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<https://doi.org/10.5109/17866>

出版情報 : 九州大学大学院農学研究院紀要. 55 (1), pp.111-116, 2010-02-26. Faculty of Agriculture, Kyushu University

バージョン :

権利関係 :

Evaluation of Finger-jointed Laminae for Glulam Timber by Acoustic Emission III Examination of Condition in Evaluating of Finger-jointed Laminae with Evaluation System

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(Received October 30, 2009 and accepted November 19, 2009)

In our previous study, the evaluation system for the finger-jointed laminae was constructed. This system was composed of three parts. The first part is the motive power part for the hydraulic pump and cylinder. The second part is the AE measurement part. The third part is the data collection part which controls some devices and collects sampling data. In this study, the optimum condition needed in the evaluating test with this evaluation system was examined. In addition, the effects of the temperature and the open assembly time in finger jointing on the strength properties of the finger-jointed laminae with this evaluate system were examined. The main results are summarized as follows: The peak in the waveform of AE signals obtained by the evaluation system was recognized in the laminae with starved joint. The peak and the starved joint part were corresponded. In evaluation test of the finger-jointed laminae with this system, the necessary conditions set in this test were the deflection and the feed speed, and these optimum conditions were 3 mm and high speed (480 mm/s), respectively. The strength properties of the finger-jointed laminae with the open assembly time showed the tendency to decrease with higher the temperature in jointing. Therefore, it became clear that the high temperature in jointing was the condition that the starved joint part was caused. The MOE and MOR of the finger-jointed laminae showed the tendency to decrease with increasing the maximum value of the AE accumulated signal. Thus, it was clear that there was a high correlation between the maximum value and the strength properties. Therefore, this evaluation system was promising for the detection of the difference of the bonding performance caused by the influence of bonding conditions such as the temperature and the open assembly time in jointing.

INTRODUCTION

In our previous studies, we clarified that AE generated during the bending test of the finger-jointed laminae was promising for the detection of starved joints in the finger-joint at the early stage of the bending test. In addition, it became clear that the position of starved joints in finger-joint could be presumed by one-dimensional method of using AE signal (Ohuchi *et al.*, 2004; Yano *et al.*, 2007). Furthermore, in consideration of installing the AE monitoring method into the production line of the finger-joint laminae, a special attachment (jig) for the AE sensor installed into the production line was developed. From the result of verification test with the jig, it was clear that the possibility of the detection of the starved joints by AE as a non-destructive method with the jig was suggested (Ohuchi *et al.*, 2009). However, it was pointed out that this method with the jig was not efficient for the following two reasons; first, it is difficult to set the position of the jig beforehand because neither the position nor the number of finger-joint parts in the laminae is decided. Secondly, it is necessary to stop the production line for the bend-

ing process. Then, for the main purpose of development of the new evaluation method for detecting of the laminae with starved joints without stopping the production line regardless of both the position and the number of finger-joint parts in the laminae, the new type attachment (jig) which installed the AE sensor as non-destructive method for the detection of the laminae with starved joints was designed. The evaluation system which installed the new jig was then constructed. Hinoki (*Chamaecyparis obtusa*) finger-jointed laminae with starved joints were prepared, and the evaluation tests of finger-joint properties were conducted by using this system. From the result, this system which installed the jig with AE sensor was promising for detecting of both the starved joints and the presence of defects as such knots and loosed grain in the laminae without stopping the production line regardless of both the position and the number of finger-joint parts (Sato *et al.*, 2009).

In this study, the optimum condition needed in the evaluating test with this evaluation system was examined. That is, the feed speed and the deflection which should be set in detecting the starved joints with the evaluation system were examined under various conditions. In addition, we paid attention at the temperature and the open assembly time in finger jointing as a cause of the starved joints, and the effects of the temperature and the open assembly time on the strength properties of the finger-jointed laminae with this evaluate system were examined.

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MATERIALS AND METHODS

In this study, two experiments were conducted as follows: one in which the feed speed and the deflection which should be set in detecting the starved joints with the evaluation system were examined under various conditions (experiment 1), and the other in which the effects of the temperature and the open assembly time in finger jointing on the strength properties of the finger-jointed laminae with this evaluate system were examined (experiment 2).

