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Strength properties of laminated veneer lumber in compression perpendicular to its grain

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Abstract Tests of compression perpendicular to the grain were carried out on laminated veneer lumber (LVL) and timber. The species tested were sugi, radiata pine, karamatsu, akamatsu, and dahurian larch; two sets of sugi specimens were tested, with the sugi LVL products being manufactured in different plants. The strength properties of the materials for different loading directions were compared for LVL and timber. At 5% compressive strain in the same materials, the average stress in the tangential direction of timber was larger than that in the radial direction for all species except for radiata pine, and the average stress in the edge-wise direction of LVL was larger than that in the flat-wise direction for all species except for radiata pine. When the stress at 5% strain was compared in the same direction, the average stress of LVL in the edge-wise direction was larger than that in timber in the tangential direction for all species, but there were no great differences between the average stress of LVL in the flat-wise direction and that of timber in the radial direction for all species except for radiation pine. There was a close relationship between density and stress at 5% strain in LVL, especially in the edge-wise direction. For all results, radiata pine did not follow the trend of the other species; The large annual ring width of radiata pine was considered to have affected the results.

Key words Compression perpendicular to the grain · Strength property · Laminated veneer lumber (LVL) · Timber · Loading direction

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Introduction

According to the Ministry of Land, Infrastructure, Transport and Tourism, the design value of compression perpendicular to the grain of laminated veneer lumber (LVL) is set to the same value as that for glued laminated timber when LVL is to be used for purposes such as constructing building foundations.[1] In this system, the design value is given by species. However, it has been pointed out that some species of LVL cannot be used for foundations of three-story houses because of inadequate strength of the design value. LVL has a higher density than timber or glued laminated timber because it is produced by a hot press and the proportion of adhesive is higher than that in the other materials. Therefore, LVL is expected to have higher compression strength perpendicular to the grain than timber or glued laminated timber. In this study, tests of compression perpendicular to the grain were carried out using LVL produced from major species, and the strength properties were compared with those of timber. Additionally, the strength properties in different loading directions were compared in LVL and timber.

Materials and methods

Production of test specimens of LVL and timber

A total of 30 logs were used, five for each of six groups that included five species: sugi (Japanese cedar, *Cryptomeria japonica*), radiata pine (*Pinus radiata*), karamatsu (Japanese larch, *Larix kaempferi*), akamatsu (Japanese red pine, *Pinus densiflora*), and dahurian larch (*Larix gmelinii*); there were six groups because two sets of specimens were used for sugi, with the LVL products manufactured at different plants. Figure 1 shows how the specimens were collected. The logs 4000 mm in length were cut into two logs 2000 mm in length for the LVL and timber specimens. Logs for the LVL specimens were taken to an LVL manufacturing plant. Original LVL boards made from the mature wood of the logs were produced in the plant, and 12 specimens were taken from

Table 1. The manufacturing conditions of laminated veneer lumber (LVL)

Species	Thickness of veneer (mm)	Number of plies	Adhesive application rate (g/m^2)	Hot pressing		
				Temp. (°C)	Pressure (MPa)	Time (min)
Sugi (group A)	3.2	14	272	130	0.7	33
Sugi (group B)	3.9	12	224	130	0.8	31
Radiata pine	4.3	10	288	130	1.2	24
Karamatsu	3.5	13	272	130	0.9	33
Akamatsu	3.5	13	272	130	0.9	33
Dahurian larch	3.5	13	272	130	0.9	33

