Microfibril Angle in Wood and its Biological Significance

Cedars, firs, larches, pines and spruces belong to the order Coniferales or softwoods, which are important as lumber and as raw material. Sugi, *Crypromeria japonica* is a unique genus, and is adapted so well to our climate that it has become one of the most planted species in Japanese forests.

Wood is a cellular composite that consists of many hollow fibrous cells primarily aligned parallel to the trunk or branch (Fig. 1). Cells are produced by cell division in the vascular cambium, a thin layer of cells located concentrically underneath the bark. The cambium produces bark towards the outside and wood towards the inside of the tree. In the temperate zone, the earlywood is formed in spring and the latewood formed at the end of the growing season. Thus the growth ring, an annual ring in this case, appears as a result of such cambial activity. Most of the cells remain as cell walls, which were once living tissue. Each cell wall is multi-layered, in which the cellulose microfibrils are encrusted by hemicellulose and lignin to achieve a so called fiber-reinforced structure.

Tracheids comprise 95% of cells in softwoods. The cell walls contain several sub-layers of cellulose microfibrils, variously oriented, and are divided into primary and secondary walls. Primary walls are formed during cell elongation, while secondary walls are formed subsequently. The microfibrils are highly ordered bundles of cellulose chains (the crystal modulus along fiber axis is greater than 100 GPa) that give strength and stiffness to the cell wall. The microfibrils in the middle layer of the secondary wall S_2 (approx. 80% of the thickness) form a right-handed spiral which makes an angle with the cell axis called the microfibril angle, MFA.

Obviously, the MFA has a strong correlation with wood quality as well as with the physicomechanical function of a tree. When a tree is young, it needs to be elastic in order to move in the wind. After some decades, however, the cells produced by mature trunk cambium have a smaller MFA for stiffness and for keeping the trunk upright. By contrast, branches have to be rather elastic, allowing them to bent with the weight of snow and shed it. Therefore, MFA needs to be larger. The MFA is thus critical to the total mechanical balance of the tree, and correct MFAs are essential for its survival.

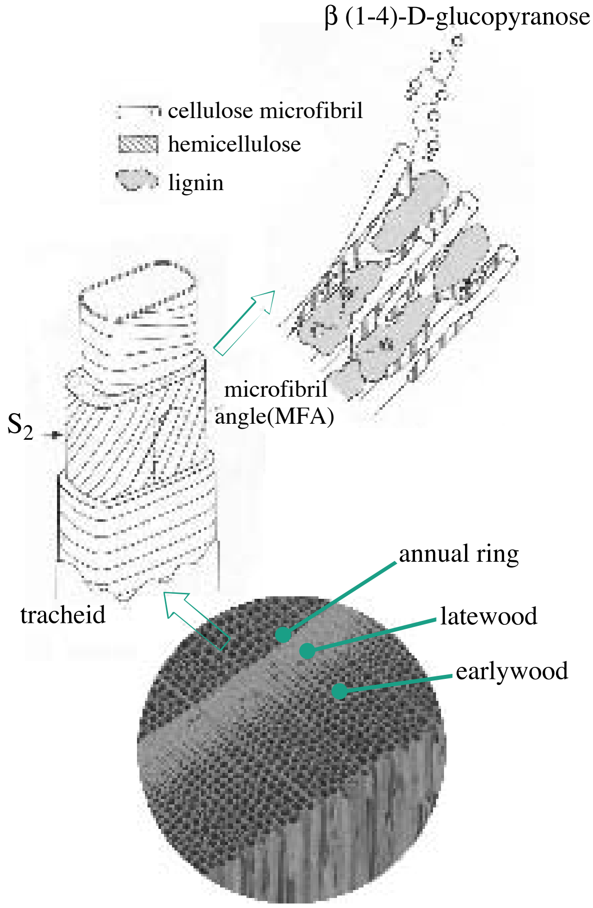

Fig. 1. Hierarchical strucuture of softwoods. From tissues to molecules. (SEM: courtesy of Dr. Fujii, FFPRI).

Traditional methods of MFA measurement based on optical microscopy, such as of the orientation of the cross-field pit apertures, or of the maximum extinction position using a polarizing microscope, demanded highly-skilled sample preparation and measurements on many samples to obtain reliable MFAs, and are thus time-consuming. In contrast, there are advantages in using X-ray diffraction techniques, which are sensitive to the dispersion of microfibril orientation. WAXS and SAXS are frequently used techniques, and in this study we performed SAXS experiments. The high flux of synchrotron radiation at beamline **BL40B2** enables us to obtain high-quality SAXS data in a short exposure, thus making large scale surveys of MFA practical.

The averaged MFAs and lateral diameters obtained form *C. japonica* are exemplified in Fig. 2 together with the corresponding SAXS patterns. The MFAs were generally found to be larger in the lower and basal parts of a branch, whereas the upper parts generally exhibited larger MFAs when the branch angle was altered. The radius of gyration, however, remained constant. Our goal is to visualize the optimization of MFAs in response to the actual mechanical demands on various parts of a tree, and the mapping of whole trunks, including those of some hardwoods, is also in progress.

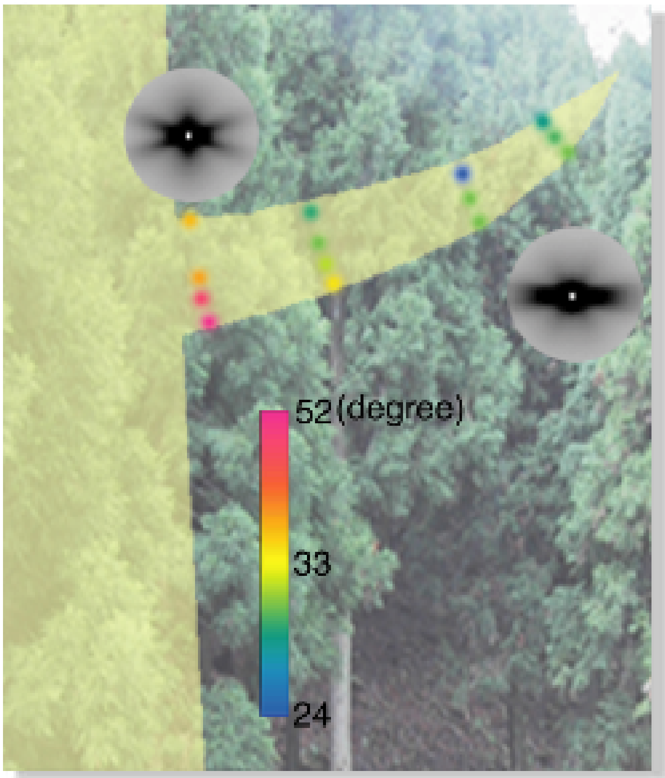

Fig. 2. Microfibril angles obtained from various portions of a branch in Sugi (C. japonica).

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