J Wood Sci (2005) 51:274–277
DOI 10.1007/s10086-004-0649-8

NOTE

Yuko Fujiwara · Yoshihisa Fujii · Shogo Okumura

Relationship between roughness parameters based on material ratio curve and tactile roughness for sanded surfaces of two hardwoods

Received: March 24, 2004 / Accepted: May 25, 2004

Abstract The roughness parameters on the material ratio curves were related to tactile roughness for samples of buna and mizunara. The surfaces of the samples were sanded using various grades of coated abrasives and the roughness parameters, reduced peak height (*Rpk*), core roughness depth (*Rk*), and reduced valley depth (*Rvk*), were estimated on the material ratio curves, which were obtained from roughness profiles determined using robust Gaussian regression filter. The values of *Rpk* and *Rk* were almost the same for buna and mizunara under the same sanding conditions and increased exponentially with tactile roughness. The coefficients of determination of those parameters and tactile roughness were higher than 0.79 at all cutoff wavelengths. On the other hand, the value of *Rvk* for mizunara was significantly larger than that for buna because of the deep local valleys. There was no relationship between *Rvk* and tactile roughness for both species.

Key words Surface roughness · Tactile roughness · Material ratio curve · Sanded surface

Introduction

Surface roughness of materials is an important criterion in assessing tool conditions, machining performance, and product quality. In the wood industry, the visual and tactile senses are crucial for determining the surface roughness because they provide a faster and more economical measurement than other methods using surface-measuring equipment. However, such methods yield only the subjective and qualitative estimates that cannot be used to ensure product or process qualities or to control automatic processing of wood. There has existed a need to evaluate the surface roughness of machined wood with objective and quantitative parameters for a long time.

Several roughness parameters have already been defined in a series of international and national standards such as ISO 4287-1996 or JIS B 0601-2001. However, the parameters cannot always relate to visual and tactile assessment of the machined wood surface.[1–3] On the other hand, roughness evaluation using a material ratio curve, which is defined by ISO 13565 series together with parameters, reduced peak height (*Rpk*), core roughness depth (*Rk*), and reduced valley depth (*Rvk*), is expected to connect with tactile roughness because the parameters would evaluate the surface irregularities that are directly touched by fingers and thus have a good correlation with tactile roughness. Westkämper and Riegel[4] showed that *Rk* reflected the flatness and roughness caused by processing and Westkämper and Schadoffsky[5,6] also showed that *Rpk*, *Rk*, and *Rvk* could be related to the irregularities derived from fuzzy grain, processing, and pores of cellular structures, respectively. However, they did not discuss the relationship between the parameters and tactile roughness.

The purpose of this study was to examine the relationship between roughness parameters for the material ratio curve and tactile roughness. The parameters were estimated on the surface sanded with various grit numbers of abrasive papers for mizunara and buna. The tactile roughness was determined by sensory evaluation. In this experiment, roughness profiles were obtained from primary profiles using robust Gaussian regression filter (RGRF) that was adjusted for evaluating wood surface roughness.[7] This filter was used because it does not generate artificial peaks around deep valleys in a roughness profile.[7] The effect of cutoff wavelength on the relationship between the parameters and tactile roughness is also discussed.

Y. Fujiwara (✉) · Y. Fujii · S. Okumura
Graduate School of Agriculture, Kyoto University, Kyoto 606-8502, Japan
Tel. +81-75-753-6245; Fax +81-75-753-6245
e-mail: fujiwara@h3news1.kais.kyoto-u.ac.jp

Materials and methods

Specimens

Samples of air-dried flat and edge grain boards of mizunara (*Quercus mongolica* var. *grosseserrata*) and buna (*Fagus crenata*) were sanded manually on a surface using various abrasive papers with grit numbers: P80, P120, P150, P180, and P240. Abrasive papers were moved perpendicular to the grain. The samples were cut into 35 × 65 × 15 mm pieces with their longitudinal dimension of 35 mm. The average annual ring widths and the specific gravities of specimens of mizunara and buna were 0.64–2.0 mm and 0.59–0.69, and 1.2–3.1 mm and 0.63–0.69, respectively.