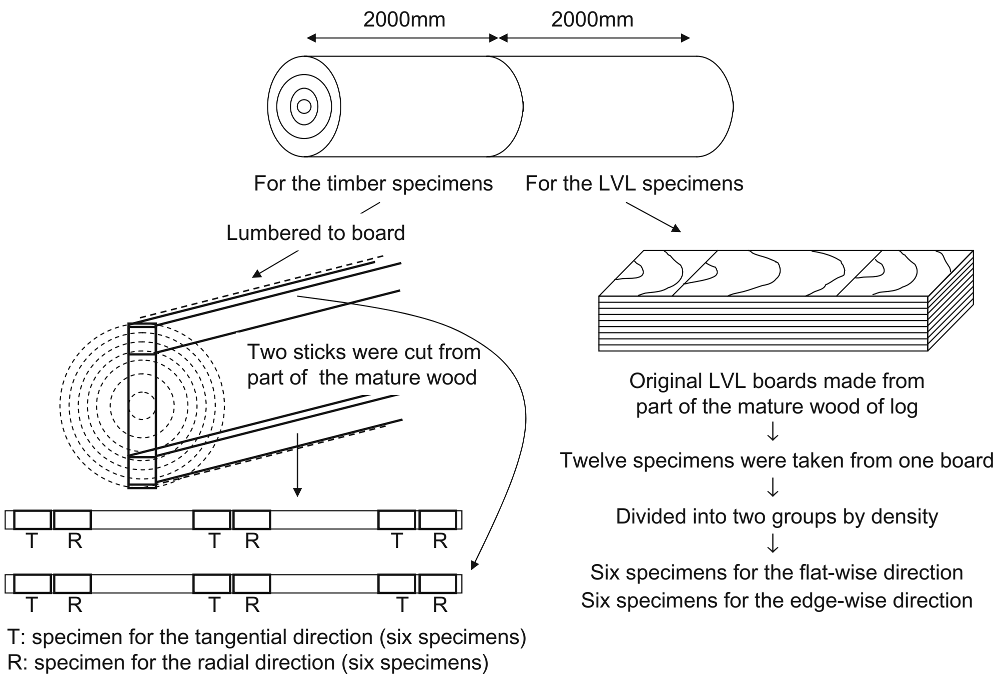


Fig. 1. Specimen collection procedures. *LVL*, laminated veneer lumber

one original board of LVL. The specimens were conditioned for several months in a room kept at a constant temperature of 20°C and a relative humidity of 65% in the Forestry and Forest Products Research Institute (FFPRI), Tsukuba, Japan. All LVL was glued using phenol-formaldehyde resin. The manufacturing conditions of the LVL are shown in Table 1. The logs for the timber specimens were lumbered to boards that included the pith before being air-dried for 2 months in the laboratory. Two sticks were cut from part of the mature wood of the boards to match the LVL specimens. Six specimens in the radial direction and six in the tangential direction were cut from sticks that had been air-dried in the laboratory for 1 month. Specimens were then conditioned for 1 month in a room at the FFPRI kept at a constant temperature of 20°C and a relative humidity of 65%. As shown in Fig. 2, the radiata pine specimens were collected from a different part of the log than the other specimens. Six specimens in a 3×2 pattern on one side and six on the opposite side were taken from a log, and prepared for radial loading. In addition, long-axis specimens were taken from the same end-matched positions, and these specimens were prepared for tangential loading. Thus, 12 specimens for each loading direction were taken from one log.

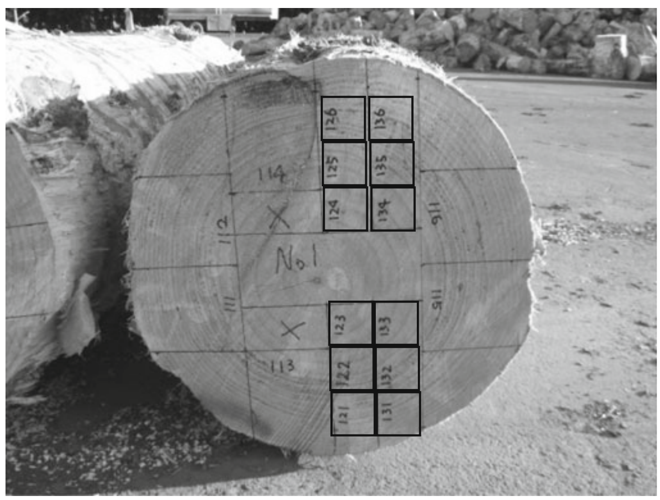


Fig. 2. Locations (enclosed with *squares*) where timber specimens of radiata pine were extracted. This procedure was different from that for the other species

The dimensions of both the LVL and timber specimens were 40 mm × 40 mm in cross section and 120 mm in length. Before testing, the density of the LVL specimens was measured, and the density and average annual ring width were measured for the timber specimens. The twelve LVL specimens for each group were divided into two sets with almost the same mean and standard deviation of density. Half of the specimens in each set were loaded in the flat-wise direction and the other half in the edge-wise direction.

