Technical Note

Evaluation of Shear Strength of Japanese Wood Species as a Function of Surface Roughness

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Abstract

The objective of this study was to evaluate shear strength characteristics of four commonly used Japanese species, namely, Japanese cedar-sugi (*Cryptomeria japonica* D. Don), Japanese cypress-hinoki (*Chamaecyparis obusta* Endl.), false arborvitae-hiba (*Thuobsis dolabrate* Sieb. et Zucc.), and Japanese larch-karamatsu (*Larix leptlepis* Gordon), as function of their surface quality. Samples with radial and tangential grain orientations from each species were prepared using a planer and sanded with one of the sandpapers with 80-, 120-, and 240-grit size. A stylus type of equipment was employed to determine surface roughness of each sample before they were bonded in radial and tangential pairs using polyvinyl acetate (PVAc) adhesive at a spread rate of 260 g/m^2. None of the samples showed any superiority from each other in terms of their surface quality based on three parameters: average roughness (R_a), mean peak-to-valley height (R_z), and maximum roughness (R_{max}). Average roughness value of both tangential and radial surfaces of the samples sanded with 80-grit sandpaper resulted in significant differences from those of the control samples. The highest shear strength value was 96.1 kg/cm^2 for the radial karamatsu samples sanded with 80-grit sandpaper followed by tangential hinoki samples with the value of 79.6 kg/cm^2. In general, the samples finished with 80-grit sandpaper resulted in higher shear strength values than the others tested in this work. It appears that stylus-type equipment can be used to evaluate surface quality of such solid wood samples. Based on the results of this study, sanding of the samples with 80-grit sandpaper improved overall shear strength of the specimens by developing a better glue line between two pieces.

Shear strength of wood is one of the most important properties when they are bonded together to be used for different applications. Grain orientation, porosity, density, type of adhesive, surface quality, press parameters, adhesive spread rate, and exposure conditions are some of the raw material and manufacturing parameters influencing the efficient bonding of two members so that finished product can be used effectively without having any significant problems. Various tropical species were tested to evaluate their shear strength under wet and dry conditions (Hernández and Almeida 2003). Polyvinyl acetate (PVAc)– and resorcinol formaldehyde–bonded specimens of such samples were found to be affected by wood density when they were tested in a dry condition (Hernández and Almeida 2003). In another study, a nonhomogeneous structure of wood related to shear strength properties was investigated using a nonlinear finite element analysis approach (Serrano 2004). It was concluded that adhesive type, density, as well as grain orientation of the samples were the main parameters controlling the test results (Serrano 2004). The effect of the extractive content of tropical species on shear strength of PVAc-bonded specimens was carried out in another study, and it was determined that once chemicals were extracted from the wood, their shear strength characteristics improved (Sakuna and Moredo 1993). Gupta et al. (2004) studied the effects of defects such as knots on shear strength of Douglas fir, and the results revealed that there was no significant influence of the knots on the shear strength of the specimens.

Surface quality of solid wood also plays an important role in the development of quality bonding with a uniform glue line. Various studies have been carried out to evaluate the surface quality of different species by using a stylus technique and related to their shear strength and other mechanical properties of bonded samples (Bustos et al.

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2004, Anwar et al. 2005, Burdurlu et al. 2006, de Moura and Hernández 2006, Iskra and Hernández 2009).

Adhesive shear strength between solid wood veneer sheets and the particleboard substrate was also evaluated in a past study (Hiziroglu and Rabiej 2005). The adhesive rate on the surface of beech and yellow poplar veneer sheets and roughness of the particleboard substrate influenced overall shear strength between two members (Hiziroglu and Rabiej 2005). It was also found that increasing the adhesive rate from 100 to 300 g/m^2 significantly improved shear strength values of the samples.

