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Effect of moisture content of members on mechanical properties of timber joints

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Abstract To investigate the effect of moisture content (MC) of members on the mechanical properties of timber joints, bending tests of precut joints and shear tests of dowel-type joints were carried out using timbers of Japanese cedar (*Cryptomeria japonica* D. Don) with three moisture conditions: green, kiln-dried with a MC target of 15%, and over-kiln-dried with a MC target of 5%. For the bending test, timbers were processed with a precut processing machine into "koshikake-ari" (a kind of dovetail joint) and "koshikake-kama" (a kind of mortise and tenon joint). A pair of members was jointed together without mechanical fasteners. Bolts (diameter = 12 mm) and nails (diameter = 2.45 mm) were used as dowels in the shear test. Bolted joints were constructed with one bolt and two metal side plates. Two nails and two metal side plates were used for the nailed joint. For precut joints, no clear effect of MC was recognized on maximum moment and initial stiffness. The maximum strength of mechanical joints assembled with kiln-dried wood was changed by the degree of drying. Stiffness of the joints assembled with kiln-dried specimens was larger than that of the joints assembled with green specimens.

Key words Moisture content · Timber joint · Precut joint · Shear · Maximum moment · Stiffness · Maximum stress

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Introduction

Wood changes its dimensions as it absorbs or desorbs moisture under the fiber saturation point (FSP). It shrinks when desorbing moisture and swells on absorbing moisture. Shrinkage can result in checking, warping, and other damage to wood. In addition, it may cause loosening of metal fasteners that have been driven into the wood.

Historically, there have been few problems in conventional Japanese wooden houses, even if the timber was insufficiently dried, because the construction period of houses was long. However, shortening of the construction period over recent decades is one of the causes that insufficiently dried timber is used in house construction.

The lack of consideration for controlling moisture content (MC) of structural timbers has caused some serious structural problems, for example, excessive deflection of beams and distortion of the house. To avoid these problems, kiln-dried timbers should be used, although these timbers may contain some damage caused by drying, for example, internal cracks and the degradation of wood by high-temperature heating. Therefore, the effect of the degree of drying on the performance of timber joints needs to be investigated.

In this study, the mechanical properties of timber joints of kiln-dried timbers were examined. As control specimens, joints with green timbers and excessively kiln-dried timbers were prepared.

Three types of joints were tested: precut joints, bolted joints, and nailed joints. Precut joints are timber joints that simplify Japanese traditional joints. Generally, these joints are processed with special machines that allow mass-production at high accuracy at the factory before shipment to the construction site.

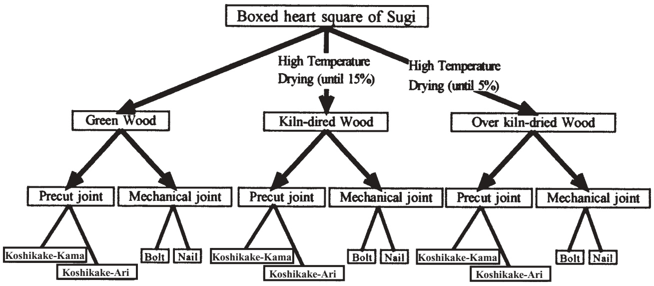

Fig. 1. Preparation of test specimens

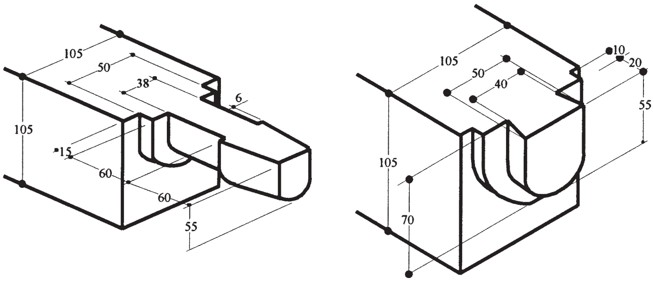

Fig. 2. Precut joints. Diagram of "koshikake-kama" (*left*) and "koshikake-ari" (*right*)

