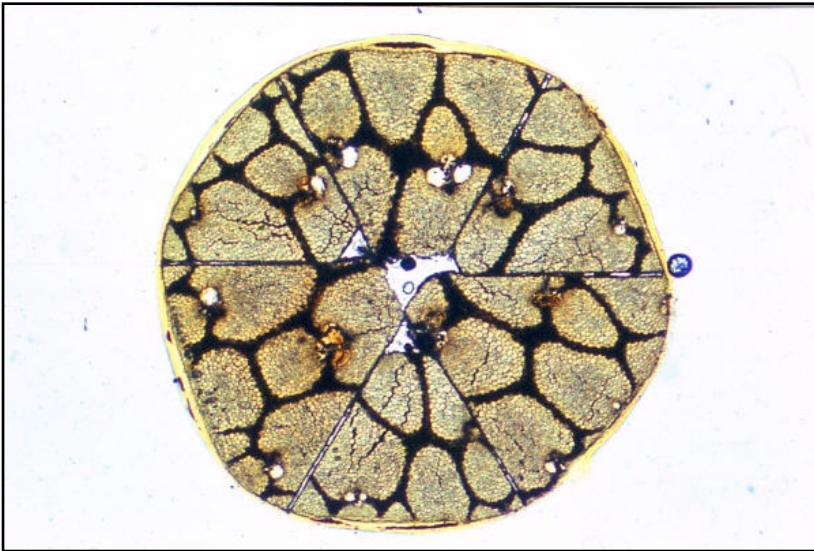
Fig. 35
Long side of picture: 3.2 mm (0.126 in)
A cross section through the tip of a milled rod. Flat-to-flat dimensions approximately 1.9 mm (0.075 in). Center angles 60 degrees, apexes trimmed. All six flats sanded to various degrees, corners rounded. Why every other strip is deeper than its neighbour, I do not know. Maybe it is intended, maybe just an accidental mismatch, with three strips taken, as a mistake, from the "wrong heap". This is a 3-and-3 strip, and node, rod. Thin varnish (yellow), mostly on the flats, and very little on the corners.
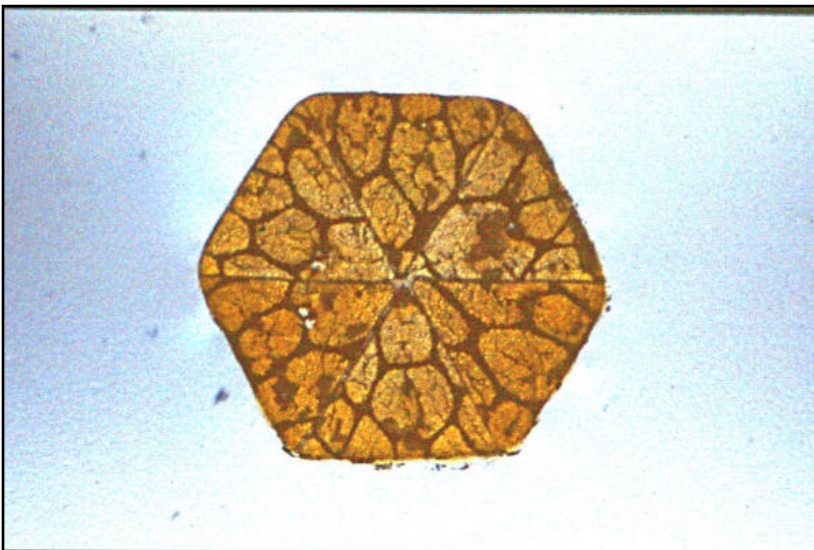
Fig. 36
Long side of picture: 3.2 mm (0.126 in)
Cross-section through leeway cut-off from the tip of a 7' # 3 rod, milled. Flat-to-flat dimensions 1.46 mm (0.0574 in), very symmetrical. A three-and-three strip configuration (3 taken from one culm, and 3 from another). The top, bottom-left and bottom-right strips have a darker colour than the remaining other three. Not a very sharp photo, but I included it to demonstrate perfect milling and gluing, even down to such delicate dimensions. Hand planing can achieve the same precision, of course, and usually does so. However, mind your vascular bundles. There are not many left in such a tip.
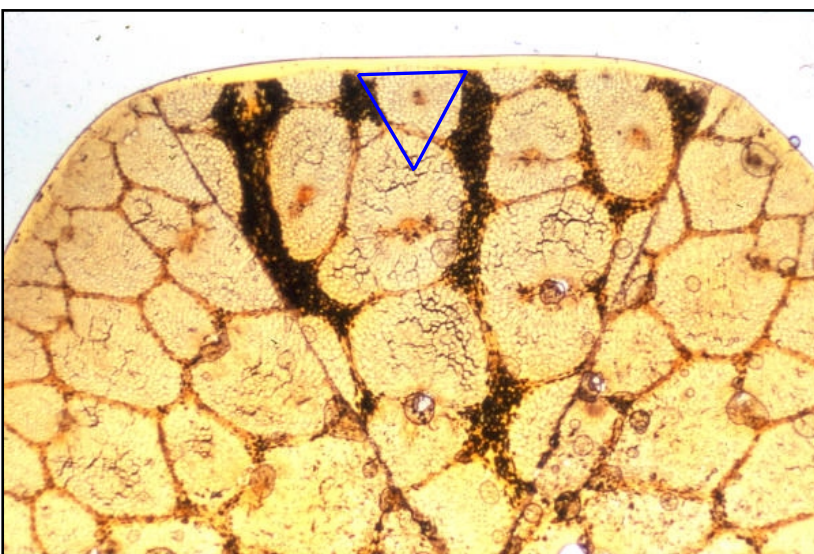