Roughness measurement

Five primary profiles were sampled on each specimen using a stylus instrument (Surfcom 1400A-3DF-12, Tokyo Seimitsu) with a 5 μmR, 90° angle stylus tip. The stylus was moved perpendicularly to the fiber direction at a speed of 0.6 mm/s over a distance of 15 mm. The output signal of the instrument was recorded at a sampling interval of 5 μm.

Roughness profiles were obtained from the primary profiles using RGRF at cutoff wavelengths of 0.8, 2.5, and 8.0 mm. The RGRF had been adjusted for the evaluation of wood surface roughness.[8] Abbott curves were determined from each roughness profile for the evaluation length of 15 mm. The parameters *Rpk*, *Rk*, and *Rvk* were obtained from each Abbott curve and the values of parameters for each profile were averaged for every cutoff wavelength.

Sensory evaluation

Subjects (11 men and 5 women), sat in front of a pair of specimens, rubbed his or her index finger back and forth on the specimen's surface, and identified the rougher of the two. The manner of touching, for example, the direction of finger movement, was entirely left to the subjects. A standing board prevented the subjects from seeing specimens during the test. The pairs of specimens were chosen randomly from among ten specimens for buna and mizunara. The subjects judged the roughness of each possible pair. The tactile perception of roughness for each specimen was estimated from the number of judgments of "rougher surface" according to the composite standard method.[9] Details of the estimation were given by Tanaka,[9] and a brief outline is described as follows:

$$x = \frac{R_+ + 0.5N}{nN} \tag{1}$$

where x is the score for each specimen, R_+ the number of judgments of "rougher surface", N the number of subjects, and n the number of specimens. The score standardized using the standard deviation σ as shown in Eq. 2 is the tactile roughness Z of a specimen.

$$Z = \frac{x - 0.5}{\sigma} \tag{2}$$

where σ is defined as

$$\sigma = \sqrt{\frac{\sum (x - 0.5)^2}{n}} \tag{3}$$

A set of Z values for a species in this study indicated an interval scale, that is, the distance between adjacent points on the scale are equal but no absolute zero point is given.

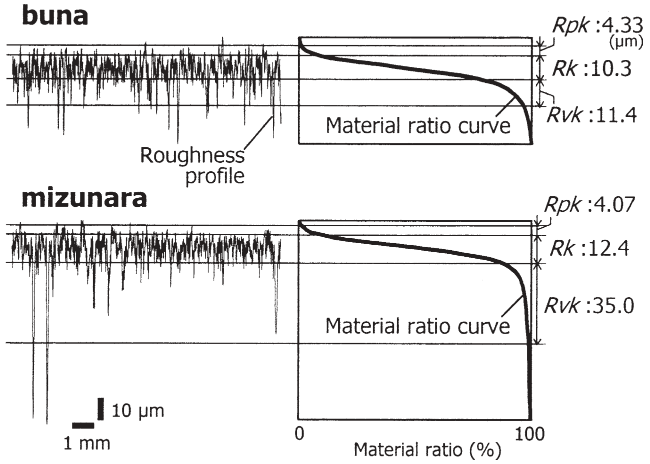

Fig. 1. Relationship between roughness profile and material ratio curve at a cutoff wavelength of 2.5 mm for buna and mizunara. Both specimens were sanded with a P150 coated abrasive. *Rpk*, reduced peak height; *Rk*, core roughness depth; *Rvk*, reduced valley depth

Results and discussion

Relationship between roughness profile and material ratio curve

Figure 1 shows examples of roughness profiles at a cutoff wavelength of 2.5 mm and their material ratio curves for buna and mizunara that were sanded with the coated abrasives of P150. The estimated values of *Rpk*, *Rk*, and *Rvk* for each material ratio curve are also shown. It is clear from Fig. 1 that *Rpk* and *Rk* reflect only the surface irregularities that could be directly touched by fingers. The material ratio curve for mizunara falls deeply at the area of the higher material ratio because of the local deep valleys shown in the roughness profile, so that *Rvk* for mizunara was significantly larger than that for buna, which had no extremely deep valleys in the roughness profile. On the other hand, *Rpk* and *Rk* were little affected by such valleys and were almost the same for buna and mizunara (Table 1).

