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Impact Bending Strength of Small Specimens Cut from Japanese larch Timber Kiln-dried by the High-temperature Setting Method

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Abstract

Japanese larch (*Larix kaempferi* Carriere) is the most important tree species in Nagano prefecture, Japan. It is necessary to expand supply and demand for thinned wood to improve forest amenities. Then the high-temperature setting method (HTS), which is one of high-temperature kiln-drying, was developed for rapid drying of box-hearted square timbers, which are usually used as columns of Japanese conventional houses.

In this paper, we examined the effects of the HTS on mechanical properties of small specimens cut from Japanese larch box-hearted square timbers since we expected that heat and hot water within the timbers should effect on wood properties such as strength, and the effects should differ between inner and outer portion of the timbers. The small clear specimens were cut from kiln-dried timbers (105 x 105 x 3000 mm). In the cross section, tested timbers were cut into four parts horizontally and vertically, then 16 specimens were obtained for a timber. The small specimens were sorted to "corner", "outside", "core" by the portion of the timber. The specimens were prepared for static bending, static compression, and impact bending according to Japanese Industrial Standard (JIS). The impact bending tests were conducted by the Charpy type. The controlled specimens (AS) were cut from natural seasoned timbers without kiln-drying.

For both HTS and AS specimens, core specimens were weaker than corner specimens in the above tests. In compressive tests, the differences were small between HTS and AS, but impact strength of HTS was significantly lower than AS specimens. Particularly, the tendency was remarkable in the core specimens. For static bending strength, it seemed intermediate between compressive strength and impact bending strength.

Key words: static bending strength, static compressive strength, impact bending strength, boxed-heart square timber, small clear specimen

Introduction

In Nagano prefecture, Japan, about 80 % of the prefecture area is covered with natural and planted forests, and the most important tree species is Japanese larch (*Larix kaempferi* Carriere), which occupies approximate 36 % of the forests. It is necessary to expand supply and demand for the thinned wood to improve forest amenities and activities. Japanese larch small timbers had been used for civil structures as timber piles. Recently, demand for Japanese larch timbers shifted from the civil purpose to house constructions.

In Japan, half of a million wooden houses are built every year, and approximately 80 % of these are constructed using Japanese conventional timber structures known as "Jikugumi". Details of Japanese house constructions should be referred to ex. Hirai *et al.* (1997). Many posts with relative big cross section, whose dimensions are 105 x 105 mm or 120 x 120 mm, are used for the constructions. The development of rapid and low-cost kiln-drying methods is one of the most effective skills to increase structural uses. Then the high-temperature setting (HTS) method, which is one of high-temperature steam-heated kiln-drying, was developed by Yoshida *et al.* (2000). The method enables rapid drying of box-hearted square timber, which is commonly used as columns of Japanese conventional houses. In HTS method, the difference between initial dry- and wet-bulb temperatures is relative big compared to the conventional method referred to Culperpper (1990). Topics of recent studies on properties of wood kiln-dried by the HTS are drying set by Tokumoto *et al.* (2004), surface checks by Yoshida *et al.* (2004), and bending strength by Takeda *et al.* (2004).

For Japanese larch timber, the effects of the HTS method on mechanical properties were investigated on bending strength by Yoshida *et al.* (1999) and compressive strength by Nakashima *et al.* (1999) as previous researches. Then we investigated on the differences of mechanical properties among inner portions of cross section. It was also expected to clear wet-thermal effect on mechanical properties.

Materials and Methods

Materials

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The thinned Japanese larch logs for the tests were harvested in Nagano prefecture, Japan. The logs were 3 m long and with top diameters ranged from 16 cm to 20 cm. The numbers of prepared logs were 274. All logs were processed into square timbers with a pith, and the dimensions of them were 120 mm x 120 mm x 3000 mm. The 224 green timbers were kiln-dried, and the other 50 timbers were one-year natural air seasoned. The air seasoned timbers were assumed as control specimens.

The kiln-drying schedule, which is called as "High-temperature setting method" (HTS), was 48 hours with dry bulb temperature of 130℃ and wet bulb temperature of 80℃ after steaming of 5 hours. During drying, the weight of 3.5 ton was loaded on the stacks to reduce twist or crook. The timbers were seasoned for one year after kiln-drying.

