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研究資料（Research record）

Variations in internal- and end checks in boxed-heart square timber of sugi (*Cryptomeria japonica*) cultivars dried by the high-temperature setting method

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Abstract

The variations of internal- and end checks formed in the boxed-heart square timber of sugi by the high-temperature setting method were examined with three cultivars. Total lengths of internal- and end checks were longer for aya-sugi than other cultivars. The total lengths of internal- and end checks exhibited high positive correlations with density and latewood percentage.

Key words : sugi boxed-heart square timber, high-temperature setting method, internal check, end check, wood properties

1. Introduction

Boxed-heart timber without a kerf is susceptible to surface checks, which are likely to trigger complaints related to housing construction. Various kiln drying methods to prevent surface check forming have been developed (Kuroda 2007). The high-temperature setting method developed by Yoshida et al. (Yoshida et al. 2000) makes drying set at the outer part of the timber by treating timber under conditions of high temperature and low moisture during the early stage (Tokumoto et al. 2004). Nowadays, this is one of the mainstream methods used for kiln drying of boxed-heart square timber in Japan. Recently, drying schedules which are not prone to cause internal check or strength deterioration have been studied for the main softwood species (Yoshida et al. 2004, Tokumoto et al. 2005, Research Group of Development of Technology for producing Safe and Trustful Dried Timber 2012).

Sugi (*Cryptomeria japonica* D. Don), the most common plantation species, shows significant variations in wood properties such as moisture content, shrinkage, density, and strength, which is why drying-check also varies by timber. In our previous study, boxed-heart square timber of two cultivars with different levels of tangential shrinkage and similar densities were kiln dried together using the high-temperature setting method, and the timber with larger tangential shrinkage formed a larger area of internal checks (Yamashita et al. 2012b). In this study, internal- and end checks were examined among three cultivars which had different wood properties in density and tree ring structures.

For the high-temperature setting method, it is known that internal checks increase with extension of the high-temperature setting treatment and the dry-bulb temperature at drying (Yoshida et al. 2004, Research Group of Development of Technology for producing Safe and Trustful Dried Timber 2012), which suggests that a small difference in drying condition would make a difference in internal check. In this study, different cultivars were dried separately. Although the small difference in drying condition might have affected the drying-check difference among cultivars, some internal check characteristics by cultivars considered to have been affected by their wood properties were observed.

2. Materials and methods

2.1 Materials

Three sugi cultivars, boka-sugi (B), aya-sugi (A), and ryuunohige (R) were used. The sample trees were the same as those used in our previous studies on bow (Yamashita et

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al. 2011). Trees of each cultivar were taken from the same stands (boka-sugi: Takaoka, Toyama; aya-sugi: Kahoku, Kumamoto; ryuunohige: Kikuchi, Kumamoto). As shown in Fig. 1, logs were taken at two heights above ground (lower height, “timber 1”; upper height, “timber 4”) and sawn into 1.8–1.9 m-long boxed-heart square timber with a 115 × 115 mm cross-section including pith at the center of each end. Disks were cut at both ends of the logs to measure the fundamental wood properties.

2.2 Wood properties

Moisture contents of the heartwood (MC_{HW}) and sapwood (MC_{SW}) were measured using disks. The heartwood area percentage (HWP) on the transverse faces was calculated from the heartwood radius and timber dimension. Basic density (BD) was measured using small blocks cut at 20 mm intervals from the pith to the edge of the timber, whereupon their mean values were calculated. The tree ring parameters, ring width (RW), latewood percentage (LWP), earlywood density (EWD), and latewood density (LWD), were measured by soft X-ray densitometry (Yamashita et al. 2009) and averaged through rings included in each timber. The earlywood and latewood boundary was set at 550 kg/m^3. Tangential and radial shrinkages from green to oven-dried condition (α_T, α_R) were measured using small clear samples of dimensions 30 (T) × 30 (R) × 5 (L) mm, at a distance of 30 mm from the pith where internal checks appeared most prominently. Those wood properties in diametrically opposed directions were averaged for each disk, and the mean values at both ends of the timber were calculated.