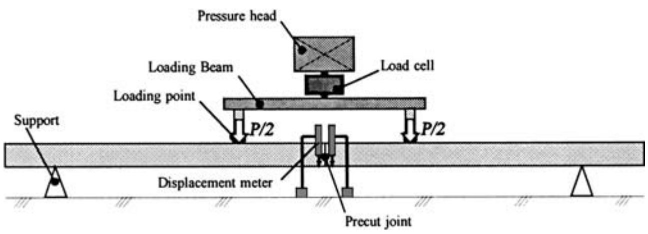

Fig. 3. Loading method for precut joints

Materials and methods

Specimens

Boxed heart green squares of sugi (Japanese cedar, *Cryptomeria japonica* D. Don.) were prepared. These timbers were conditioned to obtain three moisture-content categories: "green wood," "kiln-dried wood," which targeted a MC of 15%, and "over-kiln-dried wood," which targeted a MC of 5% (Fig. 1).

The conditioned timbers were processed into specimens that were 105 × 105 mm in cross section, 1500 mm long, and in two types of precut joints: "koshikake-ari" (a kind of dovetail joint) and "koshikake-kama" (a kind of mortise and tenon joint) (Fig. 2). Other timbers were cut into specimens that were 400 mm long and were used for the mechanical joints (bolted and nailed joints).

Test methods

Loading tests for precut joints were carried out with the four-point bending system (Fig. 3). Span was 2400 mm and the distance between loading points was 800 mm. Load was measured with a load cell installed between a pressure head and a loading beam, and vertical deflection at the center of the specimen was measured with strain gauge-type displacement transducer (SGDT). Bending moment at the point of midspan was calculated as the product of the obtained load and a half of the span (1200 mm). Deflection angle was calculated as the arctangent of measured deflection divided by a half of the span. The mean value of the displacement measured by two SGDTs (front and back) was designated as the deflection of the joint. The deformation rate was 5 mm/min for koshikake-kama and 3 mm/min for koshikake-ari. Four specimens were prepared for each condition.

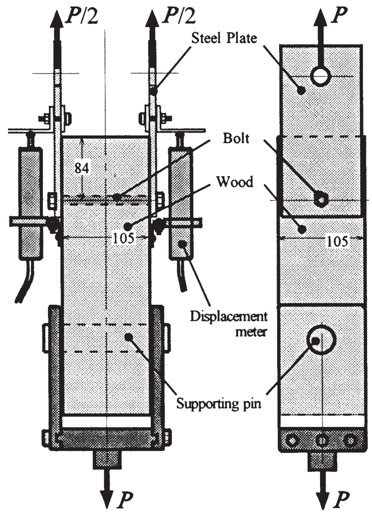

Fig. 4. Loading method for bolted joints

Figure 4 shows the loading apparatus for the mechanical joints. Fasteners were bolts (M12; diameter = 12 mm) and nails (N45; diameter = 2.45 mm). The location of a bolt was $7d$ (d: diameter of a bolt) from the end of the specimen and more than $4d$ from the edge, in accordance with the standard for structural design of timber structures.[1] Load was measured with a load cell, and relative displacement between steel plates and wood was measured with two SGDTs. The loading method was the same in nailed and bolted joints. Predrilled steel plates (thickness = 9 mm) were put on both sides of the specimen and a nail was driven into each side. The location of a nail was the same as that of a bolted joint. The deformation rate was 5 mm/min for both types of joints. The embedding stress was calculated as the value of the obtained load divided by the product of penetration length and the diameter of these fasteners. Shear deformation was defined as the mean value of two relative displacements. Four specimens were prepared for each condition.

