Method for Computing a Roughness Factor For Veneer Surfaces

CHUNG-YUN HSE

ABSTRACT. Equations for determining the roughness factor (ratio of true surface to apparent area) of rotary-cut veneer were derived from an assumed tracheid model. With data measured on southern pine veneers, the equations indicated that the roughness factor of latewood was near unity, whereas that of earlywood was about 2.

THE ROUGHNESS of a veneer surface affects the wettability of the surface and hence the gluability. Wenzel[1] defined roughness as

$$R = \frac{\text{True surface area}}{\text{Apparent surface area}} \qquad [1]$$

where the true area is the total exposed (or daylit) surface including all irregularities, and the apparent area is the area of the cut surface as projected to the cutting plane.

Thus defined, the factor R is a quantitative assessment of surface roughness. Wenzel then derived an equation showing the effect of R on contact angle, which in turn is strongly correlated with wettability.

Wenzel worked with non-wood surfaces. Other workers have devised ways of appraising the roughness of veneer, but none of the methods yield values that can be directly related to contact angle. The present paper develops a method of computing R for an assumed tracheid model, and illustrates the computation with measured data from southern pine veneer.

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[1]Wenzel, R. N. 1936. Resistance of solid surfaces to wetting by water. Ind. Eng. Chem. 28: 988-994.

The author is Wood Scientist, Forest Products Utilization Research, Southern Forest Experiment Station, USDA Forest Service, Pineville, La. This paper was received for publication in January 1971.

Derivation of Expression of Roughness Factor

Consider the profile of rotary-peeled veneer (Fig. 1). The true (daylit) surface is composed of lumen walls and cut cell walls. The relative areas of these two types of surfaces vary according to the manner in which the veneer knife severs the cells.

Figure 2A shows the simple situation commonly found in rotary-peeled latewood veneers[2] in which the knife has passed close to the intercellular layer and the surface is composed of cell walls only. If cell wall roughness resulting from deposits of physiological debris or microfibril damage is ignored, the roughness factor (R_1) of veneer comprised of these cells is unity, as follows:

$$R_1 = \frac{d_T}{d_T} = 1 \qquad [2]$$

where d_T = tangential tracheid diameter.

In earlywood veneers, however, the knife frequently cuts across lumens to expose a total surface comprised of cut radial cell walls, lumen surfaces of tangential walls, and lumen surfaces of radial walls. If the knife cuts through the radial walls as shown in Figure 2B, that portion of the surface comprised of cut radial cell walls, and lumen surfaces of tangential walls remains constant; but, as indicated in Figure 3, the

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[2]Leney, L. 1960. Mechanism of veneer formation at the cellular level. Mo. Agric. Exp. Stn. Res. Bull. 744, 111 p.
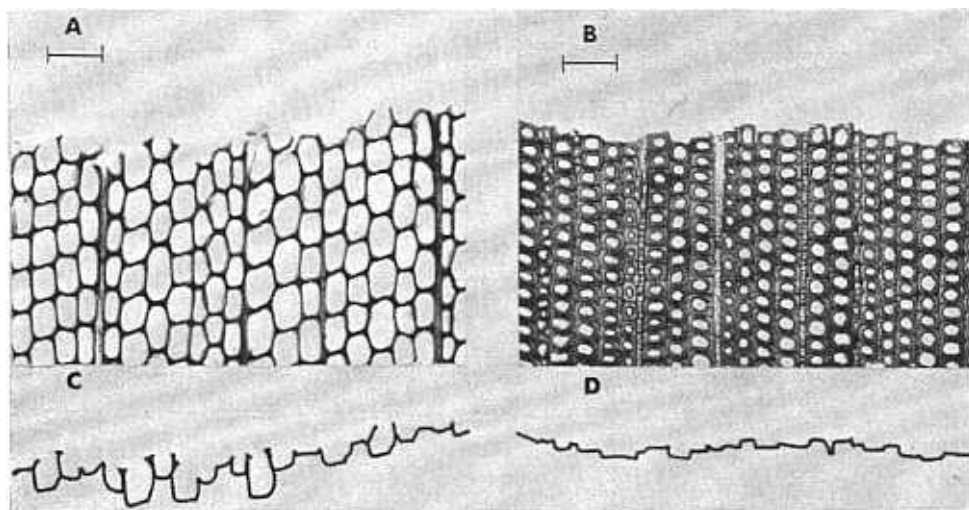
Figure 1. — Surfaces of tight side of rotary-cut southern pine veneer. (A, B) Photomicrographs of transverse sections of earlywood and latewood. (C, D) Surface profile. Scale mark = 100 μm.

exposed area of lumen surface on the radial walls is directly proportional to the fraction (k) of the radial lumen wall remaining exposed. If the tracheids are assumed to be rectangular in

Figure 2. — Models of veneer surfaces cut during rotary peeling. (A) Cut within cell wall. (B) Cut across cell wall through lumen.