Both HTS and natural air seasoned (AS) timbers were planed with the cross section of 105 mm x 105 mm. Static bending tests were conducted on these structural-sized timbers, and sound blocks were cut from the non-destructive portion of the tested timbers. The compressive tests were conducted on the short columns cut from the blocks. The other blocks were cut into 16 sticks (20mm x 20mm x about 400 mm) as shown in Fig. 1. The cross section of them was 20 mm x 20 mm. The sticks were designated to "Corner (A)", "Outside (B)", or "Core (C)" according to the portion within the cross section. Small clear specimens for impact bending, static bending and static compression were obtained from the sticks.

Static tests for structural timber

Static bending tests for structural timbers were conducted on the both HTS and AS timbers. Before bending tests, dynamic Young's modulus was measured by the longitudinal vibration method. The tests was four-point bending at loading speed of 5 mm/min. The span was 2700 mm, and the distance between loading points was 900 mm. *MOE* and *MOR* were calculated by the following equations.

$$MOE = \frac{a\Delta P}{48I\Delta y}(3L^2 - 4a^2) \qquad (1)$$

where a is distance between loading and supporting points, L is span, ΔP is increment of load, Δy is increment of deflection at midspan, $I = bh^3/12$, b is width, h is depth.

$$MOR = \frac{aP}{2Z} \qquad (2)$$

where a is distance between loading and supporting points, P is maximum load, $Z = bh^2/6$, b is width, h is depth.

Static compressive tests were conducted on the short columns (105 mm x 105 mm x 515 mm, slenderness λ=17). The loading speed was 9.81 N/mm^2, and Young's modulus (*CE*) and compressive strength (*CS*) was obtained by equation (3) and (4), respectively.

$$CE = \frac{\Delta P\ell}{A\Delta\ell} \qquad (3)$$

where ΔP is increment of load, ℓ is length, $\Delta\ell$ is increment of length, A is cross section area (= 105 mm x 105 mm).

$$CS = \frac{P}{A} \qquad (4)$$

where P is maximum load, A is cross section area.

The mean moisture contents of structural timbers at testing were 11.8% (1.09%) for HTS and 15.4% (0.56%) for AS, respectively. The values in parentheses denote standard deviations.

Impact bending test

The tested specimens for impact bending according to JIS (1994) were 20 mm x 20 mm x 300 mm. The impact bending tests were conducted with the 10 kgf·m Charpy type testing machine (Maekawa Co.). The span was 240 mm. The weight of the hammer was 10.922 kg, and the initial velocity of the hammer was 4.72 m/sec. Absorbed energy was calculated by the following equation.

$$U = \frac{Q}{A} \qquad (5)$$

where U is absorbed energy (J/cm^2), Q is work (J), A is cross section area (cm^2).

The acceleration of the hammer was also measured with acceleration pickup and FFT analyzer (sound and vibration signal analyzer SA-74, RION Co.). Impact bending strength (= ultimate stress) was calculated by equation (6).

$$\sigma_a = \frac{3l}{2bh^2}F \qquad (6)$$

where σ_a is impact bending strength, ℓ is span, b is width, h is depth, F is maximum load.

Ductility (or brittleness) was estimated with deflection at ultimate stress calculated by equation (7).

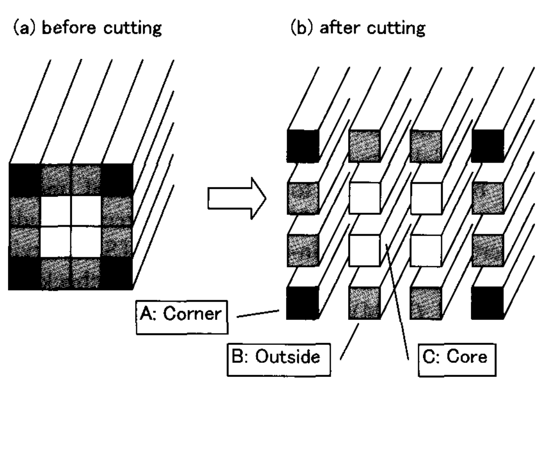

Fig. 1. Small clear specimens cut from square-sawn timber.
Note: Corner, outside and core were as filled, shaded and blank boxes, respectively.

$$Y_a = \iint \alpha \, dt \quad (7)$$

where Y_a is deflection (μm) at ultimate stress, α is acceleration. The integration was calculated from initial contact to ultimate acceleration.