Results and discussion

Figure 5 shows a typical moment – deflection angle curve obtained from bending tests of the precut joint, and a typi-

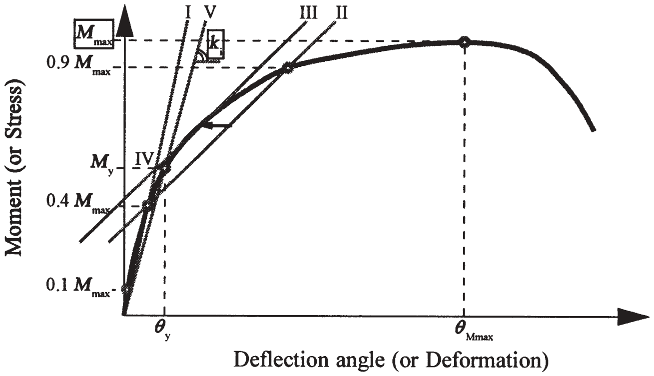

Fig. 5. Definition of the strength properties of the joints. M_{max}, maximum moment; M_y, yield moment; k_i, initial stiffness; θ_y, yield angle; θ_{Mmax}, deflection angle at maximum moment. Moment (M) and deflection angle (θ) need to be converted into stress (σ) and deformation (ε) respectively for the case of shearing test

cal stress – deformation curve obtained from shear tests of the mechanical joint. Initial stiffness was calculated by the evaluation method for the wood frame construction described as follows:[2]

1. Line I, a straight line that connects $0.1M_{max}$ and $0.4M_{max}$ in the moment–deflection angle curve, where M_{max} denotes maximum moment, was drawn.
2. Line II, a straight line that connects $0.4M_{max}$ and $0.9M_{max}$ in the curve, was drawn.
3. Line II was offset in the x-axis direction to become a line tangent to the curve. This new line was defined as line III.
4. The load corresponding to the intersection of lines I and III was defined as the yield moment (M_y). Line IV was drawn parallel to the x-axis through this point.
5. Deflection angle corresponding to the intersection of line IV and the curve was defined as the yield deflection angle (θ_y).
6. The straight line that connects the origin and the coordinates (M_y, θ_y), was drawn. A slope of this line was defined as initial stiffness (k).

It is noted that moment (M) and deflection angle (θ) need to be converted into stress (σ) and deformation (ε) respectively in the case of the shear test.

Bending performances of precut joints

Figure 6 shows the relationships between MC and maximum bending moment for precut joints. In Fig. 6, the x-axis shows the MC of the specimens measured by oven drying. In both types of joints, there were no significant differences between over-kiln-dried (OKD), kiln-dried (KD), and green (G) specimens, so no clear relationships were recognized between MC and the moment. The coefficient of variation (COV) of M_{max} of kama joints (Fig. 6a) had a range of 14%–32% and that of ari joints (Fig. 6b) was 6%–51%. This variation is a cause of no clear relationships, and the reasons for the dispersion are under investigation.