The influence of surface quality of spruce (*Picea orientalis*) veneers on shear strength of urea formaldehyde– and phenol formaldehyde–bonded plywood samples was investigated by Aydin et al. (2006). In another study, the shear strength plywood samples made from Calabian pine (*Pinus brutia* Ten.) with radial and tangential grain orientations was determined as a function of their surface roughness and press parameters (Aydin 2004). It was concluded that the shear strength of the samples bonded with PVAc increased with an increase in their surface roughness. Aydin also evaluated the effect of surface roughness of steam-treated beech veneer samples sanded with 100- and 180-grit sandpapers. The results showed that plywood panels made from sanded veneer sheets had higher shear strength than those of unsanded samples (Aydin 2004).

Hinoki, hiba, sugi, and karamatsu are native softwood species that are used widely for many different applications in Japan. Sugi is one of the main raw materials for architectural uses, such as pillars, paneling, decorative columns, and even boat manufacturing. Sugi wood has been discovered in many ancient temples and houses in the form of structural uses. Hinoki is also used for high-quality artistic applications such as sculptures, partitions in shrines and temples, and novelty items. Both hiba and karamatsu are extensively used for structural purposes and furniture manufacture in Japan. High resistance of hiba against biological deterioration makes this species an excellent raw material to manufacture joist and foundation lumber. Currently, there is no information on shear strength of these four species as a function of their surface quality. Therefore, the main objective of this study was to evaluate surface roughness of solid wood samples prepared in radial and tangential grain orientations from these species and determine shear strength of the samples bonded together using PVAc adhesive. It is expected that the initial findings found from this work will provide some basic data for Japanese manufacturers so that the above species can be used more efficiently and effectively for different bonded applications.

Materials and Methods

Defect-free boards, 25 mm thick, of four species were supplied by a local joiner manufacturer, Nagona Inc. Samples with radial and tangential grain orientation were planed and cut with dimensions of 20 by 20 by 30 mm and 20 by 20 by 10 mm for the shear tests based on a Japanese Industrial Standard (JIS 2009). All the samples were conditioned in a climate chamber with a relative humidity of 65% and a temperature of 20°C until they reached an equilibrium moisture content of 12 percent. A total of 40 pairs of shear strength test specimens were prepared for each species. The density of each individual sample was determined by measuring their dimensions at an accuracy of 0.1 mm and weighing them at an accuracy of 0.01 g. Radial and tangential surfaces of each sample were sanded with one of the sandpapers having 80, 120, and 240 grit by applying five light strokes to their surface along the grain orientation. Unsanded samples were also included for the tests as control specimens.

Two roughness measurements were taken from the surface of each sample across the grain orientation prior to bonding them together in pairs for shear strength test. A fine stylus type of equipment, T-500 Hommel profilometer, was used for the roughness measurements. The device consisted of the main unit and the pickup with a skid-type diamond tip stylus having a radius of 5 µm (American National Standards Institute 1985). Three roughness parameters—average roughness (R_a), mean peak-to-valley height (R_z), and maximum roughness (R_{max})—were used to evaluate the surface quality of control and sanded samples. Specifications of these parameters and fundamentals of stylus roughness measurement technique have been detailed in numerous past works (Stombo 1963, Peter and Cumming 1970, Drew 1992, Lemaster and Beal 1993). Tracing span and cutoff length for the roughness measurements were 15 and 0.25 mm, respectively (Mummery 1991). Figures 1 and 2 illustrate schematics of the test samples and typical roughness profiles taken from the surface of the specimens.

PVAc is a widely used adhesive for engineered wood products. This adhesive was also applied on both surfaces of each shear pairs by brushing at a spread rate of 260 g/m^2. After adhesive application, the specimens were pressed together using a light pressure of 1 kg/cm^2 for 8 hours at room temperature. Bonded samples were also kept in a conditioning chamber having a relative humidity of 65 percent and a temperature of 20°C for 2 days prior to the shear test. A total of 160 specimens for four species were tested for their shear strength values. Table 1 displays the sampling design and specifications of the samples. An Instron testing system Model-4202 having a load capacity of 5,000 kg was used for the tests. Crosshead speed was 0.5 mm/min for the shear test based on a Japanese Industrial Standard (JIS 2009). The shear test setup is shown in Figure 3.

