Nondestructive testing for durability assessment of plywood used for wood-framed houses

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ABSTRACT

In order to assess nondestructively the durability of wood-based materials in use, ultrasonic velocity of plywood used for walls in nineteen years old wood-framed houses was measured. Relationships between ultrasonic velocity and mechanical properties were investigated. And possibility of nondestructive testing for assessing the durability of wood-based materials in use was discussed.

Ultrasonic velocity along longitudinal direction of bending specimens measured by surface transmission procedure, pressing transmitting and receiving probes onto same surface of the specimens, was lower than that measured by direct transmission procedure, pressing two probes onto the opposite ends of the specimens. However, there was a positive correlation between ultrasonic velocity measured by direct and surface transmission procedures and there was no significant difference between ultrasonic velocity measured by indoor and outdoor surface transmission procedures. This means indoor surface transmission procedure is sufficient enough to detect the change of ultrasonic velocity of plywood.

Ultrasonic velocity measured by surface transmission procedure of decayed part was lower than that of sound part. Ultrasonic velocity changed with the visual deterioration level. This fact means ultrasonic velocity measured by surface transmission procedure is sufficient enough to estimate the deterioration level.

Density, modulus of elasticity and modulus of rapture increased with increasing of ultrasonic velocity. There was a close positive correlation between modulus of elasticity and dynamic modulus of elasticity calculated from ultrasonic velocity and density. There was no relationship between ultrasonic velocity and tensile shear strength. On the other hand, there was a positive correlation between ultrasonic velocity and internal bond strength. Ultrasonic velocity decreased as measuring point goes closer to the decayed part of the plywood which showed the lower internal bond strength. From these findings, it is concluded that bending properties and internal bond strength of plywood in use can be assessed nondestructively by ultrasonic velocity.

INTRODUCTION

Wood-based materials such as plywood used for walls of wood-framed houses dominate strength of the buildings. Therefore it is very important to clarify the durability of the wood-based materials and figure out how to extend the service life of these structural members. The authors surveyed the durability of external walls in nineteen years old wood-framed townhouse and measured mechanical properties of plywood sampled from the walls to assess the durability of wood-framed houses (Nanami et.al. 2000). Results of the research revealed that mechanical properties of decayed part of plywood were low. If it is possible to assess nondestructively the durability of wood-based materials in use, it should be

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effective to rehabilitate these houses.

There are some reports regarding nondestructive testing of biological degraded solid wood (Chudnoff et al. 1984, Wang et al. 1980) and intensive reports regarding nondestructive evaluation of wood-based materials (Pellerin et al. 1973, Ross et al. 1988, Vogt 1986). But little information is available of nondestructive testing for durability assessment of wood-based materials in use.

In this paper, ultrasonic velocity of plywood used for walls of nineteen years old wood-framed houses was measured. Relationships between ultrasonic velocity and mechanical properties were investigated. And possibility of nondestructive testing for assessing the durability of wood-based materials in use was discussed.

METHODS

Raw materials
Specimens for static bending, tensile shear and internal bond strength tests were sampled from plywood used for external walls of nineteen years old wood-framed houses. The details of the investigated houses were described in the previous report (Nanami et al. 2000). Sample plywood with dimension of 500mm x 300mm was cut from the walls of all aspects and use of rooms. Collected plywood was classified into sound plywood and decayed plywood by the visual deterioration level. Specimens of static bending and adhesive strength tests were collected from both upper side and lower side of all sample plywood. Specimens for internal bond strength were sampled from both ends of static bending specimens after testing. Specimens from the decayed plywood were classified into decayed part group which include decayed part in the specimens and sound part group which don't include decayed part in them. New unused plywood was also examined as control to compare with collected plywood. All plywood examined was structural plywood of red meranti (Shorea spp.), 9mm nominal thickness, 5ply, Type Special and Class 1 specified in Japanese Agricultural Standard (JAS) for Structural Plywood. Prior to the measurement, the specimens were conditioned at 20 degrees centigrade and 65 percent relative humidity.

Measurement of ultrasonic velocity
Prior to the strength measurement, ultrasonic propagation time through thickness of the specimens for tensile shear strength and internal bond strength tests was measured. Portable ultrasonic nondestructive digital indicating tester (PUNDIT Mark V: C.N.S. Electronics, England) with 54kHz and 200kHz probes was used. Figure 1 shows the schematics of the measurements for specimens for tensile shear strength and internal bond strength tests.

![Figure 1. Schematics of ultrasonic measurements for tensile shear and internal bond strength specimens.](image)

As for the specimens for static bending test, ultrasonic propagation time along longitudinal direction of the specimens was measured by following two procedures: 1. direct transmission; two probes, transmitting and receiving probes were pressed onto the opposite ends of the specimens, 2. surface transmission; two probes were pressed onto same surface of the specimens. Figure 2 shows the schematics of direct transmission and surface transmission procedures. Contact medium (Sonicoat-E: Nichigo acetylene, Japan) was spread on vibrating faces of the probes. After that, gum caps were attached on the vibrating faces of the probes to prevent the specimens from being contaminated by the contact medium.