Mean moisture contents for each portion were as follows: A: 7.9% (0.30%), B: 8.2% (0.65%), C: 8.8% (0.57%) for HTS, and A: 10.8% (0.37%), B. 10.9% (0.43%), C: 10.9% (0.38%). The values in parentheses denote standard deviations.

JIS bending and compressive tests

Static bending tests were also conducted on small clear specimens according to JIS. The cross section of the specimens was same to the impact bending test. The span was 280 mm. The loading point was midspan, and loading speed was 3mm/min. Dynamic Young's modulus was also measured before static bending test.

Dynamic Young's modulus (E_f), Static Young's modulus (E_b), and bending strength (σ_b) were calculated by the following equations.

$$E_f = (2f\ell)^2 \cdot \rho \quad (8)$$

where E_f is dynamic Young's modulus, f is resonance frequency of the tap tone with a fast Fourier transform (FFT) spectrum analyzer, ℓ is length, ρ is density.

$$E_b = \frac{\Delta P \ell^3}{48 I \Delta y} \quad (9)$$

where ΔP is increment of load, ℓ is span, Δy is increment of deflection at midspan, $I = bh^3/12$, b is width, h is depth.

$$\sigma_b = \frac{P_m \ell}{4Z} \quad (10)$$

where P_m is maximum load, ℓ is span, $Z = bh^2/6$, b is width, h is depth. Y_b was deflection at maximum load.

JIS compressive tests were conducted on small clear specimens (20 mm x 20 mm x 40 mm). The loading speed was 9.8 N/mm^2. Compressive strength was calculated as the follows.

$$\sigma_c = \frac{P_m}{A} \quad (11)$$

where P_m is maximum compressive load, A is cross section area.

Results and discussion

Mechanical properties of structural timber

The result of static bending tests on structural timber was shown in Fig. 2. While the difference between HTS and AS was very small for *MOE*, *MOR* of HTS was smaller than that of AS. Figure 3 shows compressive Young's modulus (*CE*) and compressive strength (*CS*). *CE* or *CS* of HTS and AS were almost equal. Thermal effect of HTS was obvious in bending strength for the structural size.

Impact bending for small clear specimens

As the results of impact bending tests, toughness, impact bending strength, and deflection at ultimate stress was shown in Fig. 4 (a), (b), and (c), respectively. It was clear that HTS reduced toughness, strength, and ductility.

JIS bending and compressive tests

Dynamic Young's modulus (E_f) was shown in Fig. 5. E_f of HTS was slightly bigger than AS. Static bending Young's modulus (E_b), static bending strength (σ_b), and deflection at ultimate stress (Y_b) were shown in Fig. 6 (a), (b), and (c), respectively. *Eb* of HTS was slightly bigger than AS as similar as E_f. On the other hand,σ_b or Y_b of HTS were smaller than those of AS. As similar as

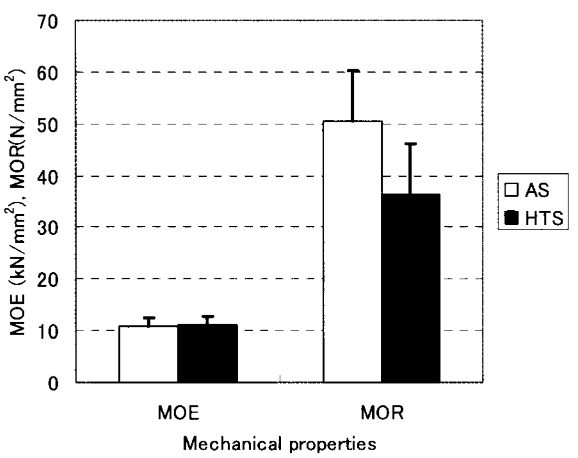

Fig. 2. Bending properties of structural timber.
Note: AS: air-seasoned,
HTS: High-temperature setting method,
bars: standard deviations.