Test method

Tests of compression perpendicular to the grain were carried out according to JIS Z 2101.[2] The loading direction is shown in Fig. 3. A universal testing machine with a 5-ton force capacity was used for loading, and we tried to keep the average loading speed under 0.98 N/mm^2 per minute. Some dahurian larch samples that were estimated to exceed the 5-ton maximum load were tested using the 3000-kN capacity of the compression testing machine with a 150-kN range.

A loading plate 40 mm in length with a round edge was used. Displacement transducers with a 10 mm range (Tokyo Sokki Kenkyujo, CDP-10) were attached to both ends of the loading plate and the displacements were measured. The average of the two values was determined to be the displacement. Tests were ended at 10% strain of the thickness of specimens. Load and displacement were recorded by a data logger (Tokyo Sokki Kenkyujo, TDS-601 or TDS-303). Compressive stress perpendicular to the grain was calculated from the load divided by the material width and length of the loading plate (40 mm). After the test, the moisture content of all specimens was measured by the oven-dry method.

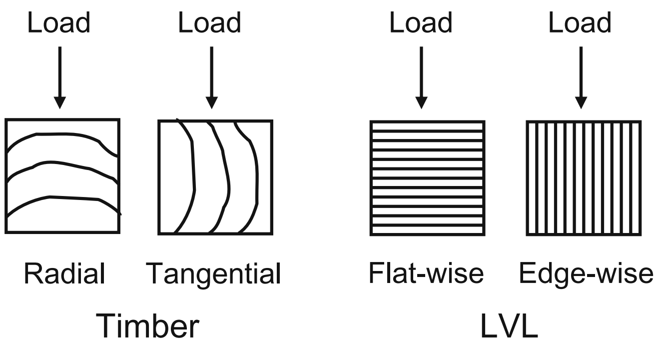


Fig. 3. Loading directions

Results and discussion

Table 2 shows the average annual ring width, density, moisture content, and stress at the proportional limit and at 5% strain. The definition of stress at the proportional limit and 5% strain are illustrated in Fig. 4. The moisture content of timber was 1.7%–4.1% higher than that of LVL in all groups. However, the effect of moisture content on strength is not taken into consideration in the following discussion because the effect of moisture content on compressive strength perpendicular to the grain is not sufficiently clear, e.g., ASTM

Table 2. Test results of each value in average

Species	Material	Loading direction	Number of specimens tested	ARW (mm)	ρ (kg/m^3)	MC (%)	σ_p (N/mm^2)	$\sigma_{5\%}$ (N/mm^2)
Sugi (Group A)	Timber	Radial	30	2.5 (18.2)	357 (9.7)	14.6 (1.9)	2.40 (20.0)	4.58 (14.8)
		Tangential	30	2.5 (16.5)	353 (9.3)	14.5 (2.1)	3.49 (24.4)	5.57 (14.6)
	LVL	Flat-wise	30	–	437 (6.9)	11.9 (3.1)	2.49 (15.1)	4.83 (22.1)
		Edge-wise	30	–	436 (6.9)	12.0 (2.6)	6.63 (15.5)	8.20 (15.8)
Sugi (Group B)	Timber	Radial	30	4.3 (17.9)	340 (5.6)	14.5 (1.3)	2.33 (30.1)	5.16 (14.8)
		Tangential	30	4.3 (18.0)	338 (5.5)	14.5 (1.1)	3.46 (27.1)	6.24 (16.1)
	LVL	Flat-wise	30	–	402 (8.9)	9.16 (4.9)	3.00 (18.1)	5.60 (21.6)
		Edge-wise	30	–	403 (8.9)	9.17 (5.1)	5.01 (31.2)	8.37 (20.1)
Radiata pine	Timber	Radial	60	14 (30.1)	473 (5.5)	11.1 (1.9)	7.80 (22.3)	12.1 (17.1)
		Tangential	60	14 (32.1)	469 (4.7)	11.1 (1.8)	6.31 (15.7)	10.4 (11.7)
	LVL	Flat-wise	30	–	526 (5.3)	9.42 (5.3)	7.49 (13.2)	14.0 (9.04)
		Edge-wise	30	–	526 (4.6)	9.43 (5.7)	7.78 (16.8)	13.9 (13.6)
Karamatsu	Timber	Radial	30	2.3 (9.8)	597 (10.0)	14.2 (2.3)	3.30 (32.1)	7.29 (31.5)
		Tangential	30	2.3 (10.3)	594 (9.6)	14.2 (2.4)	7.16 (23.4)	11.3 (17.2)
	LVL	Flat-wise	30	–	647 (5.9)	10.7 (6.8)	4.11 (21.9)	7.57 (24.9)
		Edge-wise	30	–	646 (5.7)	10.7 (5.5)	9.09 (13.6)	16.6 (15.0)
Akamatsu	Timber	Radial	30	2.7 (24.7)	528 (8.8)	14.4 (1.6)	3.65 (19.9)	7.94 (15.5)
		Tangential	30	2.6 (23.4)	525 (9.3)	14.3 (1.4)	5.44 (20.7)	9.60 (18.9)
	LVL	Flat-wise	30	–	585 (7.3)	11.3 (6.6)	4.54 (12.2)	8.36 (13.5)
		Edge-wise	30	–	584 (7.1)	11.2 (6.0)	8.37 (14.7)	14.1 (13.8)
Dahurian larch	Timber	Radial	30	1.0 (34.2)	677 (16.9)	14.4 (3.0)	5.66 (41.3)	10.8 (30.3)
		Tangential	30	1.0 (32.9)	678 (16.9)	14.3 (2.6)	8.02 (36.0)	13.1 (30.6)
	LVL	Flat-wise	30	–	711 (10.2)	10.3 (9.2)	5.91 (37.6)	11.2 (33.2)
		Edge-wise	30	–	710 (10.2)	10.3 (9.4)	13.3 (37.6)	20.4 (28.5)