![Figure 2. Schematics of ultrasonic measurements for bending specimens.](image)
Ultrasonic velocity was calculated with following equation:

\[ v = \frac{l}{t} \]

where \( v \) is ultrasonic velocity, \( l \) is propagation path length and \( t \) is propagation time. As for the velocity through the thickness and along the longitudinal direction by direct transmission, the propagation path length was assumed to be the dimension of specimen in propagating direction. As for the surface transmission, the propagation path length was assumed to be the center-center distance between the probes.

Dynamic modulus of elasticity (dynamic MOE) was calculated with following equation:

\[ E_d = v^2 \times DS \]

where \( E_d \) is dynamic MOE and \( DS \) is density of the specimen.

Mechanical properties of the plywood  
Three-point static bending test was conducted with the bending span of 150mm and the average deformation rate of 5mm/minute according to the past research (Arima 1981). 200mm x 50mm specimens were collected each two pieces so that the direction of bending span became parallel and perpendicular to grain of the face veneer. Modulus of elasticity (MOE) and modulus of rupture (MOR) were obtained.

Tensile shear (adhesive strength) tests with the loading rate of 5.88kN/minute under air-dry and wet (72-hour continuous boiling) conditions were carried out according to JAS for Structural Plywood (1992), and the tensile shear strength (TS) was obtained. Directions of lathe check of core veneer and load were reverse (open) and distance between two slits was 13mm.

Internal bond strength test with the average deformation rate of 2mm/minute was carried out according to Japanese Industrial Standard (JIS) A 5908 (1994), and the internal bond strength (IB) was obtained.

All these mechanical property tests were performed using digital materials testing instrument (Instron 5569: Instron, U.S.A.).

RESULTS AND DISCUSSIONS

The effect of measuring procedures of ultrasonic velocity  
Figure 3 shows the relationship between ultrasonic velocity along longitudinal direction of bending specimens measured by surface transmission and direct transmission procedures. Ultrasonic velocity measured by surface transmission was lower than that measured by direct transmission. From further observation, the following finding was obtained: Ultrasonic velocity measured by surface transmission procedure was affected by partial property of surface layer because the vibrating faces of the probes are contacted only surface layer, while that measured by direct transmission procedure represents properties of all layers because, in this procedure, the vibrating faces of the probes are contacted all layers. That is why there lies the difference between ultrasonic velocity measured by direct and surface transmission procedures. However, there was a positive correlation between ultrasonic velocity measured by two procedures and there was no significant difference between ultrasonic velocity measured by indoor and outdoor surface transmission procedures. This means indoor surface transmission procedure is sufficient.
enough to detect the change of ultrasonic velocity of plywood. Additionally, indoor surface transmission procedure is more applicable to assess wood-based panels in use because cross sections of panels should not be exposed and interior finishes can be removed easier than exterior finishes if necessary. From the view points of sufficiency and applicability, ultrasonic velocity measured by indoor surface transmission is used as representative of ultrasonic velocity along longitudinal direction of bending specimens after this.

Deterioration level of plywood
Figure 4 shows the comparison of ultrasonic velocity of bending specimens measured by indoor surface transmission procedure among their visual deterioration levels. Ultrasonic velocity in parallel direction was higher than that in perpendicular direction for all visual deterioration levels. Ultrasonic velocity of decayed part of decayed plywood was lower than those of new plywood, sound plywood and sound part. And ultrasonic velocity changed with the visual deterioration level. In this experiment, only the decayed part showed ultrasonic velocity below 2km/second in both directions. These facts mean the deterioration level of plywood can be estimated with ultrasonic velocity measured by indoor surface transmission procedure.

Mechanical properties of plywood
Figure 5 shows the relationship between ultrasonic velocity and density of bending specimens. Density increased with increasing of ultrasonic velocity. As for the decayed part, both density and ultrasonic velocity showed relatively lower values. Thus, ultrasonic velocity can detect mass loss caused by decay of plywood.

Figure 6 shows the relationship between ultrasonic velocity and MOE. MOE increased with increasing of ultrasonic velocity and they had a positive correlation. Same tendency was observed in the relationship between ultrasonic velocity and MOR as shown in Figure 7. As for the decayed part, MOE, MOR and ultrasonic velocity were distributed relatively lower ranges. The ultrasonic velocity of the specimens that showed lower bending properties was low, though the decay was not observed in them. Figure 8 shows the relationship between MOE and dynamic MOE calculated from ultrasonic velocity and density. They had a close relationship and coefficient of correlation was higher than that shown in Figure 6. Thus, the effect of density on bending properties should be
counted in order to improve the accuracy of estimation. From above, the decrease of bending properties caused by decay
of plywood can be estimated with ultrasonic velocity.

There was no relationship between ultrasonic velocity and tensile shear strength as shown in Figure 9. On the other hand, there was a positive correlation between ultrasonic velocity and internal bond strength as shown in Figure 10. Ultrasonic velocity decreased as measuring point goes closer to the decayed part of the plywood that showed the lower internal bond strength. Internal bond strength is determined by the weakest layer through the thickness, while tensile shear strength depends on one layer of measuring object. Thus, internal bond strength is more sensitive to the effect of decay.

From these findings, it is concluded that bending properties and internal bond strength of plywood in use can be assessed
CONCLUSIONS

Ultrasonic velocity of plywood used for walls in nineteen years old wood-framed houses was measured. Relationships between ultrasonic velocity and mechanical properties were investigated. And possibility of nondestructive testing for assessing the durability of wood-based materials in use was discussed.

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REFERENCES