Fig. 37
Long side of picture: 6.6 mm (0.26 in)
Cross section through milled rod, 60°, varnished, and cut through node. Few and large vascular bundles, with much parenchyma; compare with the two other strips.
In blue, to scale, a triangle of 0.7 mm (0.027 in) depth (cf. Fig. 36). It may contain next to no, or one half, or even one whole, vascular bundle of inferior quality (cf. Figs. 1, 5 and 6). Three such nodes in one position will produce a very weak area indeed. I have seen several rods that broke, within the last 10 to 15 inches or so, of the tip, in such node stations.
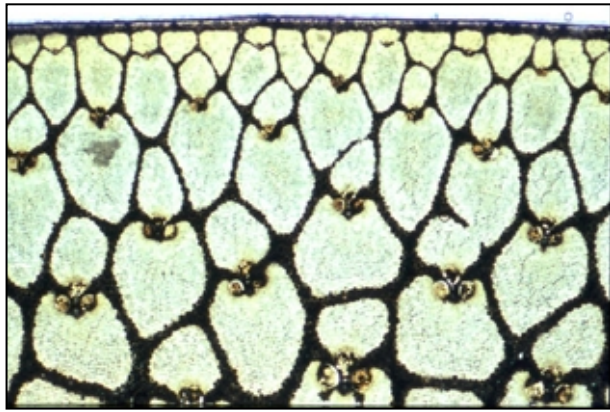
16

Fig. 38
Long side of picture: 3.2 mm (0.126 in)
A cross section through the outer third or so of a culm. Skin on top of picture. This is an average culm, and the area of this picture contains 75 % vascular bundles, or "powerfibers", and 25 % parenchyma, or "pith".

The amount and size of vascular bundles in finished rods can, and does, change considerably, depending on the care the strips have received. This affects the strength of the rod, of course.
Below a few examples. All to the same scale, for easy comparison.
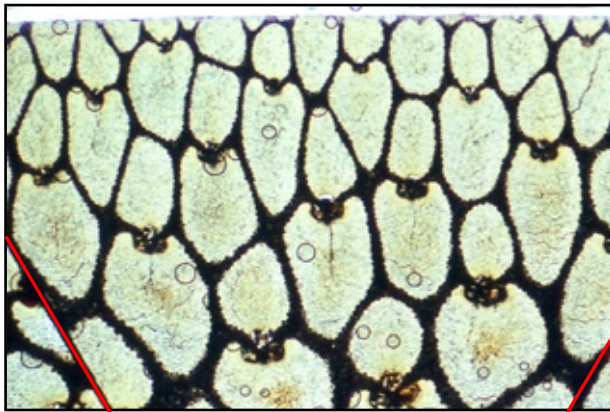
Fig. 39
Long side of picture: 3.2 mm (0.126 in)
One strip of a hand planed rod. The glue lines are indicated in red near bottom left and right corner. On top of picture, the surface of the strip. (In all 3 Figs. 39-41). An ever so slight rounding is seen, following the natural curvature of the culm. Little more than the skin has been removed. Compare size and distribution of vascular bundles with Fig 34. This (whole) strip has 74 % "powerfibers" and 26 % "pith".
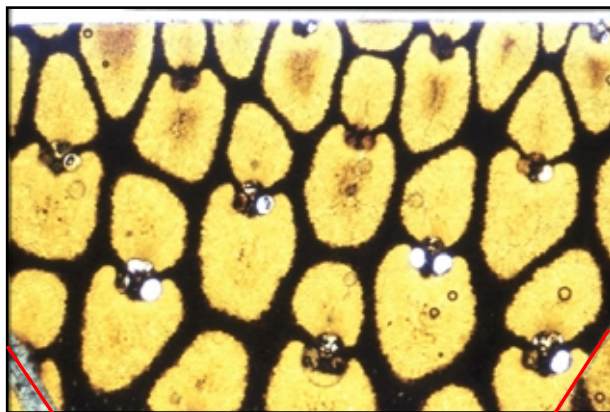

Fig. 40
Long side of picture: 3.2 mm (0.126 in)
One strip of a milled rod. Surface (top of picture) heavily sanded or scraped. The vascular bundles are large/coarse and their original position in the culm has been rather deep below the surface. White circles are mayor vessels, the sort that is seen in the inner (left) half of Fig. 1. This strip has 64 % "powerfibers" and 36 % "pith".
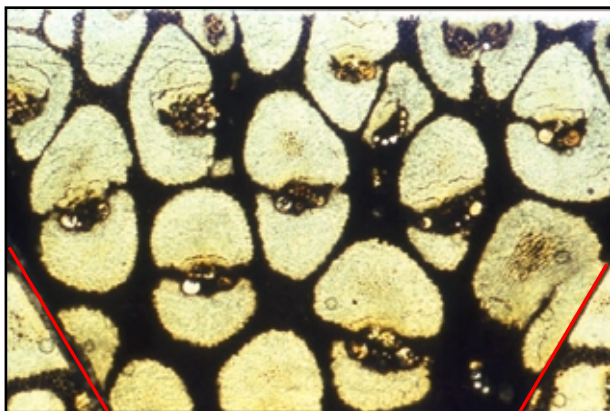
A close up of Fig. 24

Fig. 41
Long side of picture: 3.2 mm (0.126 in)
One strip of a node, milled rod. Surface heavily sanded. Very coarse vascular bundles, typical for nodes. Node not pressed, but sanded flat. Only 60 % "powerfibers", and 40 % "pith" in this strip.