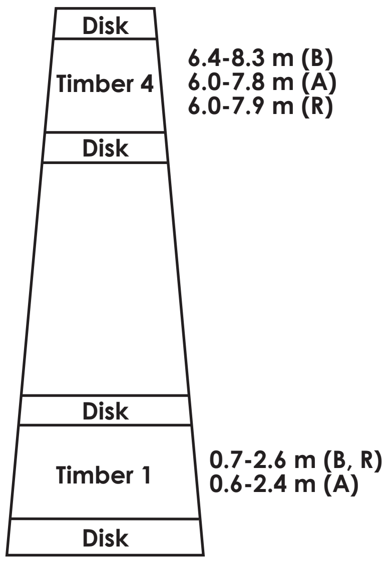

Fig. 1. Sampling heights above ground for boka-sugi (B), aya-sugi (A), and ryuunohige (R)

2.3 Kiln-drying

Timbers 1 and 4 from each cultivar were arranged alternately in stacked layers in the kiln (SKIF10LPT, Shinshiba) (Table 1). The drying schedule was as follows: steaming (90°C dry bulb, 90°C wet bulb, 8 h), drying (120°C dry bulb, 90°C wet bulb, 88 h), and conditioning (95°C dry bulb, 91°C wet bulb, 24 h). The moisture content of the green (MC_{GT}) and dried timber (MC_{DT}) was obtained as the water weight per oven-dry wood weight.

2.4 Measuring internal checks

As shown in Fig. 2, after kiln drying, 40-mm-thick transverse slices were taken using a circular saw from five longitudinal positions: both ends (slices 1 and 5), the center (slice 3), and their mid-section (slices 2 and 4). The internal check was measured using slices 2, 3, and 4. The end check was measured using the inner faces 40 mm from the ends of slices 1 and 5, because the end surface cut by a chainsaw was rough. The transverse face of each slice was

Table 1. Heartwood area percentage and the moisture contents of the heartwood, the sapwood, green timber, and kiln-dried timber

Kiln group	Cultivar	Sample	N	H (m)	HWP (%)		MC_{HW}		MC_{SW}		MC_{GT} (%)		MC_{DT} (%)	
					Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	Boka-sugi	B1	21	0.7–2.6	95.8	8.5	81.5	16.1	244.5	31.1	78.3	11.0	6.6	3.6
1		B4	21	6.4–8.3	37.1	16.4	87.4	11.6	216.3	18.0	125.6	18.6	9.5	4.6
2	Aya-sugi	A1	15	0.6–2.4	100	0.0	47.5	2.9	—	—	41.4	5.5	7.6	3.2
2		A4	15	6.0–7.8	98.8	4.5	40.1	1.3	108.3	2.9	44.9	3.9	13.0	2.9
3	Ryunohige	R1	8	0.7–2.6	100	0.0	100.0	13.5	—	—	50.4	15.9	4.2	2.0
3		R4	8	6.0–7.9	65.5	10.3	47.9	3.2	137.9	21.4	32.9	6.9	5.3	3.1

H: Height above ground of the timber source, HWP: heartwood area percentage on the transverse face of timber, MC_{HW}: moisture content of the heartwood, MC_{SW}: moisture content of the sapwood, MC_{GT}: moisture content of green timber, MC_{DT}: moisture content of dried timber.

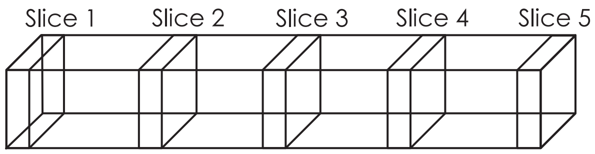

Fig. 2. Drying-check measurement positions within a timber

scanned by an image scanner (GT-F600, Epson) and printed out on white paper. The outline of the check was traced on the back of the printed paper, and its image captured by the scanner. The numbers (NIC, NEC), total areas (TAIC, TAEC), and average areas (AAIC, AAEC) of the internal- and end checks were obtained by an image processing program (ImageJ, NIH). Total lengths of the internal- and end check (TLIC, TLEC) were measured using a ruler. The number, total length, and total area of drying-checks were calculated per square meter of the green timber transverse area.