Results and Discussion

Table 2 displays average surface roughness and shear strength values of the samples from four species. Overall roughness characteristics of the specimens increased as

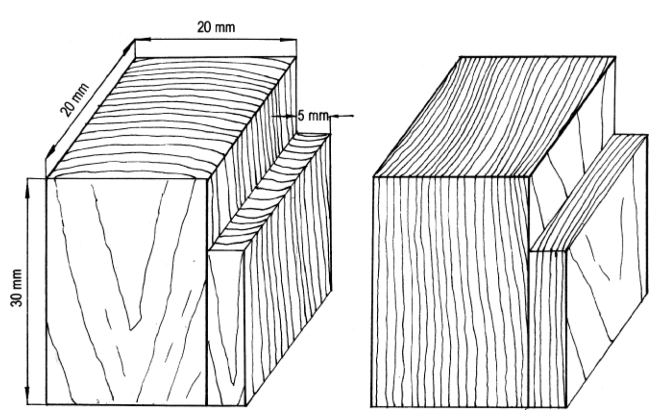

Figure 1.—Dimensions of the radial and tangential shear samples.

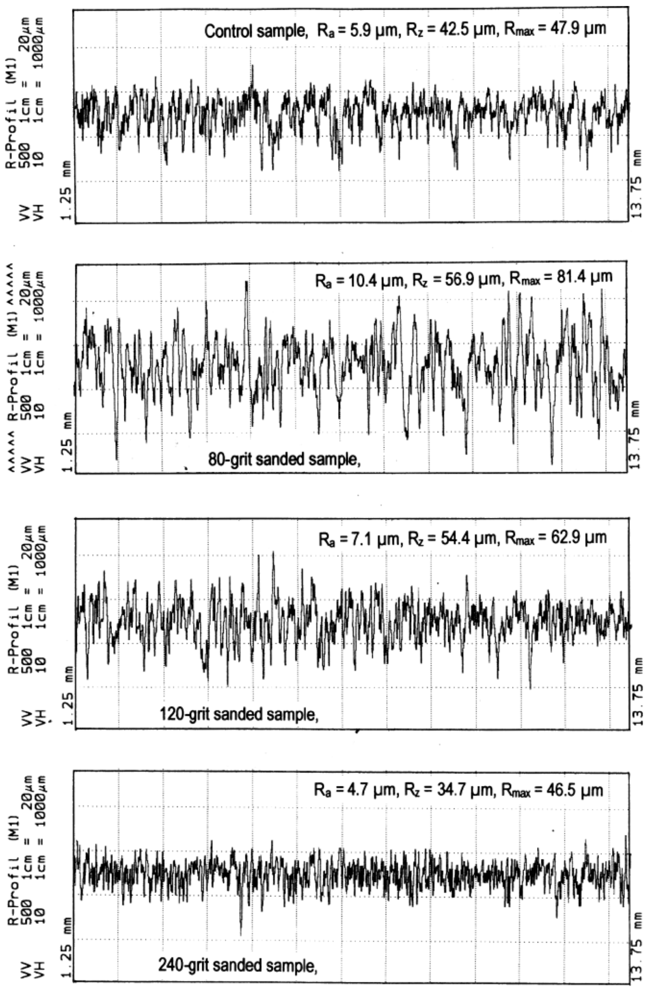

Figure 2.—Typical roughness profiles of the specimens.

they were sanded with 80-grit sandpaper. Average roughness values of the radial samples sanded with 80-grit sandpaper ranged from 1.21 to 2.5 times higher than those of the radial control samples. Corresponding values

Figure 3.—Shear test setup.

of tangential surfaces of the samples ranged from 1.60 to 2.31 times higher. Control samples of hiba and hinoki had the smoothest surface with an average R_a value of 3.5 μm followed by sugi with an average R_a value of 4.9 μm on the tangential grain orientation. Based on *t* test analysis, there was a significant difference between R_a, R_z, and R_{max} values of control samples and samples sanded with 80-grit sandpaper. However, once samples were sanded with 120- and 240-grit sandpaper, no statistical difference between roughness values of the samples was observed. Also, no significant difference was found between surface roughness values determined from radial and tangential grain orientation of control and sanded samples at a 95 percent confidence level. Samples sanded with 240- and 120-grit sandpapers showed roughness values comparable to those of control samples within the range of variation of 1 or 2 μm. Figures 4 and 5 also illustrate average R_a values of the specimens.