A close up of Fig. 25

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Measuring the amount of "powerfibers", or vascular bundles, in various rod cross sections made by different makers, a number of data were obtained. The following eight samples were all taken from about midpoint (near ferrules) of rods. They are quite representative.

1: 64 % (milled, one strip)	5: 73 % (milled, 3 strips)
2: 65 % (milled, one strip)	6: 72 % (milled, 6 strips)
3: 60 % (milled, one strip, node)	7: 74 % (hand planed, 3 strips)
4: 65 % (milled, 3 strips)	8: 75 % (hand planed, 3 strips)

The result shows that milled rods usually have a lower amount of powerfibers, as compared to hand planed ones. This is mainly due to sanding or scraping the flats, cleaning them from glue and taking off the rind, often with power equipment. It also shows that it is quite possible to make good rods with milling machines (and here I mean the proper choice and processing of material). No. 5 and 6 are excellent examples. However, good hand planing and careful removing of the skin seems to be superior.

The amount of powerfibers in tips will usually be a little higher (as high as 78-80 % in hand planed rods), depending also, on the quality of the culm. Thin-walled culms, which often have many small and very densely packed vascular bundles with very little basic tissue, or parenchyma cells, can with advantage be used for tips, and for hollow built rods.

All larger manufacturers (the professionals) of bamboo rods had and have to use power equipment like mills to speed up the process of rod making. Some sand off the skin together with protruding nodes to provide for a flat surface prior to milling. Others use belt sanders to remove glue, string and skin after gluing, and possibly a good deal of the most valuable outer powerfibers along with it. Shown below are two such examples.
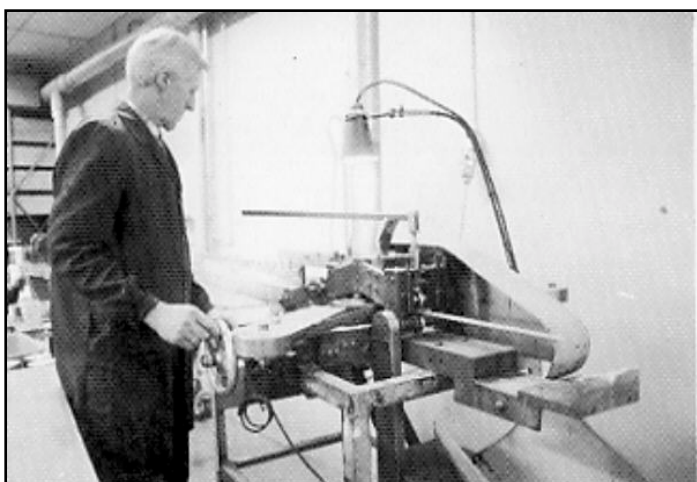

Fig. 42
Two opposing sides of a glued up rod section are simultaneously cleaned with double belt sanders. Both skin, glue and binding thread are taken off. The hand wheel controls the "gap" between the two belts, while the rod passes through, moved by a transport mechanism. Much skill is needed to follow the taper, repeatedly in three successive runs, especially with tips ...

I have seen this machine in operation in 1984.

Fig. 43
Another belt sander in action,
cleaning the surfaces of a rod blank.

Gluing

The following three pictures show samples from three different rod makers. With one of them, I have carried out some experiments. He had used a number of differently diluted (with alcohol) batches of resorcinol, gluing up short rod sections with it. I made the thin sections (and photos) and reported the results to him. The purpose was to find out the optimum mixture. Fig. 46 is from this series.

Nutshell-powder, which is part of the 2-component glue and which carries the reacting compound, formaldehyde, can be substituted with formaldehyde solution. I have used, with good results, formaldehyde solution 37 % by weight, stabilized with ca. 10 % methanol. It can be further diluted with alcohol. A few percent of this solution are enough to set the glue. Nutshell grains, although sieved, can prevent the strips from achieving a really close contact. With liquid only, the glue lines are next to invisible on the finished rod.
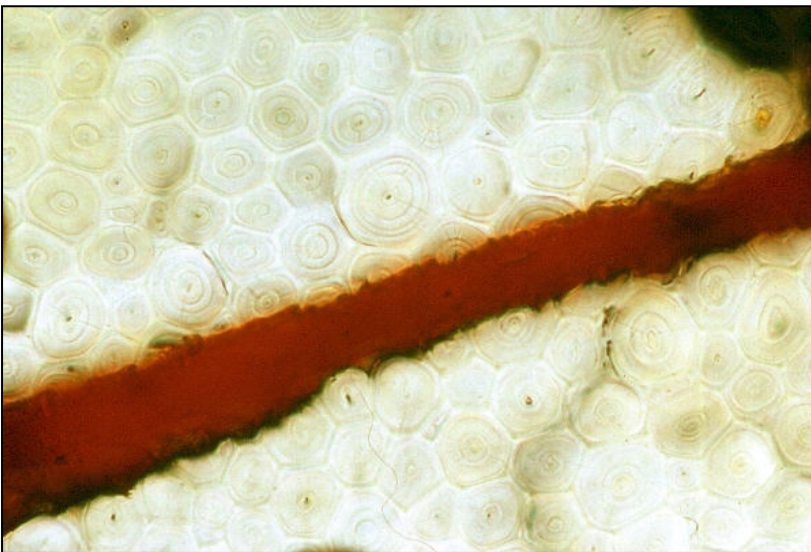