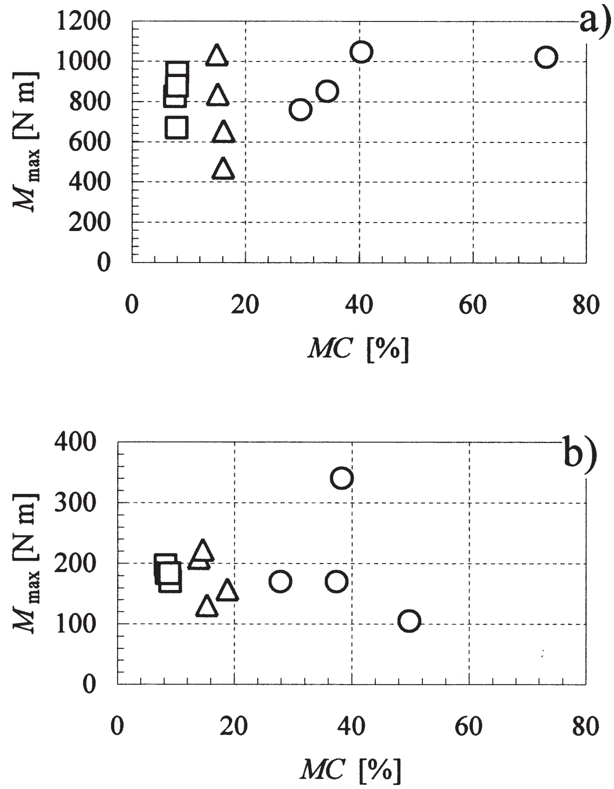

Fig. 6. Relationships between moisture content and maximum moment for precut joints: "koshikake-kama"(**a**) and "koshikake-ari"(**b**). M_{max}, Maximum moment; MC, moisture content. *Circles*, green wood; *triangles*, kiln-dried wood; *squares*, over-kiln-dried wood

Figure 7 shows relationships between MC and initial stiffness for the kama type and ari type. The effect of the MC could not be recognized on both joint types of the specimens. An experiment that uses more specimens is necessary to obtain any general tendency, because an insufficient number of samples was used in this study.

Shearing performances of mechanical joints

Relationships between MC and maximum stress for bolted joints and nailed joints are shown in Fig. 8. No significant differences between OKD, KD, and G specimens were observed for bolted joints (Fig. 8b). In case of the nailed joints (Fig. 8a), there was a difference at a significance level of 1% between OKD and KD, with the strength of mechanical joints assembled with kiln-dried wood changed by the degree of drying.

Relationships between MC and initial stiffness for bolted and nailed joints are shown in Fig. 9. Significant differences were recognized at levels of less than 5% between OKD and G, and KD and G specimens with bolted joints (Fig. 9a), and at levels of 5% between OKD and G specimens with nailed joints (Fig. 9b). The stiffness of mechanical joints assembled with KD specimens was higher than that of joints assembled with G specimens. These results are similar to the relationships between MC and modulus of elasticity of Douglas fir (38 × 140 × 3660 mm).[3] Therefore, the

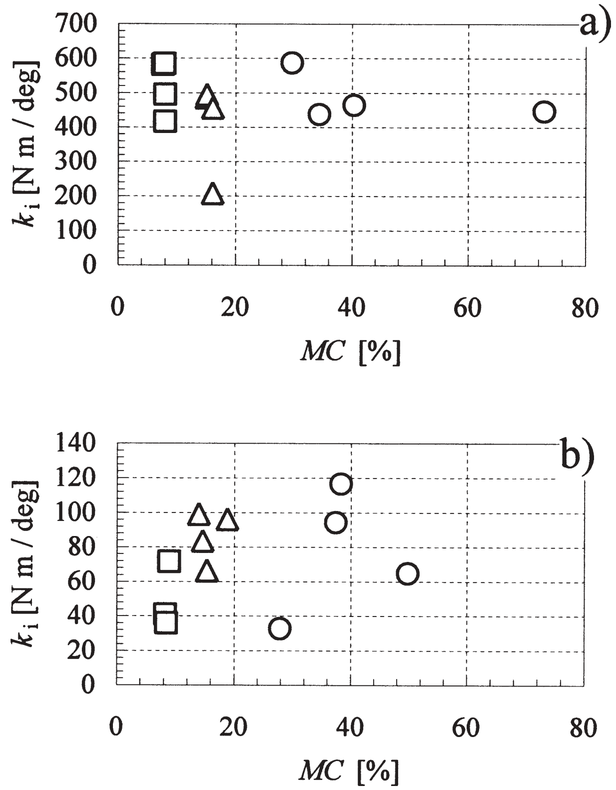

Fig. 7. Relationships between moisture content and initial stiffness for "koshikake-kama"(**a**) and "koshikake-ari"(**b**). k_i, Initial stiffness