3. Results and discussion

3.1 Wood properties

The heartwood area percentage (HWP) differed by samples (Table 1). Timbers 1 and 4 of aya-sugi (A1 and A4) and ryuunohige timber 1 (R1) were occupied with the heartwood. For boka-sugi timber 1 (B1), some timber contained the sapwood at its edges. For timber 4 of boka-sugi (B4) and ryuunohige (R4), the heartwood was inside the inscribed circle.

The moisture content of green timber (MC_{GT}) was high for B4, which contained high percentage of the sapwood (Table 1). The MC_{GT} was low for aya-sugi, of which moisture content of the heartwood (MC_{HW}) was low and HWP was high. Ryuunohige timber 1 (R1) exhibited higher MC_{GT} than timber 4 (R4), because its MC_{HW} was higher. The moisture content of dried timber (MC_{DT}) was high for aya-sugi, and low for ryuunohige.

The basic density (BD) and the latewood percentage (LWP) were large for aya-sugi and small for boka-sugi (Table 2). The ring width (RW) was large for aya-sugi and small for ryuunohige. Boka-sugi exhibited large earlywood density (EWD) and small latewood density (LWD), while ryuunohige exhibited small EWD and large LWD. Tangential shrinkage (α_T) and radial shrinkage (α_R) were large for ryuunohige and small for boka-sugi (Table 2).

3.2 Variation of internal checks

First, the variation within timber in the longitudinal direction was examined. Slices 1 and 5 taken from the timber ends showed many small checks all over the transverse face, while slices 2, 3, and 4 showed fewer and larger checks (Fig. 3). As a result of check measurement, the number and total area were larger, total length longer, and average area smaller for slices 1 and 5 compared to slices 2, 3, and 4 (Fig. 4). Among slices 2, 3, and 4, no significant difference emerged in the internal check parameters except number of R1, average areas of B4 and R1 ($P < 0.05$). Therefore, we decided to use slice 3 as representative of internal check of each timber.

As for internal check, aya-sugi formed many small checks. Aya-sugi exhibited the largest number (NIC), the longest total length (TLIC), and the smallest average area (AAIC) (Fig. 5). The difference among cultivars of NIC and TLIC were significant by Tukey-Kramer HSD test ($P < 0.05$). The MC_{DT} of aya-sugi was higher than the others (Table 1), which suggested that its internal check might be more prominent when they are dried at the same level as the others. Previous study also reported that internal check occurrence was more prominent for aya-sugi than obi-sugi and shakain (Research Group of Development of Technology for producing Safe and Trustful Dried Timber 2012). It might be attributable to the wood property of aya-sugi.

Table 2. Basic density, tree ring structures, and shrinkage

Sample	BD (kg/m^3)		RW (mm)		LWP (%)		EWD (kg/m^3)		LWD (kg/m^3)		α_T (%)		α_R (%)		α_T/α_R (%/%)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
B1	343	16	3.70	0.56	27.9	4.6	365	17	758	26	5.25	0.48	2.56	0.21	2.09	0.22
B4	322	14	3.88	0.47	23.4	5.9	381	13	765	21	5.53	0.40	2.68	0.25	2.08	0.15
A1	373	15	4.36	0.86	40.4	7.5	344	26	781	26	6.12	0.31	2.44	0.23	2.55	0.17
A4	405	9	4.17	0.66	43.2	4.5	379	24	801	27	6.46	0.33	2.35	0.13	2.77	0.11
R1	356	7	2.56	0.60	29.0	4.6	337	30	848	33	7.24	0.46	2.81	0.21	2.58	0.13
R4	373	10	2.28	0.47	34.0	3.1	330	19	888	18	7.40	0.41	3.16	0.10	2.35	0.12

BD: basic density, RW: ring width, LWP: latewood percentage, EWD: earlywood density, LWD: latewood density, α_T: tangential shrinkage, α_R: radial shrinkage.