Fig. 44
Long side of picture: 0.23 mm (0.009 in)
A glue-line under high magnification. The fibers (cells), which have a diameter of . 0.01 mm (0.0004 in) to 0.02 mm (0.0008 in), are cut lengthwise, halving many. This needs a sharp iron. Resorcinol glue is used here, undiluted. Thickness of glue-line is approximately 0.02 mm (0.0008 in). The glue has not penetrated into the fibers.
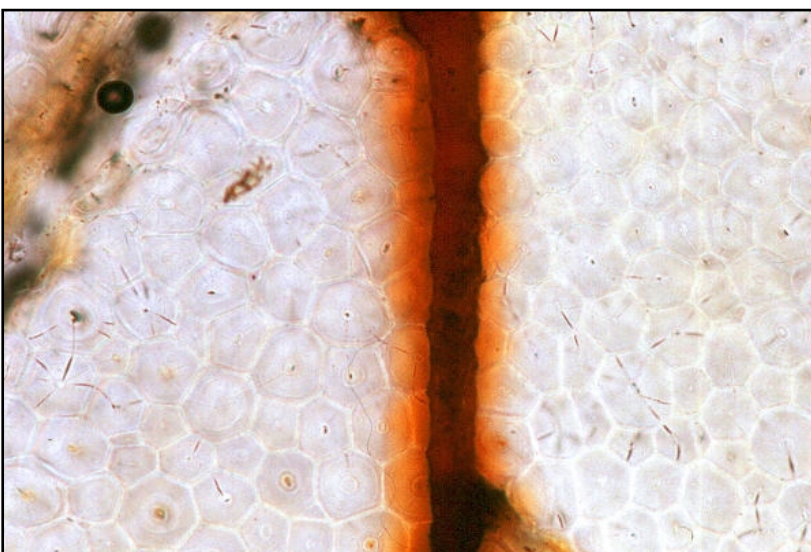

Fig. 45
Long side of picture: 0.23 mm (0.009 in)
Moderately diluted resorcinol glue. This has penetrated into the fibers, giving a better hold for the glue. Thickness of glue-line 0.01 mm (0.0004 in). About an equal penetration into the fibers has taken place.

In "Garrison", page 88 is written:
" ...he added more alcohol to the mixture so that the glue would better penetrate (as often as deep as .012") the hard primary fibers of the bamboo strips."

Such a penetration-depth has never been observed. It would fill the picture with red colour. 0.012 in = 0.305 mm.
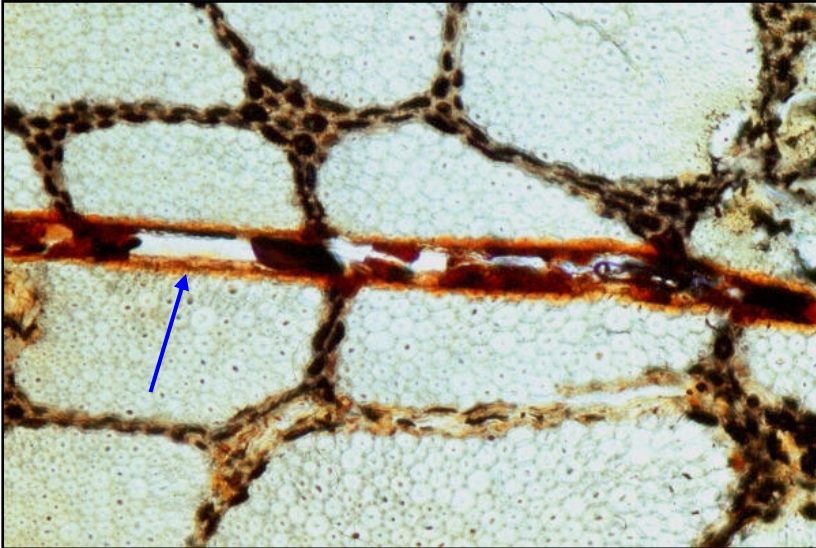
Fig. 46

Long side of picture: 1.3 mm (0.051 in)
Strongly diluted resorcinol glue. This has not really penetrated any deeper, either. However, it has left open voids, the alcohol having evaporated. Small lumps and crusts of cured glue sit in some places on either side of the joint. Red seams in the fibers (blue arrow) indicate that there once had been glue. Nutshell grains from the glue seem to have prevented a closer fit of the strips, hence a slightly broader glue line (0.05 mm = 0.002 in). Such a defect glue joint is liable to delaminate eventually, since shear-forces cannot be adequately distributed to the bamboo.
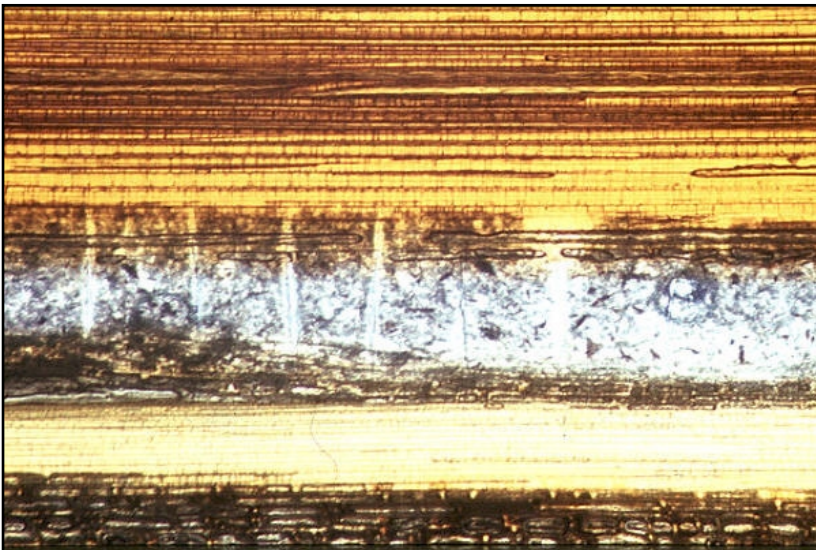