Results of shear strength of the samples bonded in radial and tangential grain orientation are also presented in Table 2. The average values of shear strength in radial and

Table 1.—Average density values of the species and sampling design.[a]

Species	Density (g/cm^3)	Grit size	No. of test samples		Shear test samples in pairs		No. of roughness measurements	
			R	T	R	T	R	T
Hinoki	0.46 (0.023)	0	10	10	5	5	20	20
		80	10	10	5	5	20	20
		120	10	10	5	5	20	20
		240	10	10	5	5	20	20
Sugi	0.37 (0.031)	0	10	10	5	5	20	20
		80	10	10	5	5	20	20
		120	10	10	5	5	20	20
		240	10	10	5	5	20	20
Hiba	0.42 (0.024)	0	10	10	5	5	20	20
		80	10	10	5	5	20	20
		120	10	10	5	5	20	20
		240	10	10	5	5	20	20
Karamatsu	0.54 (0.022)	0	10	10	5	5	20	20
		80	10	10	5	5	20	20
		120	10	10	5	5	20	20
		240	10	10	5	5	20	20

[a] Numbers in parentheses are standard deviations. R = radial; T = tangential.

Table 2.—Results of roughness parameters and shear strength of the specimens.[a]

		Roughness parameters (μm)							
		Radial			Tangential			Shear strength (kg/cm^2)	
Species	Grit size	R_a	R_z	R_{max}	R_a	R_z	R_{max}	Radial	Tangential
Hinoki	0	3.7 (0.20)	35.6 (2.31)	60.8 (3.12)	3.5 (0.31)	27.9 (2.31)	37.6 (3.09)	62.2 (2.05)	55.6 (2.09)
	80	9.3 (0.29)	63.7 (3.12)	98.6 (3.98)	8.1 (0.28)	60.6 (3.05)	81.6 (3.98)	69.1 (3.21)	72.9 (3.89)
	120	5.5 (0.25)	38.9 (2.21)	50.5 (3.21)	6.5 (0.32)	49.8 (2.08)	65.8 (2.76)	65.9 (2.89)	79.6 (3.78)
	240	4.1 (0.22)	30.4 (2.11)	49.7 (2.98)	3.8 (0.21)	39.8 (2.76)	47.9 (2.48)	72.8 (4.01)	79.3 (4.21)
Sugi	0	5.6 (0.25)	34.8 (1.98)	57.7 (3.09)	4.9 (0.34)	47.4 (2.81)	57.8 (3.08)	40.7 (2.80)	39.2 (2.03)
	80	9.2 (0.30)	64.5 (3.21)	99.7 (4.53)	9.7 (0.33)	69.7 (4.67)	93.1 (3.89)	57.9 (3.01)	52.8 (3.09)
	120	7.7 (0.27)	56.7 (2.98)	70.4 (3.87)	4.5 (0.24)	34.5 (2.45)	49.9 (2.78)	63.5 (2.68)	54.6 (3.57)
	240	4.4 (0.31)	33.4 (2.09)	58.9 (2.79)	4.3 (0.27)	37.9 (2.74)	60.2 (3.03)	57.7 (3.05)	54.0 (2.75)
Hiba	0	4.6 (0.22)	29.8 (2.06)	38.9 (2.02)	3.5 (0.29)	34.7 (2.72)	45.8 (2.56)	57.9 (2.89)	63.7 (3.89)
	80	5.7 (0.24)	60.7 (3.02)	86.7 (3.89)	7.6 (0.23)	56.9 (3.03)	96.2 (4.05)	76.5 (3.29)	76.5 (3.20)
	120	3.4 (0.22)	47.9 (2.92)	69.6 (3.02)	6.4 (0.31)	50.3 (3.18)	75.7 (2.99)	76.7 (3.02)	70.4 (3.09)
	240	3.0 (0.24)	32.9 (2.47)	46.8 (2.34)	3.9 (0.27)	36.3 (2.79)	48.9 (2.31)	86.9 (3.60)	68.8 (2.69)
Karamatsu	0	7.1 (0.32)	40.6 (3.10)	64.8 (3.54)	6.5 (0.28)	41.7 (3.02)	76.2 (2.60)	69.8 (3.67)	59.9 (2.75)
	80	8.6 (0.39)	51.8 (2.89)	62.9 (3.99)	10.4 (0.35)	67.5 (3.78)	89.9 (3.68)	96.1 (3.90)	69.9 (3.04)
	120	6.6 (0.27)	50.6 (3.08)	78.1 (2.89)	6.0 (0.38)	45.6 (2.45)	72.8 (2.48)	79.0 (2.86)	74.2 (2.90)
	240	5.4 (0.32)	36.4 (2.09)	47.1 (3.08)	5.3 (0.27)	40.6 (2.85)	55.9 (3.10)	81.3 (3.56)	65.3 (3.06)