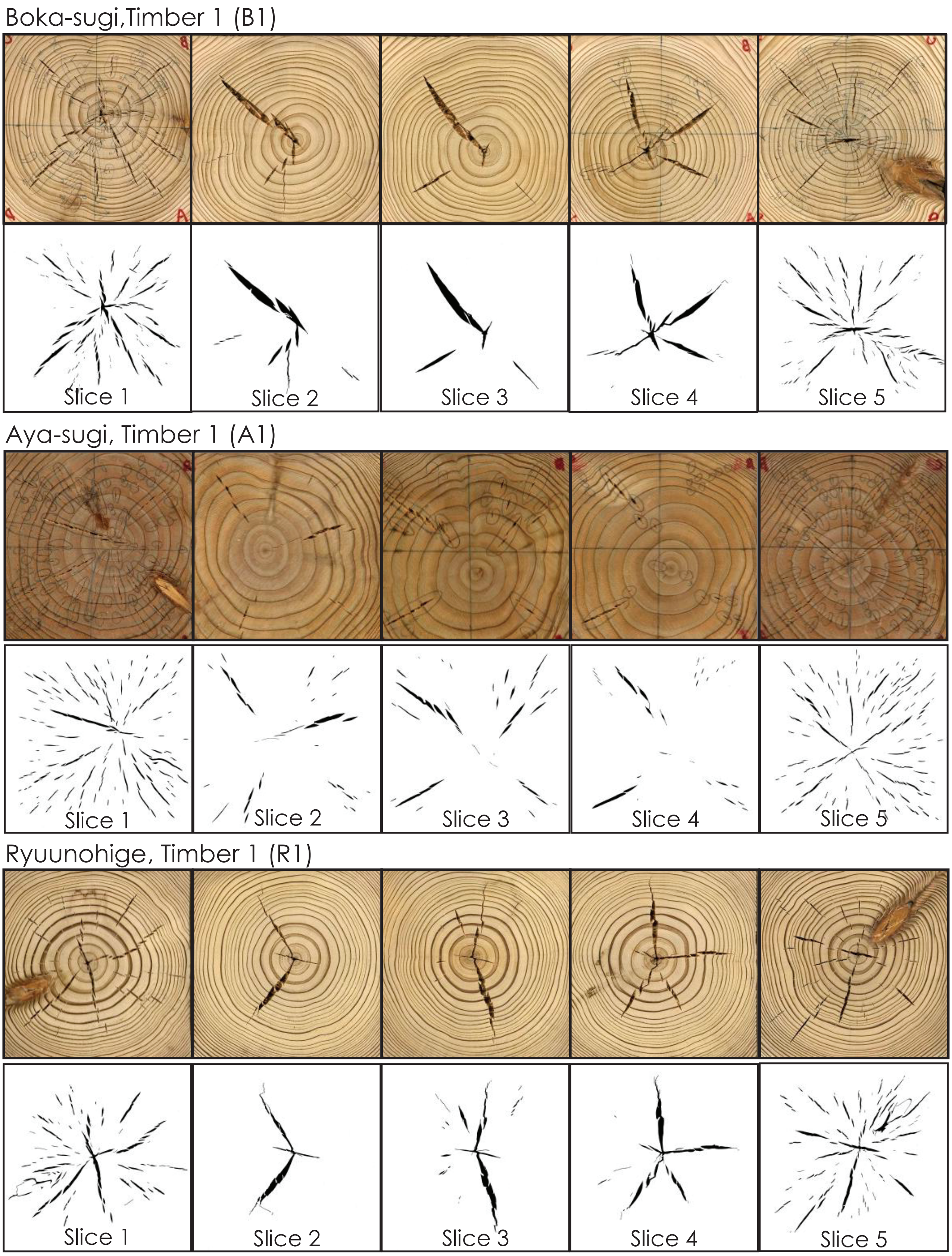

Fig. 3. Typical images of internal-check (slices 2, 3, and 4) and end-check (slices 1 and 5)