Fig. 47

Long side of picture: 1.3 mm (0.051 in)
A glue joint prepared parallel to the axis of the rod. Numerous cracks can be seen at short distances from each other. Maybe these developed as shrinking cracks during the curing of the glue (I think it is a melamin-based glue, but I am not sure). Maybe, also, they are the result of the rod's bending back and forth thousands of times, the glue being too brittle to withstand it.
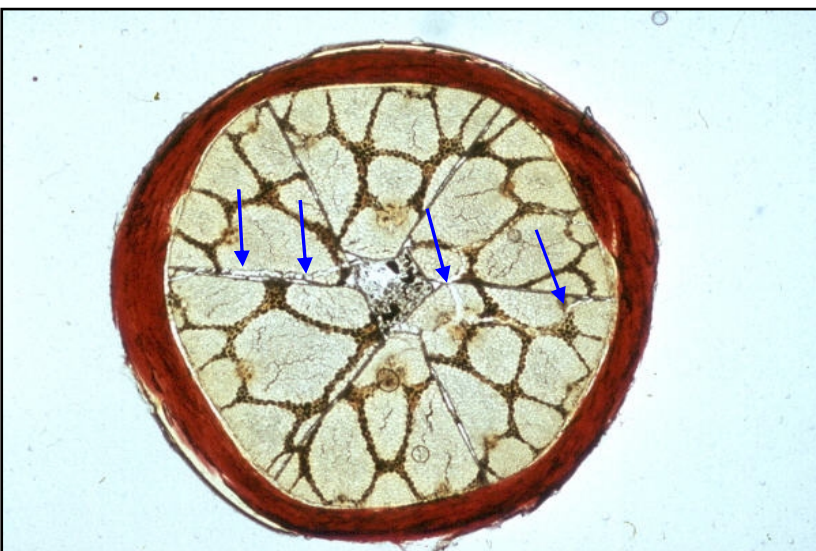

Fig. 48

Long side of picture: 3.2 mm (0.126 in)
Cross section of milled rod tip. Heavily sanded flats and corners, the rod is more round than hexagonal. Flat-to-flat dimensions of bamboo somewhere between 1.6 and 1.9 mm (0.063 and 0.075 in). Sample prepared through an intermediate winding. The drawn-under ends of the thread located on top right flat. The strips are rotated counter clock-wise around the center. This rod had broken lengthwise in two halves over a distance of some 20 cm, or ¾ foot, and was factory repaired (reglued), see arrows. Same photo as Fig. 33.
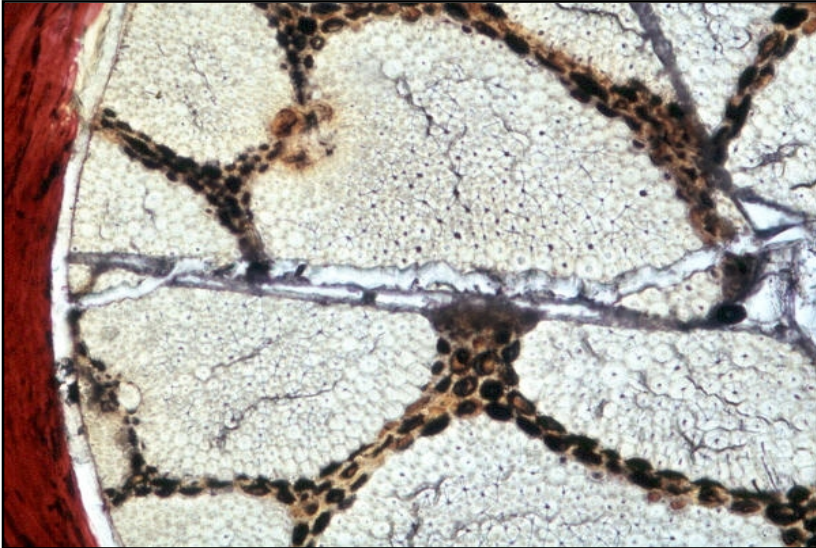
Fig. 49

Long side of picture: 0.84 mm (0.033 in)
Photo taken from the left side of Fig. 48, stronger magnification. The break went partly through bamboo (vascular bundles, or "powerfibers"), partly along the initial glue line, continued through the center of the rod (cf. Fig. 48) and again through and along borders of vascular bundles, through parenchyma cells.