Table 1. Relation of *Rpk* and *Rk* to grit number of coated abrasives

Grit number of coated abrasives	*Rpk* (μm)	*Rk* (μm)
P80	14.4[a]	25.2
	11.8[a]	18.0
P120	5.92	17.7
	6.00	11.5
P150	4.16	12.1
	3.77	11.8
P180	3.98	11.6
	5.80	11.2
P240	2.76	8.26
	3.82	7.70

Rpk, reduced peak height; *Rk*, core roughness depth, defined in ISO-13565-2-1996
[a] Upper and lower numerals are for buna and mizunara, respectively

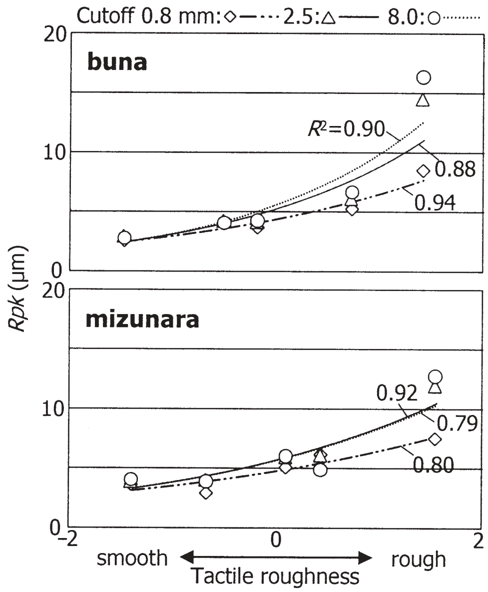

Fig. 2. Relationship between *Rpk* and tactile roughness at cutoff wavelengths of 0.8, 2.5, and 8.0 mm. R^2 denotes the coefficient of determination of exponential regression

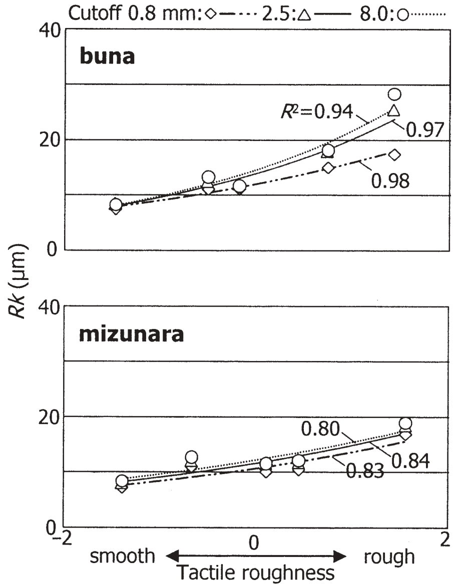

Fig. 3. Relationship between *Rk* and tactile roughness at cutoff wavelengths of 0.8, 2.5, and 8.0 mm