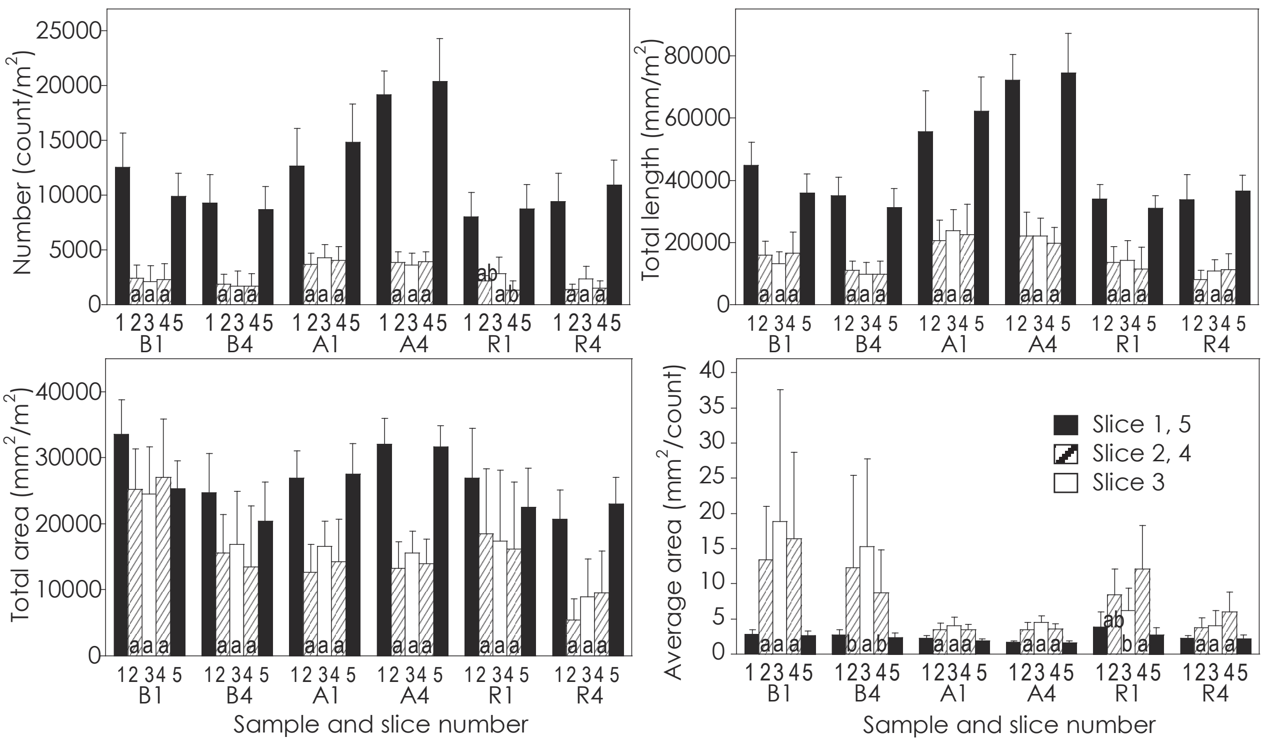

Fig. 4. Drying-check variation within a timber
a and b show significant difference among slice 2, 3, and 4 within each sample group using the Tukey-Kramer HSD test (P < 0.05).

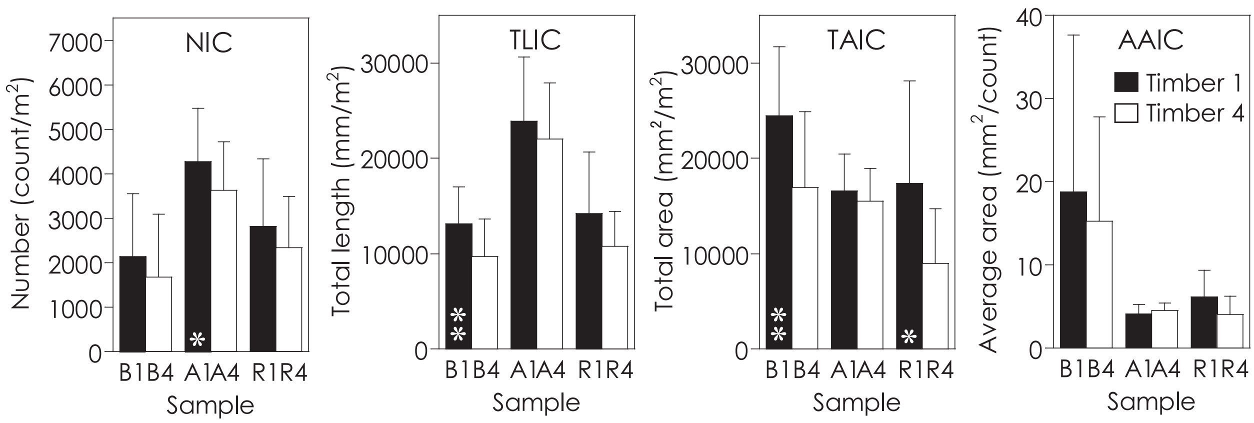

Fig. 5. Means and standard deviations of internal check parameters
Asterisks show significant difference between timber 1 and timber 4 within cultivars using a paired t-test ($^{**}P$ < 0.01, $^{*}P$ < 0.05).