Also note the layer of varnish (white) between bamboo surface and red thread at left: the rod blank has been varnished prior to winding of both guides and intermediates.
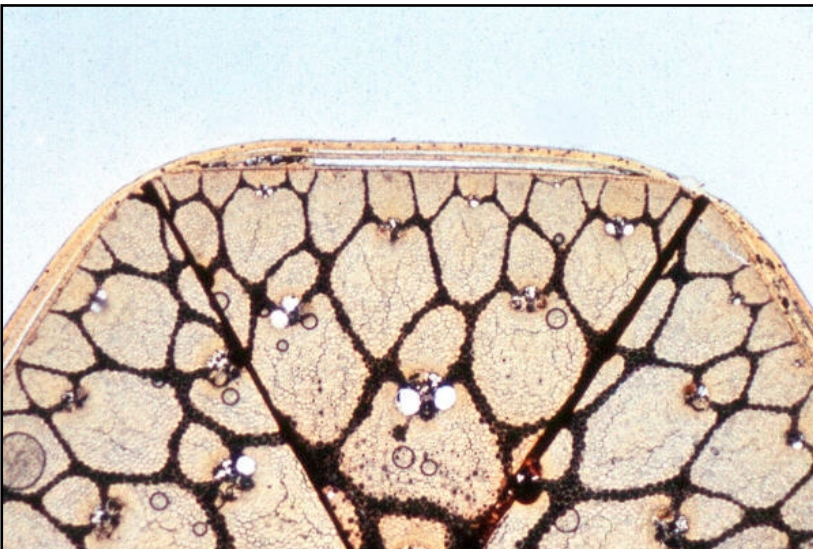
Varnishing

Fig. 50

Long side of picture: 6.6 mm (0.26 in)
Cross section of a hand planed rod. Flats are scraped/sanded flat, corners rounded. Resorcinol glue. The rod is dip-varnished three times, using an alkyd-type varnish containing polyurethane, (information given from the maker). The layers have separated, best seen at top flat. Possibly the prescribed open-time of the varnish (waiting-time between two successive coats) had been exceeded.
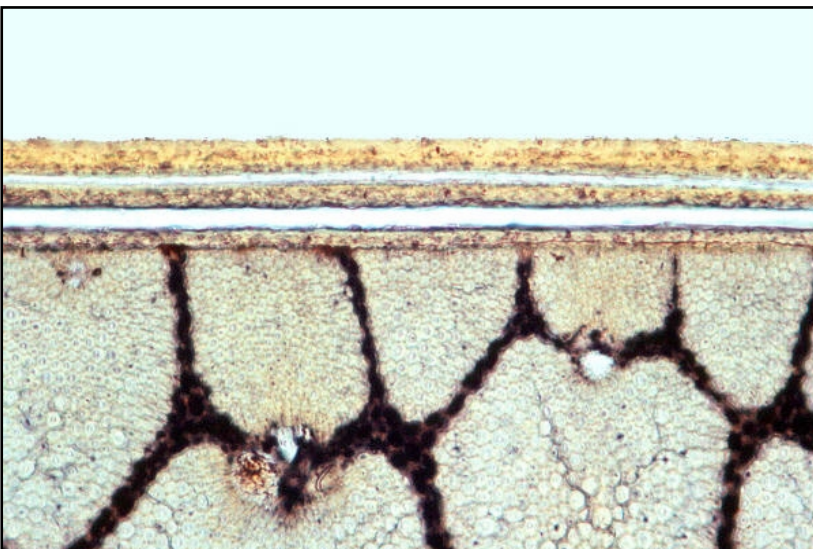

Fig. 51

Long side of picture: 0.8 mm (0.031 in)
A closer look. The first layer of varnish adheres to the rod (bamboo), but not the successive two. From top to bottom, I have measured:

0.042 mm = 0.00165 in varnish
0.007 mm = 0.00027 in air
0.026 mm = 0.00102 in varnish
0.023 mm = 0.00090 in air
0.017 mm = 0.00067 in varnish

Total: 0.115 mm = 0.00451 inches combined varnish+air in the middle of the flat. Three layers of varnish alone: 0.085 mm = 0.00334 in.
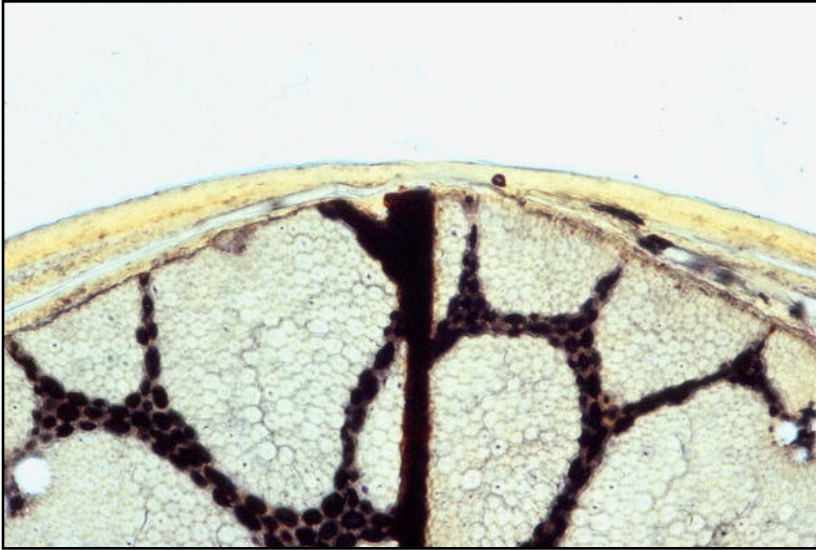
Fig. 52
Long side of picture: 0.8 mm (0.031 in)
A higher magnification of the top left corner of Fig. 50. In spite of three layers of varnish, the resulting thickness is only 0.018 mm (0.0007 in). The varnish has built up on the flats, due to surface tension. Another three dippings would have produced a round rod, without contributing considerably more varnish to the corners. And here the corners had been rounded! Had the corners been knife-sharp, even less (or no) varnish would have been deposited there.
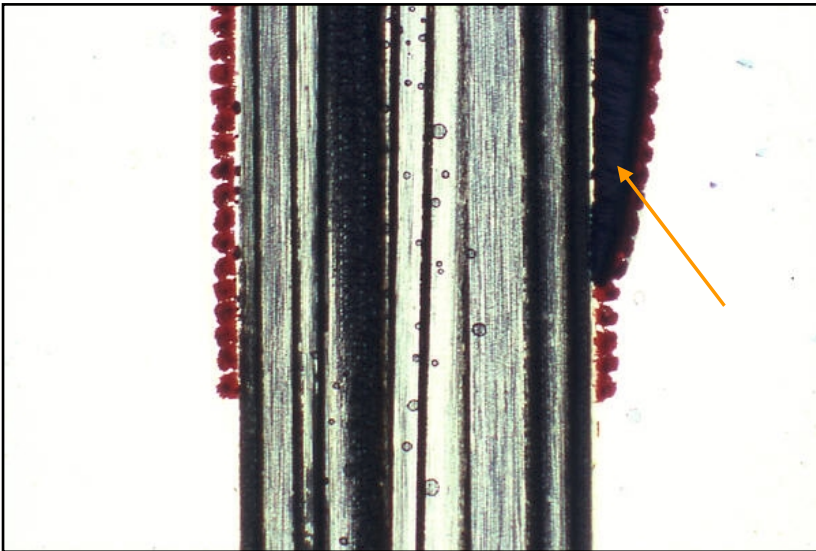In between the right side layers, some debris has been deposited during preparation of the sample.