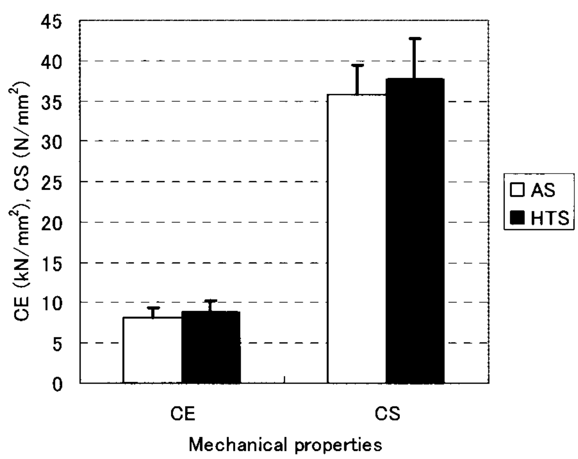

Fig. 3. Compressive properties of structural timber.
Note: AS: air-seasoned,
HTS: High-temperature setting method,
bars: standard deviations.

the case of structural timber, Young's modulus did not decrease, but strength decreased by the HTS method compared to AS.

The result of static compressive tests was shown in Fig. 7. The difference of compressive strength between HTS and AS was small, although HTS was smaller than AS for the core specimens.

It should be noted that the values decreased at the inner portion (core) throughout the above properties of small clear specimens because the most core samples might be occupied by juvenile wood.

Moist-thermal effects

In the HTS method, green timbers are kiln-dried at high temperature. Then shell of timber dried rapidly, and the core maintained high moisture content during initial stage. It might be anticipated that moisture and heat attacked wood composite at the core portion. To

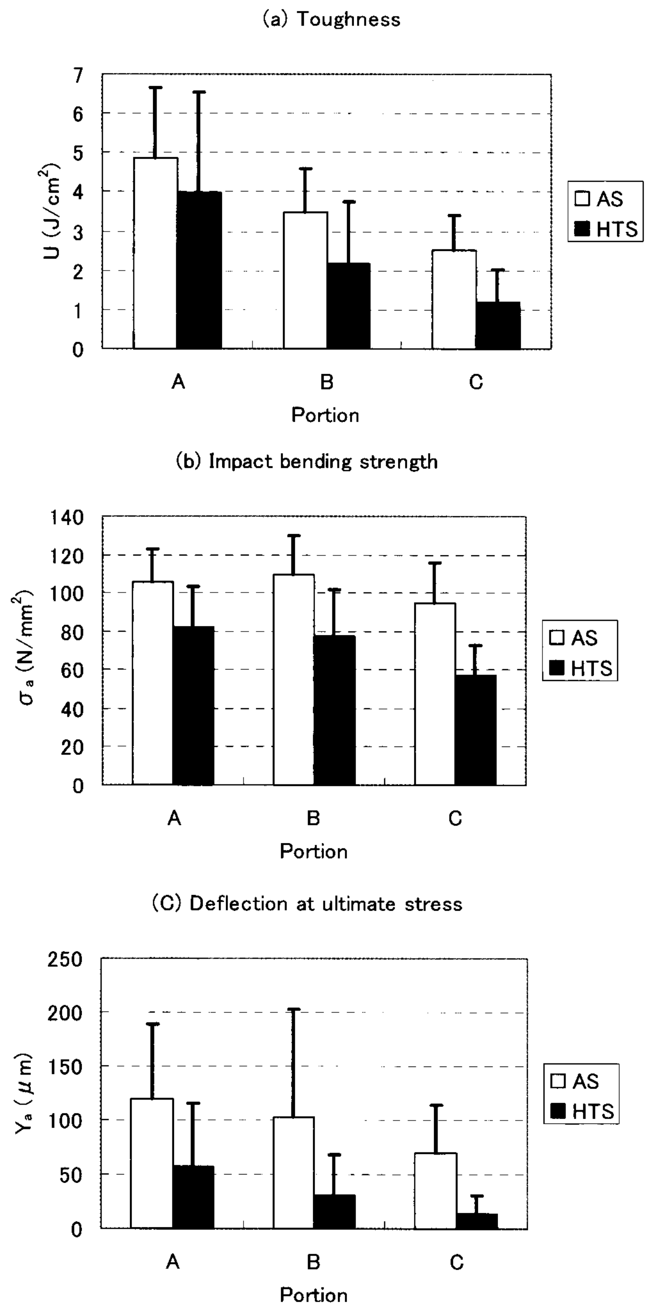

Fig. 4. Impact bending properties of small clear specimens.
Note: AS: air-seasoned,
HTS: High-temperature setting method,
bars: standard deviations,
portions: see Fig. 1.