Method of experiment 1

Specimens

Specimens used in experiment 1 were made from hinoki (*Chamaecyparis obtusa*) laminae as same as the method in our previous study (Sato *et al.*, 2009). The mean specific gravities and the mean moisture contents of specimens were 0.53 and 12.5%, respectively. These laminae were sorted not to have any knots or faults within 100 mm of the tip of finger-joint, and short-length laminae were made. The profile of the finger-joint was as follows: $l=14.0\text{ mm}$, $p=3.9\text{ mm}$, $t_1=0.7\text{ mm}$, $t_2=0.6\text{ mm}$, and $\theta=4$ in 98. These laminae were finger-jointed using resorcinol resin adhesive for wood and end pressed at 9.2 N/mm^2 . The finger-jointed laminae without starved joints were used as control specimens and assumed to be C-laminae. On the other hand, the finger-jointed laminae without curing agent were used and assumed to be NH-laminae with starved joints. These finger-jointed methods were the same as those in our previous studies (Ohuchi *et al.*, 2009; Sato *et al.*, 2009). These two types of finger-jointed laminae were 113 mm wide, 20 mm thick, and 2000 mm long. Furthermore, these finger-jointed laminae have one finger-joint part in the center of the laminae.

Method of evaluation test

The evaluation test was performed with the evaluation system developed in our previous study (Sato *et al.*, 2009). In this evaluation test, the deflection of all C- and NH-laminae was set to 2, 3, 4, and 5 mm, respectively, and the feed speed was set to 155 mm/s (low speed), 280 mm/s (middle speed), 480 mm/s (high speed), respectively. The AE signals generated during tests were measured by three jigs and AE testers. In the AE measurement, the high-pass filter was set to 100 kHz with the AE tester. The AE signals received with the jig were amplified to 66 dB and the threshold level was 100 mV with the AE tester. The resonance frequency of the AE sensor was 140 kHz. Thus, the AE average signal and the AE accumulated signal were measured under the above-mentioned measurement conditions. The bending load due to the deflection was measured with the load cell installed into the hydraulic cylinder head.

Method of experiment 2

Specimens

Specimens were made from hinoki (*Chamaecyparis*

obtusa) laminae used in experiment 1. The manufacturing method of the finger-jointed laminae was also similar to experiment 1. The bonding conditions are listed in Table 1. The adhesive was spread on the one side of the finger and end pressed. The temperature means the temperature of laminae in end pressed, and the open assembly time means for 20 minutes that the laminae was left after the adhesive was spread.

Table 1. Bonding conditions in experiment 2

adhesive	temperature (°C)	open assembly time (min)
Resorcinol resin (R-laminae)	20	20
Aqueous polymer solution-isocyanate	40	0
(I-laminae)	60	

Conditions of evaluation test and static bending test

The conditions of evaluation test in experiment 2 were set referring to the result of experiment 1. That is, the most accurate conditions of both the deflection and the feed speed in the evaluation test with this system were set after experiment 1, respectively. The experimental method was conducted with the same method in experiment 1.

After this evaluation test, to examine the bending strength properties of the finger-jointed laminae, the specimens for the bending test were made from these laminae used in experiment 2. A static bending test was conducted by using a Universal Testing Machine. Three point bending was applied over an effective span of 415 mm at a loading speed of 5 mm/min. From the result of these bending tests, the modulus of elasticity (MOE) and the modulus of rupture (MOR) for each laminae were calculated, respectively. In addition, after the bending test, the destruction form and the wood failure proportion in the breaking section of finger-jointed part were measured. Both R- and I-laminae without the open assembly time in jointing at the temperature of 20 degrees were also assumed to the control specimen.

RESULTS AND DISCUSSION

Behavior of AE generation

The typical waveforms of AE average signals in C- and NH-laminae obtained in evaluation test (experiment 1) are shown in Fig. 1. The change was not admitted in waveform of C-laminae. The peak was recognized in the waveform of NH-laminae. Based on the peak time, the position of laminae in which AE generated was verified. From this verification result, it was confirmed that the peak time and the starved joints part were corresponded. In addition, the typical waveforms of AE accumulated signals in I-laminae obtained in evaluation test (experiment 2) are shown in Fig. 2. The change was not admitted in waveform of both the laminae without the open assembly time and with the open

assembly time of 20 minutes in jointing at the temperature of 20 degrees. On the other hand, the peak was recognized in the waveform of the laminae with the open assembly time of 20 minutes in jointing at the temperature of 40 and 60 degrees. This peak time and the starved joints part were corresponded as above-mentioned in Fig. 1.

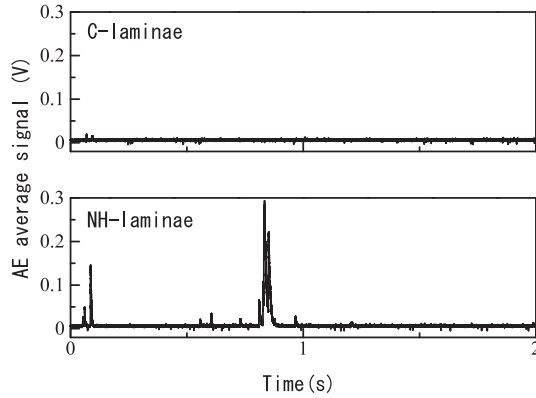


Fig. 1. Typical waveforms of AE average signal (experiment 1).