[a] Numbers in parentheses are standard deviations.

tangential samples of sugi and karamatsu were 39.95 and 64.49 kg/cm^2, respectively.

Hiba and hinoki had shear strength values of 60.80 and 58.90 kg/cm^2, which were between the minimum and maximum values among the other samples (Figs. 6 and 7). It is a fact that density of species is an important property influencing shear strength of wood. It appears that the low density of sugi would be the responsible parameter resulting in a weak bonding. Higher shear strength characteristics of karamatsu having a density of 0.54 g/cm^3 also support this conclusion. Radial samples showed better strength results in comparison to tangential samples. This can be related to nonuniform and higher variation on radial surfaces due to annual ring orientation resulting in better interlocking and bonding of the two surfaces. Roughness values of the radial surface were also determined to be slightly higher than that of the tangential surface, as can be seen in Table 2. Once samples were sanded with 80-grit sandpaper without regard to grain orientation or species, overall shear strength values increased. It seems that rougher surfaces create more peaks and valleys in the form of grooves so that two surfaces are bonded together, creating a better and stronger glue line. Similar findings were also observed by Burdurlu et al. (2006) when Calabrian pine samples sanded with 60-grit sandpaper were bonded together using PVAc adhesive. The sanded samples in that study showed higher shear strength values than those of the control samples. Species with lower density, namely, hinoki and sugi, showed a more pronounced effect of sanding with 80-grit on their shear strength values. In the case of sugi and hiba, shear strength increased 1.38 and 1.18 times when they were sanded with 80-grit sandpaper. Karamatsu, with an air-dried density of 0.54 g/cm^3, had only 1.13 times increased shear strength values when it was sanded with 80-grit size. No significant difference was found between shear strength of the samples sanded with 120- and 240-grit sandpaper at a 95 percent confidence level. In general, sanding with 240-grit sandpaper did not enhance shear strength values of both radial and tangential samples, suggesting that 80-grit sanding would be considered a threshold and ideal sandpaper grit size to have enhanced strength values of the samples. Most of the shear failures took place within the glues line with a few

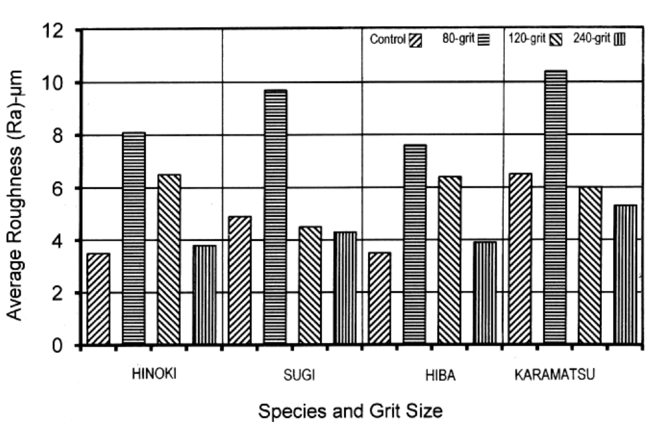

Figure 4.—Average roughness values of radial surfaces.