The value in parentheses is the coefficient of variation

ARW, annual ring width; ρ, density; MC, moisture content; σ_p, stress at the proportional limit; $\sigma_{5\%}$, stress at 5% strain of thickness

D245[3] indicates that when the moisture content changes from green lumber to 19% or 15%, the allowable property increases are 50% in both cases, despite the 4% difference in the moisture contents.

The density ratio of LVL/timber was 1.2 in sugi; 1.1 in radiata pine, karamatsu, and akamatsu; and 1.05 in dahurian larch. Thus, as the density of the timber decreased, the relative density of the corresponding LVL increased.

Stress at 5% strain

The design value of compression perpendicular to the grain is determined to be the smaller value of stress at failure or stress at 5% strain when actual-sized specimens are loaded with a loading block of the same width as the specimens.[4] Therefore, in this section, stress at 5% strain is discussed. Figure 5 shows the average stress at 5% strain and the design value of each group. The results of a *t* test comparing the loading directions and materials of each group are also shown in Fig. 5.

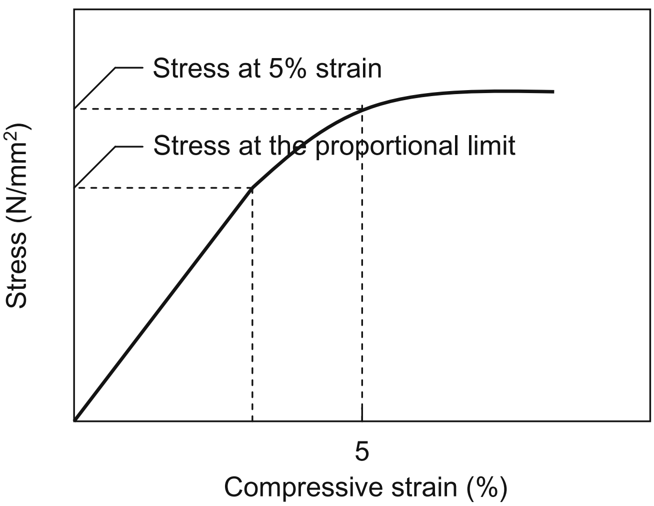
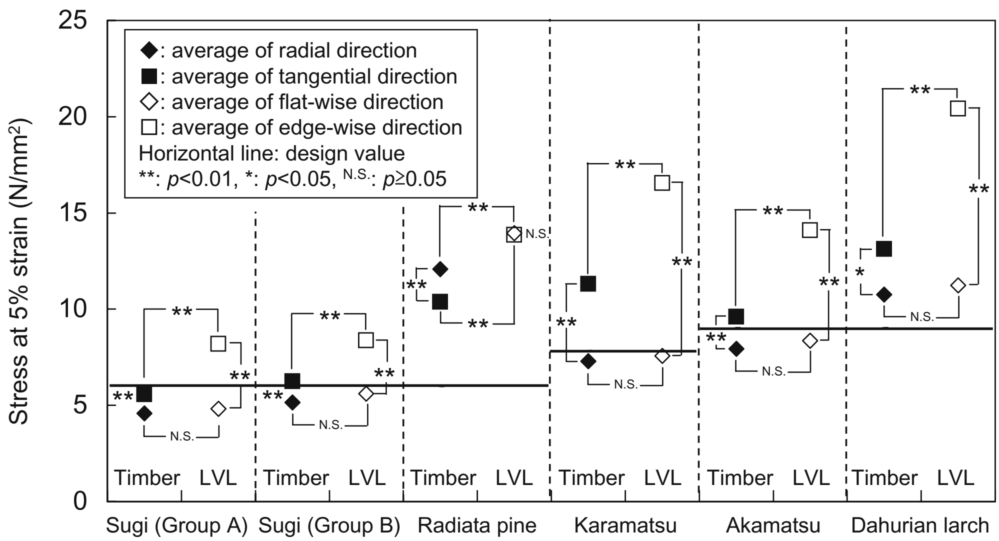