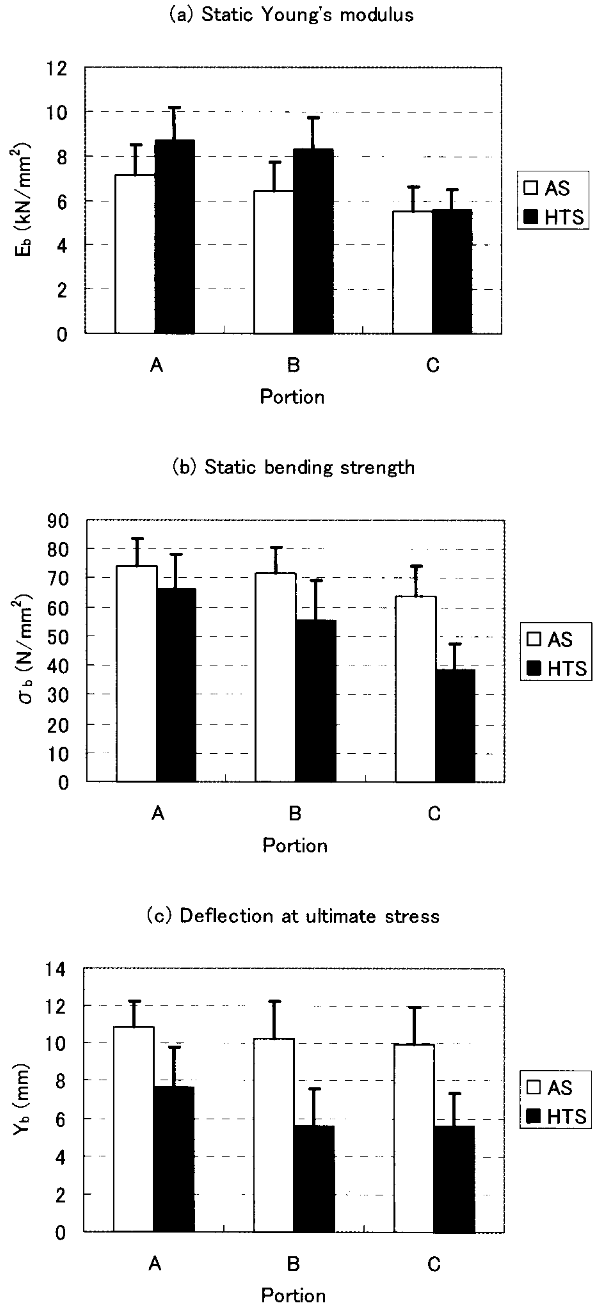

Fig. 6. Static bending properties of small clear specimens.
Note: AS: air-seasoned,
HTS: High-temperature setting method,
bars: standard deviations,
portions: see Fig. 1.

discuss on the moist-thermal effects, various measured properties were estimated by comparing HTS and AS for every portion.

The ratios of HTS to AS concerning various properties for structural timber and small clear specimens were shown in Fig. 8 (a) and (b), respectively. At the corner or outside portion, the ratio of E_f was approximate 1.0 which was almost equal to the case of *MOE*. But Young's modulus at core was 0.91. The values at only core portion were reduced by the HTS. Similar tendency was observed in compressive strength.

Impact bending strength, toughness, static bending strength, and Y_a decreased at inner portion as similar. The ratios (HTS/AS) of σ_b at corner, outside, and core was 0.895, 0.769, and 0.603, respectively. The average of those was 0.755 almost equal to 0.725 (*MOR*). The reduction of *MOR* in HTS might be occurred by the moist-thermal effect which was clear at the core portion, but the effect appeared at the outside or corner portion. In Fig. 8(b), the lowest values were for Y_a. The brittleness of HTS appeared remarkably compared to other properties.