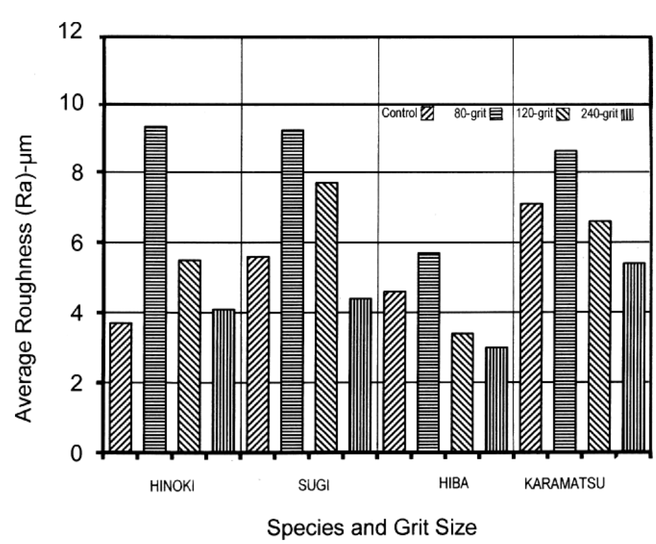

Figure 5.—Average roughness values of tangential surfaces.

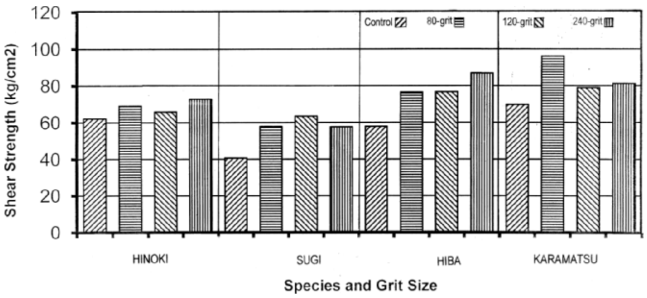

Figure 6.—Shear strength values of radial samples.

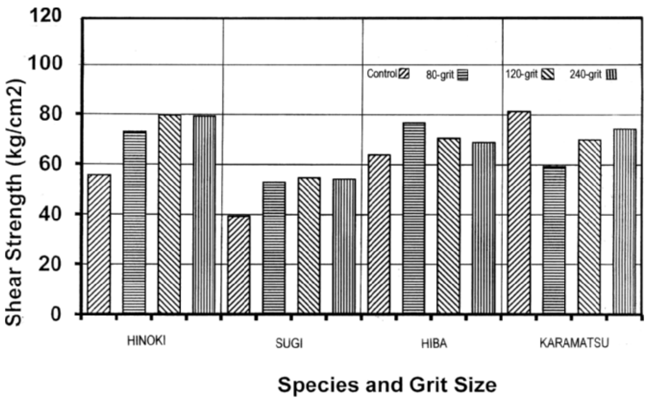

Figure 7.—Shear strength values of tangential samples.

exceptions. All the samples tested in this work satisfied minimum shear strength requirements listed by the Wood Technology Association of Japan (1989).

It is expected that initial data from this work will be employed to evaluate bonding processes of these species so that final products can be used more effectively without having any mechanical failure.

Conclusions

Based on the results from this work, it can be concluded that fine stylus-type equipment can be used to quantify the surface quality numerically of radial and tangential surfaces of solid wood species as a function of sanding with different sizes of sandpapers. Also, it appears that shear strength of the specimens was not significantly affected by the sanding process as long as grit size of the sandpaper was above 80. Density of the species was found to be an important parameter influencing the shear strength test results. In further studies, it would be desirable to investigate shear strength of four species by using more than one adhesive at various spread rates to have a better understanding of their mechanical properties.

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