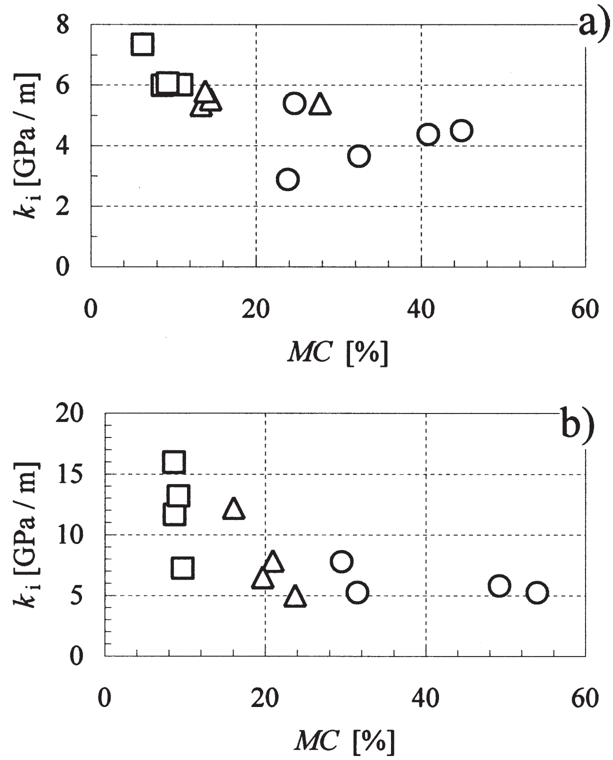

Fig. 9. Relationships between moisture content and initial stiffness for bolted joints (**a**) and nailed joints (**b**). k_i, Initial stiffness

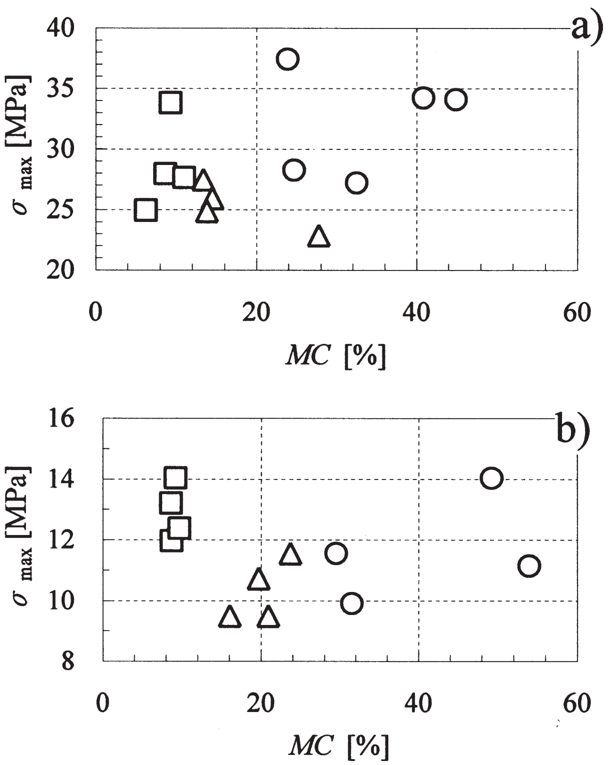

Fig. 8. Relationships between moisture content and maximum stress for mechanical joints: bolted joints (**a**) and nailed joints (**b**). σ_{max}, Maximum stress

stiffness of mechanical joints is closely related to the behavior of the wood as a member of the joint.

Conclusions

The effects of MC on mechanical properties of precut joints and mechanical joints (bolted and nailed joints) were examined in this study. For precut joints, a clear effect of MC was not recognized on the maximum moment and initial stiffness of the joints. The high COV is one reason that no clear relationships were observed, and reasons for the dispersion are under investigation.

For mechanical joints (bolted and nailed joints), the maximum strength of the joints assembled with kiln-dried wood was changed by the degree of drying, and stiffness of the joints assembled with kiln-dried specimens was larger than that of the joints assembled with green specimens.

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