Fig. 4. Definition of stress at the proportional limit and 5% strain

First, the difference of stress with loading direction was compared for the same material. In the timber, the average stress in the tangential direction was larger than that in the radial direction for all species except for radiata pine. In most of the LVL samples, the average stress in the edge-wise direction was larger than that in the flat-wise direction for all species except for radiata pine, and the range of increase was marked compared to that in the timber. The reason for the difference in strength with loading direction was considered to be as follows. In the case of timber, compression in the radial direction causes crushing failure in the earlywood zone, and compression in the tangential direction results in buckling of the growth ring.[5] These phenomena occur because latewood had a higher density and strength than earlywood in the timber.[6] When load is applied in the tangential direction, vertically lined latewood is considered to protect the earlywood from crushing. When load is applied in the radial direction, earlywood is selectively crushed. Therefore, the tangential direction showed higher strength than the radial direction. In the case of LVL, it is considered that some layers included more latewood and other layers included less latewood. This means that there were layers with higher strength and layers with lower strength within one LVL. When load was applied in the edge-wise direction, vertically lined layers with higher strength protected the weaker layers from crushing. When load was applied in the flat-wise direction, weaker layers were selectively crushed. Thus, the strength varied with the loading direction. However, radiata pine did not fit this trend, either for timber or LVL. As shown in Table 1, the annual ring width of radiata pine was quite large compared with that of the other species. This means there was substantially less latewood than earlywood in radiata pine, so mainly earlywood received the stress in both the radial and tangential directions in the timber. The LVL of radiata pine was mainly composed of earlywood, and there was no great difference between the edge-wise and flat-wise directions.

Second, the difference in materials was compared for the same loading direction. The average in the edge-wise direc-

Fig. 5. Average for 30 or 60 (radiata pine) samples of stress at 5% strain for each group