Fig. 53
Long side of picture: 6.6 mm (0.26 in)
Longitudinal cut through a guide winding. The black guide foot is on the right side (steel, not transparent, of course, see arrow). Under the foot, a thin layer of varnish, also on the opposite side, under the red winding threads (nylon in this case). The varnish is not really visible in this picture, due to strong light having been used. Many trapped air bubbles along the center of the section.
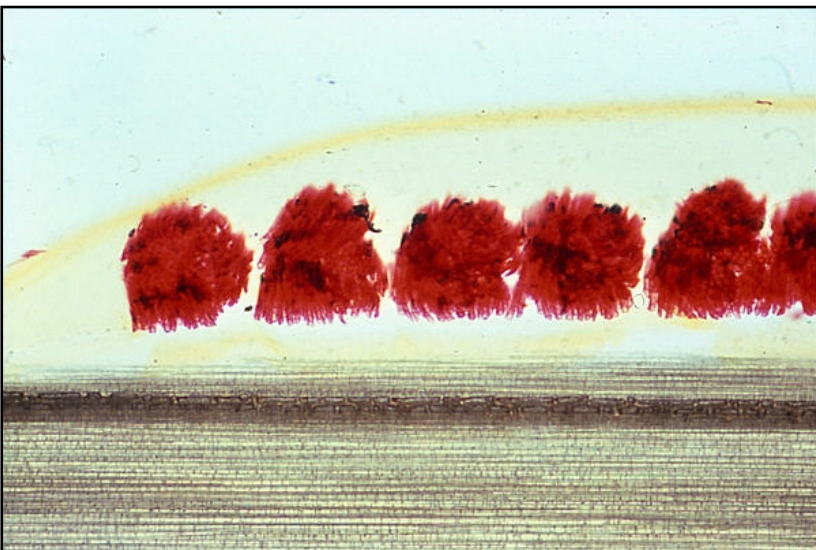

Fig. 54
Long side of picture: 1.3 mm (0.051 in)
Here the varnish becomes visible (partly crossed polarizer/analyzer in the microscope). Clearly visible a yellow layer of varnish under the threads, which appear to be floating above the surface of the bamboo, and varnish between and above the threads.

Fig. 55
Long side of picture: 0.32 mm (0.012 in)
Cross section through guide winding. The individual fibers of the thread are visible. Further four layers of varnish, with a good bond between each other. Bottom layer (1) belongs to the soaking of the windings prior to varnishing the whole rod. It has a slightly lighter colour. Maybe a different varnish was used for priming. The whole story is: 1. the blank has been varnished. 2. The guides have been wrapped on and soaked/filled with varnish. 3. The rod has been varnished three times (2, 3, 4). The topmost dark yellow line is due to light refraction between varnish and embedding epoxy and is an optical artifact.
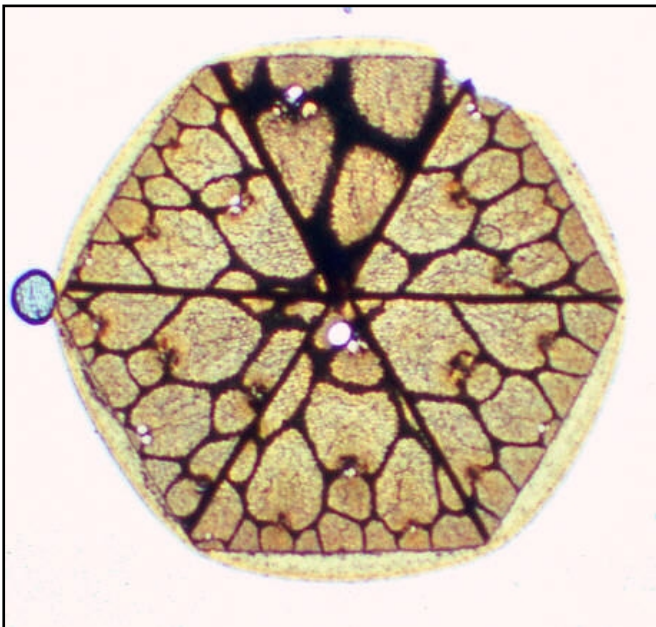

Fig. 56
Cross section through tip section of a hand planed rod, with Garrison-type node placement. Perfect 60° strips. Flat-to-flat dimensions of bamboo 2.82 mm (0.111 in). All three of them.