It was clear that strength reduction caused by the moist-thermal effects was conspicuous at the core portion. But the problem for practical use has not been examined yet. It should be also necessary to improve the HTS method for preventing strength reduction.

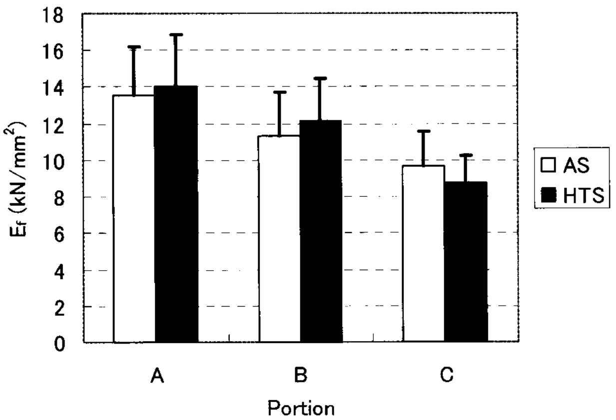

Fig. 5. Dynamic Young's modulus of small clear specimens.
Note: AS: air-seasoned,
HTS: High-temperature setting method,
bars: standard deviations,
portions: see Fig. 1.

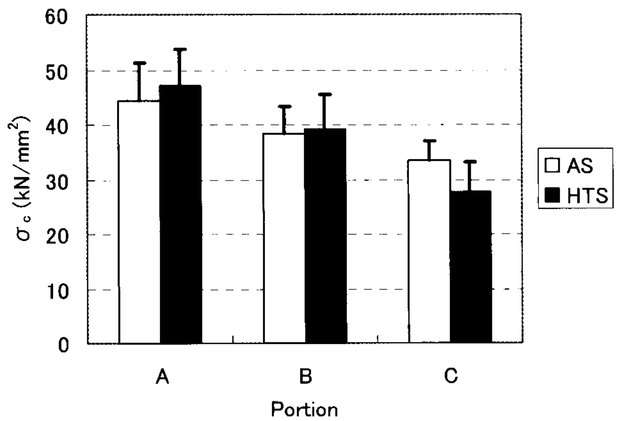

Fig. 7. Static compressive properties of small clear specimens.
Note: AS: air-seasoned,
HTS: High-temperature setting method,
bars: standard deviations,
portions: see Fig. 1.

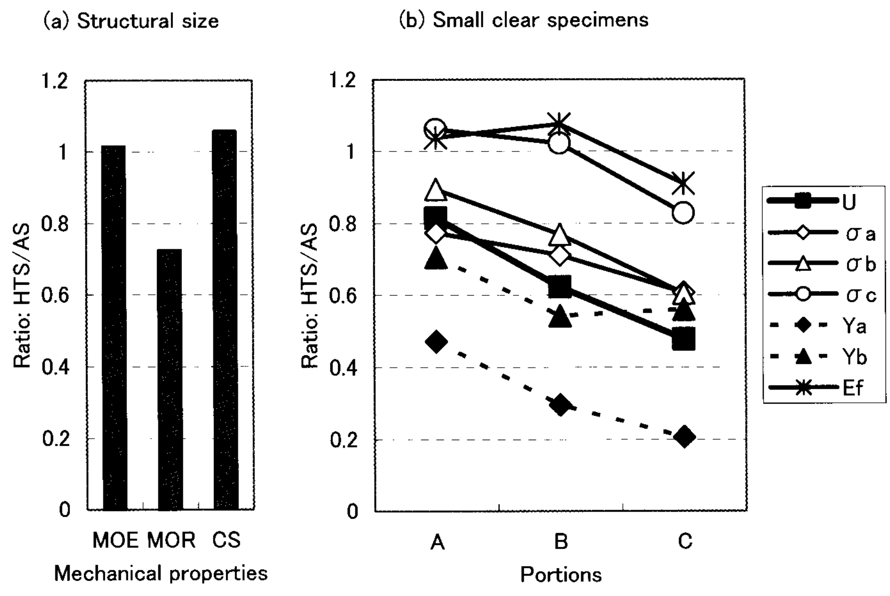

Fig. 8. Moist-thermal effects: ratio of HTS to AS.

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