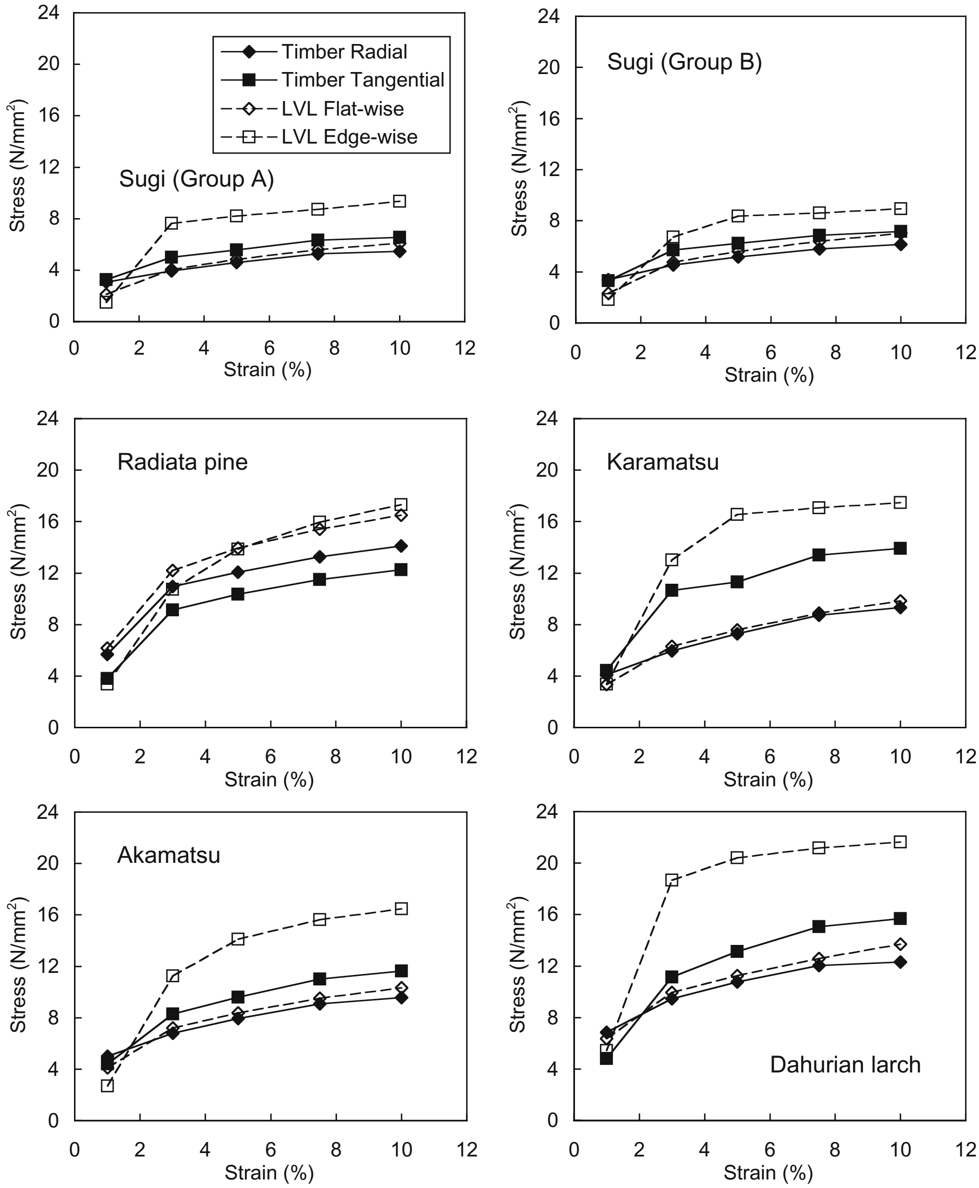


Fig. 6. Relationship between average stress and strain for each group

tion of LVL was larger than that in the tangential direction of timber for all species, but there was no great difference between the flat-wise direction of LVL and the radial direction of timber for all species except for radiata pine. These results were considered similarly to those for different loading directions. In the case of LVL in the edge-wise direction, the density was higher than that of the corresponding timber. Thus, the average stress of LVL was larger than that of the corresponding timber in the tangential direction. For LVL in the flat-wise direction, the density was also higher than that of the corresponding timber, but weaker layers of LVL still existed, and these layers crushed first. Thus, the average stress of LVL in the flat-wise direction was similar to timber in the radial direction. Therefore, when comparing the strength between timber and LVL, the loading direction should be taken into consideration.

The average stress values at 5% strain of each species were compared with the design values. The stress in the tangential and edge-wise directions mostly satisfied the design value. However, in the radial and flat-wise directions, the average stress was similar to or fell somewhat below the design value, except for radiata pine and dahurian larch.

Relationship between stress and strain

Figure 6 shows the relationship between average stress and strain for each group. Comparing the radial and tangential directions in timber, there was no clear difference in stress at 1% strain, but after 3% strain, a difference of stress gradually appeared, especially in karamatsu, akamatsu, and dahurian larch. When the flat-wise and edge-wise directions were compared in LVL, there was no clear difference of stress at 1% strain, as for timber, but at 3% strain, the difference of stress was marked compared to timber. After 5% strain, the stress reached the limit. The behavior of LVL of