Cut through a node (top strip). Compare vascular bundles in node and in other five strips. The one weak node is well backed up by five sound strips. The advantage of such a node configuration (one at a time) over a 3-and-3 is obvious.

The rod is dip-varnished three times. Varnish has built up mainly on the flats, with 0.2 mm (0.008 in) in the centers, producing a perfectly round rod ... Very little varnish at the corners, due to surface tension of the varnish.

A small chip has broken off from the right top corner during preparation of the sample. Trapped air bubble at left.

Remark: " ... nodes are Job's gift to the rod maker." The importance of proper attention to nodes, especially in thinner, or tip, calibrations, cannot be emphasised enough. Both with respect to straightening/pressing, and to distribution and positioning within a rod section. Garrison knew what he was talking about.

Remember this last photo, too, when measuring the taper of a varnished rod in order to copy it. Two times 0.2 mm = 0.4 mm (0.016 in) varnish will add 14 % to the diameter of the bamboo blank, in this case. This is more than two line sizes. In addition, if you had measured a rod with the surfaces heavily sanded, like e.g. in Figs. 24-26, and thus some of the best material removed, and your copy is made with great care with respect to this, you might add another half line weight's worth of better "powerfibers", see Figs. 38-40.

And so ends my little journey into the inner life of Arundinaria amabilis, the rod maker's bamboo.

I hope the selection of photos presented above are able to give a deeper insight into bamboo and its fashioning into fly rods. It covers six sided rods only, solid built. Conclusions drawn from these photos can be applied to hollow built rods and rods of other than six sides (quads, pents, etc.). I also hope that rod makers, both amateurs and professionals, will have seen and learned something new about their craft.

I investigated many more points of interest and could have selected more pictures, and on other topics. Three are given in the pictures below.

- Left, a double built salmon rod of 15', cut through the handle, with cork still in place.
- Middle, a thin section of a rod called "Octavia" by its maker, of octagonal, or eight-sided, outer shape, and built of 16 strips.
- Right, a thin section of a Greenheart rod.

Fig. 57
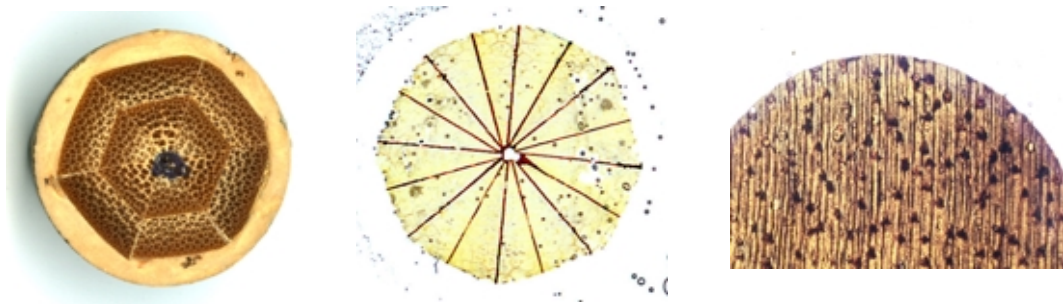
Finally, for the curious reader, a scan of five thin sections, as used for my investigations.
Size 28 x 48 mm (1.10 x 1.89 inches) each.

Fig. 58
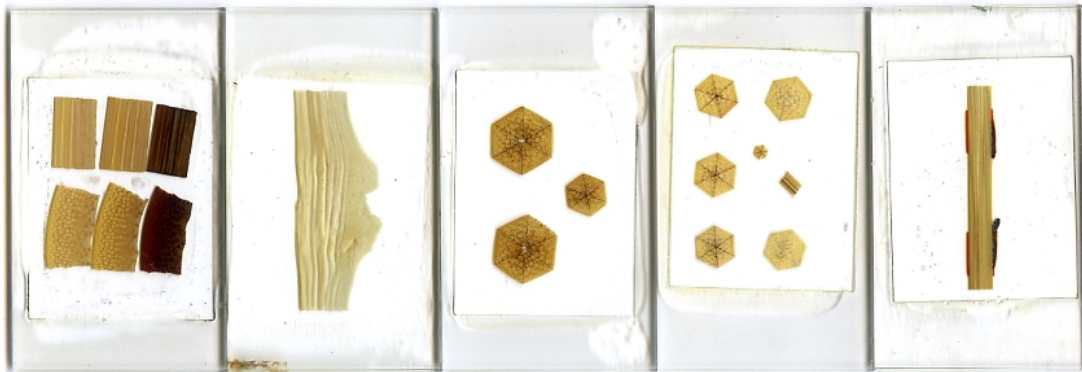
From left to right:

- Three bamboo samples from my heat-treating tests, in both longitudinal (top) and cross (bottom) cuts.
- Longitudinal cut through a node.
- Cross cuts through butt (2) and tip of the same rod.
- Five cross cuts through middle parts, and one cross plus one longitudinal cut through tip of a rod.
- Longitudinal cut through a guide station.