shape and open at both ends, the surface area exposed by a knife cutting across cell walls can be written:

True surface area =

$$\sum_{k=0}^{1} n_k \left[2d_e + (d_T - 2d_e) + 2kd_r\right] L$$

$$= \sum_{k=0}^{1} n_k L(d_T + 2kd_r) \quad [3]$$

and:

Apparent surface area =
$$N d_T L \quad [4]$$

Roughness factor, $R_1 =$

$$\frac{\sum_{k=0}^{1} n_k (d_T + 2kd_r)}{N d_T} \quad [5]$$

where:

k = fraction of radial lumen wall exposed on the veneer surface

d_T = tangential tracheid diameter

d_r = radial lumen diameter

d_e = single wall thickness

L = tracheid length

n_k = number of cells cut with k fraction of radial lumen wall exposed

N = total number of cells cut = Σn_k

The fraction n_k/N in Equation [5] is an expression of the probability of cutting cells at fraction k. In an idealized wood, the probabilities are assumed to be the same for all possible k's
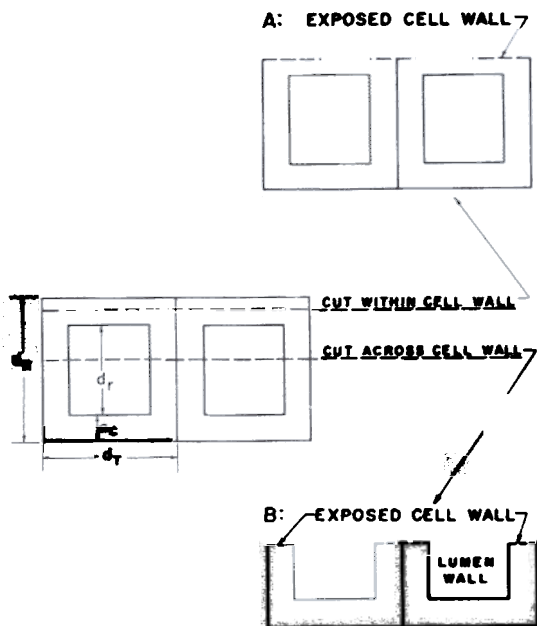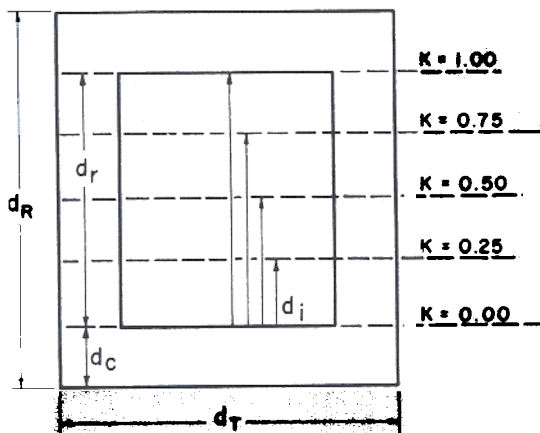
RADIAL LUMEN DIAMETER EXPOSED ON VENEER SURFACE AFTER CUTTING (d_i)

$$K = \frac{\text{RADIAL LUMEN DIAMETER EXPOSED ON VENEER SURFACE AFTER CUTTING } (d_i)}{\text{RADIAL LUMEN DIAMETER } (d_r)}$$

Figure 3. — Definition of k, on a single tracheid model in cross section. The dashed lines represent knife cuts with corresponding k values.

(*i.e.*, from $k = 0$ to $k = 1$); therefore, an average value of $k = 0.5$ is justified. By substituting $k = 0.5$ in Equation [5]:

$$R_2 = \frac{d_T + d_r}{d_T} = 1 + \frac{d_r}{d_T} \qquad [6]$$

The probabilities of cutting within and across cells are related to cell wall thickness and to radial lumen diameter, as follows:

$$p_1 = \frac{2d_c}{2d_c + d_r} = \frac{2d_c}{d_R} \qquad [7]$$

$$p_2 = \frac{d_r}{2d_c + d_r} = \frac{d_r}{d_R} \qquad [8]$$

where:

p_1 = probability of cutting within cell walls

p_2 = probability of cutting across cell walls

d_R = radial tracheid diameter

The overall roughness factor (R) for a veneer surface can therefore be stated as follows:

$$R = p_1 R_1 + p_2 R_2 \qquad [9]$$

By combining Equations [2], [5], [7], and [8]

$$R = \frac{2 d_c}{d_R} +$$

$$\left(\frac{d_r}{d_R} \right) \left[\frac{\sum\limits_{k=0}^{1} n_k \ (d_T + 2kd_r)}{N d_T} \right]$$

then, if $k = 0.5$ as assumed in Equation [6], by substitution:

$$R = \frac{2d_c}{d_R} + \frac{d_r}{d_R} \left(1 + \frac{d_r}{d_T} \right) \qquad [10a]$$