In order to evaluate internal check, different parameters such as total length, the maximum length, and total area are used depending on its purpose such as comparing with the strength properties (Ido et al. 2005, Obara et al. 2006, Saito and Tonosaki 2008, Tonosaki et al. 2010, Research Group of Development of Technology for producing Safe and Trustful Dried Timber 2012). In this study, the correlations between total length of internal check and wood properties were obtained to examine which wood properties are related to check occurrence. The BD and LWP exhibited the highest correlations among the wood properties (Table 3, Fig. 6). One possible explanation is that the timber with high density prone to form checks.

In our previous study (Yamashita et al. 2012b), timbers dried together were compared, and most timber didn't contain the sapwood. In this study, each cultivar was dried

Table 3. Correlation coefficients between total length of internal- and end checks and wood properties

	HWP	MC_{GT}	BD	RW	LWP	EWD	LWD	α_T	α_R	α_T/α_R
Internal check	0.545^{***}	-0.490^{***}	0.562^{***}	0.420^{***}	0.661^{***}	0.363^{***}	-0.160	0.188	-0.365^{***}	0.525^{***}
End check	0.344^{**}	-0.347^{***}	0.619^{***}	0.602^{***}	0.673^{***}	0.571^{***}	-0.309^{**}	0.061	-0.528^{***}	0.559^{***}

BD, RW, LWP, EWD, LWD, α_T, and α_R: see Table 2. $^{***}P < 0.001$, $^{**}P < 0.01$.

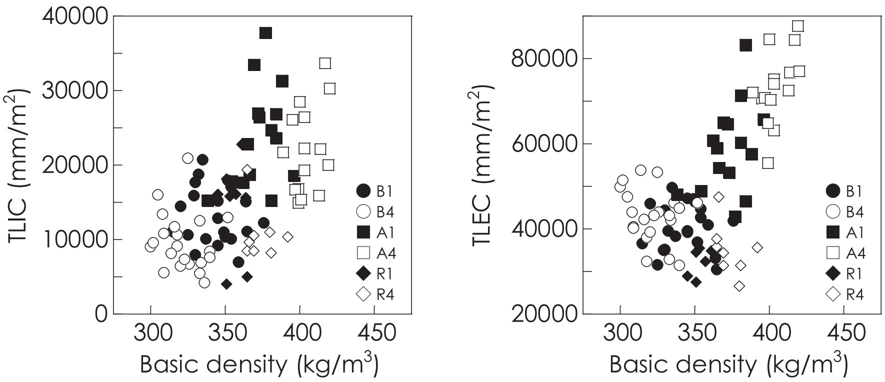

Fig. 6. Relationship between total length of check and basic density
TLIC: total length of internal check, TLEC: total length of end check.

individually, and HWP and moisture content distribution varied among samples, which made the effect of wood properties on internal checks more complicated. Most internal checks were observed within the heartwood, and TLIC exhibited a positive correlation with HWP (Table 3). The TLIC exhibited a negative correlation with MC_{GT} (Table 3). These results suggested a potentiality that the heartwood percentage and moisture content may affect internal-check formation. Surface check was not observed after drying, but there is a possibility that it had been formed at the initial stage and closed later during drying, which had an effect on drying set and internal check occurrence. Our previous study of conventional kiln drying observed that the total length of surface check was longer for the timber taken from the upper part of stem, which included more sapwood (Yamashita et al. 2012a). Kawabe et al. (Kawabe et al. 1993) reported that the internal stresses during vacuum-drying with high frequency heating were different depending on the heartwood moisture content. It is a future study whether the area and strength of drying set are different depending on the distributions of moisture content and heartwood/sapwood in high temperature setting method.