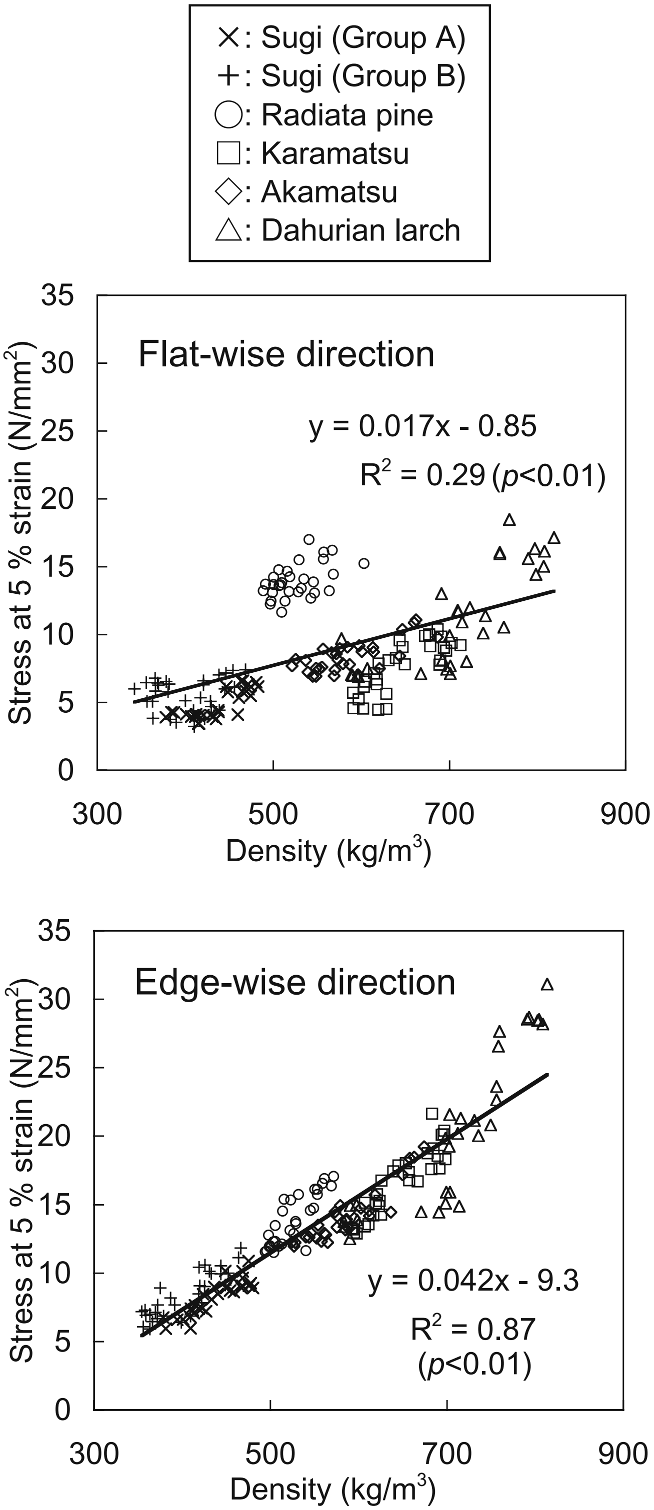


Fig. 7. Relationship between density and stress at 5% strain of LVL

radiata pine was different from that of the other species. The stress in the flat-wise direction was higher than that in the edge-wise direction at 1% strain. However, the stress in the flat-wise direction and edge-wise direction gradually reversed at around 5% strain. Miyatake et al.[7] showed a similar trend in LVL from radiata pine, i.e., the stress in the flat-wise direction was higher than that in the edge-wise direction at the proportional limit and 1% strain, but the stress in the edge-wise direction was higher than that in the flat-wise direction at strains of 3%, 5%, and 10%. Meanwhile, in Douglas-fir, the stress in the edge-wise direction was generally higher than that in the flat-wise direction.[7] As in a previous study, radiata pine also showed unique behavior in the stress–strain curve.

Relationship between density and stress at 5% strain in LVL

Density and stress show a close correlation in timber.[8] To confirm the relationship in LVL, the relationship between stress at 5% strain and the density in the flat-wise direction and edge-wise direction are shown in Fig. 7. In the flat-wise direction, the stress–density plot was relatively linear, and only the data for radiata pine did not fit the line. This result again confirmed that the strength in the flat-wise direction in LVL of radiata pine showed contrasting behavior compared with that of the other species. On the other hand, in the edge-wise direction, very linear stress–density plots were obtained, including those for radiata pine.

Conclusions

The strength properties in compression perpendicular to the grain were examined using LVL from six groups of timber from five species. The loading direction appeared to affect the strength property of both timber and LVL. It was found that the difference in strength properties between timber and LVL differed with the loading direction. However, radiata pine did not fit the trend of the other species.

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