Procedure

Ten sheets of 20- by 20-inch green, rotary-cut, southern pine veneer measuring 1/8-inch thick were selected from a plywood plant in central Louisiana. From each sheet, four pieces of earlywood and four pieces of latewood were cut; the pieces measured 1 inch along the grain and 1/4-inch tangentially across the grain. From each piece one transverse section 20 μm thick (a micrometer is 10^{-6} meter) was cut on a microtome. After being stained with safranin, the sections were dehydrated by transferring them through a series of alcohol solutions (*i.e.*, 30, 50, 70, 95, and 100 percent alcohol) to minimize shrinkage. The dehydrated sections were then cleared with xylene and mounted on slides. Cellular dimensions necessary to solve Equation [10] were measured on a light microscope equipped with a Filar eyepiece. Twenty-five measurements of each dimension were made on the tight side of each veneer section. A few tracheids had failed along the radial compound middle lamella; they were treated as exposed radial lumen surface and included in the term kd_r.

Results and Discussion

Table 1 summarizes the measurements and the results of R-value computations. Each tabulated value of cellular dimensions is the average of 100 observations (i.e., 25 per section) (four sections each of earlywood and latewood from every sheet of veneer).

As shown in the last four columns of the table, the roughness factor of earlywood (range 1.91 to 2.18) was consistently larger than that of latewood (range 1.06 to 1.22). This result was not surprising. Because earlywood has larger lumens and thinner cell walls than latewood, it is more likely to be cut across cell walls. The roughness data in the table may be summarized as:

Table 1. — TRANSVERSE CELLULAR DIMENSIONS AND ROUGHNESS FACTORS MEASURED ON THE TIGHT SIDE OF 1/8-INCH SOUTHERN PINE VENEERS.[1]

| Veneer Number | EW Tracheid Diameter | | LW Tracheid Diameter | | Radial Diameter of Lumen | | Cell Wall Thickness | | kd_r | | Roughness Factor | | | |
| | | | | | | | | | | | EW | | LW | |
	Radial	Tangential	Radial	Tangential	EW	LW	EW	LW	EW	LW	Eq. [10]	Eq. [10a]	Eq. [10]	Eq. [10a]
					μm^2									
1	60.3	39.0	30.1	38.6	49.1	15.8	5.6	7.2	24.6	4.8	2.03	2.02	1.13	1.22
2	59.3	39.2	30.2	38.2	49.5	15.2	4.9	7.5	26.9	5.4	2.14	2.05	1.14	1.20
3	60.5	34.2	32.8	40.4	50.0	15.9	5.3	8.5	23.3	4.4	2.13	2.21	1.11	1.19
4	60.0	37.1	31.0	39.2	49.2	15.5	5.4	7.8	23.1	3.4	2.02	2.09	1.09	1.20
5	59.9	37.2	34.2	39.0	49.1	17.6	5.4	8.3	20.7	3.2	1.91	2.08	1.08	1.23
6	61.2	38.8	32.1	35.7	50.4	15.5	5.4	8.3	22.5	2.6	1.95	2.07	1.07	1.21
7	59.6	36.5	28.0	34.7	49.1	13.4	5.3	7.3	20.8	2.2	1.94	2.12	1.06	1.18
8	59.5	35.4	31.3	38.5	48.9	14.7	5.3	8.3	21.8	3.0	2.01	2.13	1.07	1.18
9	56.0	35.2	32.2	39.6	46.5	15.2	4.8	8.5	23.8	2.8	2.12	2.10	1.07	1.18
10	57.7	35.8	31.3	34.2	49.3	15.0	4.2	8.2	24.3	1.9	2.16	2.18	1.06	1.21
Average	59.4	36.8	31.3	37.8	49.1	15.4	5.1	8.0	23.2	3.4	2.04	2.11	1.09	1.20

[1] EW = earlywood; LW = latewood; kd_r = the amount of radial lumen wall exposed on the veneer surface.

[2] A micrometer is 10^{-8} meter.

	Earlywood	Latewood
Equation [10]	2.04	1.09
Equation [10a]	2.11	1.20

Thus the average roughness factor of latewood was approximately 1, while that of earlywood was about 2.

Although not shown in Table 1, 802 out of 1,000 earlywood tracheids were observed cut across the cell wall, whereas only 253 out of 1,000 latewood tracheids were cut across cell walls. The probabilities of cutting across the cell walls of earlywood and latewood were therefore 0.80 and 0.25, respectively. These observations support the computations summarized in Table 1.

The two methods of computing roughness factor (i.e., Equations [10] and [10a]) are in fairly close agreement considering the rather small number of sections evaluated. Equation [10a] would therefore seem the more advantageous because of the simplicity of required measurements.