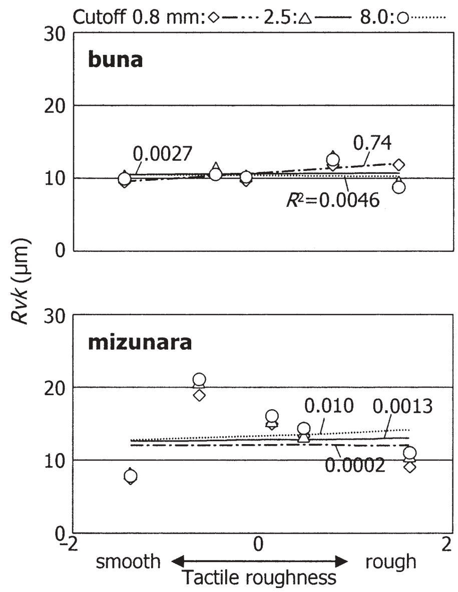

Fig. 4. Relationship between *Rvk* and tactile roughness at cutoff wavelengths of 0.8, 2.5, and 8.0 mm

Relationship between parameters for material ratio curve and tactile roughness

Peaks on the surface could generate the local deformation of skin that causes the tactile feeling,[10] so that *Rpk* is expected to have a good correlation with tactile roughness. Figures 2, 3, and 4 show the relationship between tactile roughness and the parameters of the material ratio curve, *Rpk*, *Rk*, and *Rvk*, respectively. The value of *Rpk* increased exponentially with tactile roughness for both species and they showed a good correlation as indicated by the coefficients of determination, R^2. The values of R^2 are largest at cutoff wavelengths of 0.8 mm for buna and 2.5 mm for mizunara. As shown in Fig. 3, the value of *Rk* also increased with tactile roughness and the coefficients of determination were higher than 0.90 or 0.80 at all cutoff wavelengths for buna or mizunara, respectively. On the other hand, it is clear from Fig. 4 that *Rvk* did not show any relation to tactile roughness.

Conclusions

The roughness parameters for evaluating wood surface should correspond to tactile roughness because the roughness of wood surface is often evaluated by touch. The roughness parameters *Rpk* and *Rk* for the sanded surface of buna and mizunara showed good correlation with tactile roughness at cutoff wavelengths of 0.8, 2.5, and 8.0 mm, but *Rvk* did not. Further study is necessary to confirm the applicability of the present method to other machining processes and wood species.

References

1. Fujii Y, Yoshizane M, Okumura S (1997) Evaluation of surface roughness by various parameters I. Relationship between several roughness parameters and tactile roughness (in Japanese). Mokuzai Gakkaishi 43:574–579
2. Goli G, Larricq P, Marchal R, Negri M, Costes JP (2001) Surface quality: comparison among visual grading and 3D roughness measurements. Proceedings of the 15th International Wood Machining Seminar, California, pp 459–471
3. Fujiwara Y, Fujii Y, Okumura S (2003) Effect of removal of deep valleys on the evaluation of machined surfaces of wood. Forest Prod J 53:58–62
4. Westkämper E, Riegel A (1993) Qualitätskriterien für geschliffene massiveholzoberflächen. Holz Roh Werkst 51:121–125
5. Westkämper E, Schadoffsky O (1995) Oberflächentopographie von massivholz—einflüsse und verfahren bei der meßtechnischen erfassung und bewertung von holzoberflächen (teil 1). HOB 3:74–78
6. Westkämper E, Schadoffsky O (1995) Oberflächentopographie von massivholz—einflüsse und verfahren bei der meßtechnischen erfassung und bewertung von holzoberflächen (teil 2). HOB 4:50–54
7. Bodschwinna H (2000) In: Oberflächenmeßtechnik zur beurteilung und optimirrung technischer funktionsflächen. Shaker, Aachen, pp 39–55
8. Fujiwara Y, Fujii Y, Sawada Y, Okumura S (2004) Assessment of wood surface roughness: a comparison between tactile roughness and three-dimensional parameters derived using a robust Gaussian regression filter. J Wood Sci 50:35–40
9. Tanaka Y (1973) 16 Shakudokousei. In: Tuzuki A, Yagi B (eds) Shinrigaku kenkyuuhou. Tokyodaigaku Shuppankai, Tokyo, p 126
10. Johansson RS, LaMotte RH (1983) Tactile detection thresholds for a single asperity on an otherwise smooth surface. Somatosens Res 1:21–31