In our previous study using timber at similar level of density and HWP, the correlation with internal check was high for α_T (Yamashita et al. 2012b), whereas this study showed a negative correlation with α_R and a positive correlation with α_T/α_R. These results suggest that larger tangential shrinkage and tangential/radial shrinkage anisotropy tends to increase internal checks, but its effect is complicated depending on other wood properties and drying condition.

3.3 Variation of end checks

The end of timber is prone to check, which is considered due to that shrinkage is relatively smaller in longitudinal rather than transverse direction, rapid longitudinal moisture movement results in high stresses at lumber ends due to quick drying, and the check appears in a line pattern at weak connections between ray parenchyma and tracheids (Terazawa and Tsutsumoto 1986).

The end-check difference was examined using the mean of slices 1 and 5. Among the cultivars, aya-sugi exhibited larger NEC and longer TLEC than the other two cultivars (Tukey-Kramer HSD test, $P < 0.05$) (Fig. 7). Among the wood properties, BD and LWP exhibited the highest correlations with TLEC (Table 3, Fig. 6). The HWP and α_T/α_R also exhibited positive correlations and MC_{GT} exhibited a negative correlation. Those results were common with those gained for internal check.

This study showed that both of internal- and end checks were smaller and more abundant for aya-sugi than other

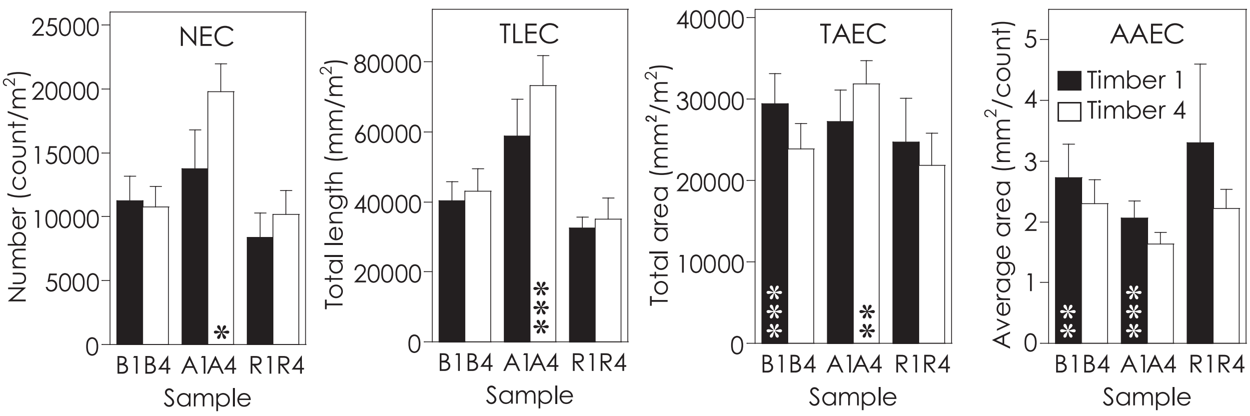

Fig. 7. Mean and standard deviation of end check parameter
Asterisks show significant difference between timber 1 and timber 4 within cultivars using a paired t-test ($^{***}P < 0.001$, $^{**}P < 0.01$, $^{*}P < 0.05$).

two cultivars (Fig. 3). Sakagami et al. (Sakagami et al. 2009) observed that microcracks occurred between tracheid and ray parenchyma in the latewood region, the crack tip advanced in both the bark and pith directions, and stopped at the earlywood region. It would be interesting to examine whether the microcrack occurrence and stopping are different among samples with different tree ring structures.

4. Conclusion

Both of internal- and end check exhibited similar trends among cultivars: aya-sugi formed many drying checks and its total length was the longest. Density and latewood percentage were correlated with the total lengths of checks, which suggested that density and tree ring parameters are candidates of factors related to the drying check occurrence and elongation.

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スギ在来品種の心持ち正角材における高温乾燥で生じた内部割れと木口割れの変動

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要 旨

スギ 3 品種から採取した心持ち正角材を高温セット法で乾燥し、生じた内部割れと木口割れの変動を調べた。内部割れおよび木口割れの総長は、アヤスギで最も長く、密度と晩材率との間に高い正の相関を示した。

キーワード：スギ心持ち正角、高温セット法、内部割れ、木口割れ、材質

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