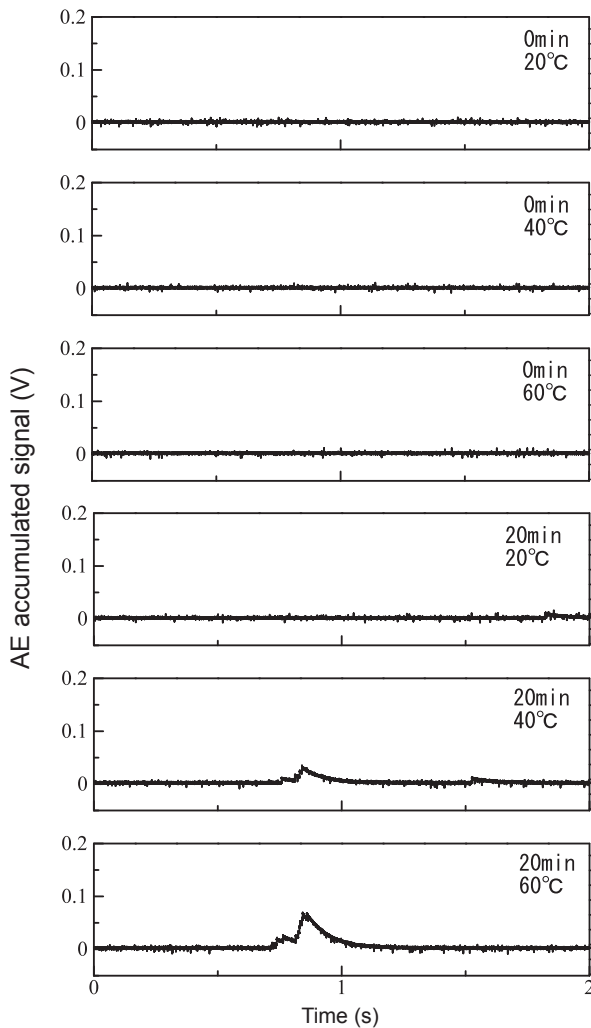


Fig. 2. Typical waveforms of AE accumulated signal in I-laminae (experiment 2).

These results suggest that this system was promising for the detection of the starved joints part in the finger-jointed laminae as well as the result of our previous research (Sato *et al.*, 2009).

Effect of feed speed

The typical waveforms of AE average signals obtained in evaluation tests (experiment 1) at the deflection of 4 mm and at the feed speed of the low-, middle- and high-speed are shown in Fig. 3, respectively. AE generated from the starved joint part was recognized at all three feed speeds. Moreover, the AE generation was remarkable with increasing the feed speed, and the same tendency was admitted in NH-laminae of other conditions. Therefore, in consideration of installing into the production line of the finger-joint laminae, we found that the proper feed speed of the laminae for detecting the starved joint with this evaluation system was to set high feed speed (480 mm/s).

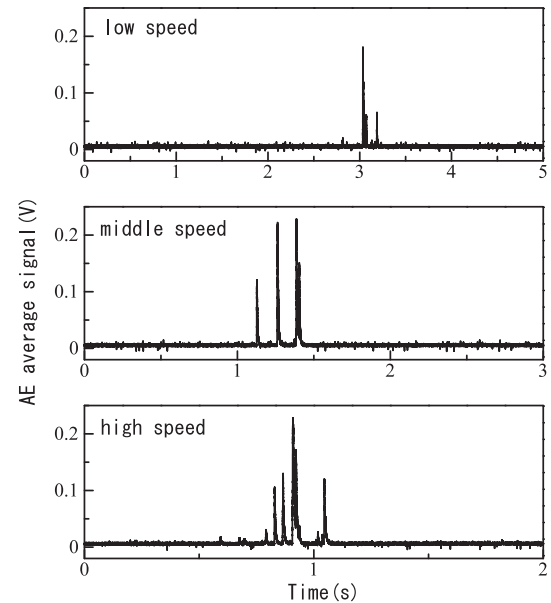


Fig. 3. Typical waveforms of AE average signal in NH-laminae at the deflection of 4 mm within the range of feed speed from low to high.

Effect of deflection

The typical waveforms of AE average signals obtained in evaluation tests (experiment 1) at the middle feed speed and at the deflection from 2 to 5 mm are shown in Fig. 4, respectively. The AE generation was not admitted at the deflection of 2 mm. However, the AE generation was admitted at the deflection of more than 3 mm. These tendencies were admitted in NH-laminae of other conditions. Therefore, it was clear that the proper deflection for detection the starved jointed with this evaluation system was more than 3 mm.

Thus, in the starved joint part of each NH-laminae, the maximum values of AE average signals and AE accumulated signal at the deflection of more than 3 mm

were examined, respectively. The result is listed in Table 2. In AE accumulated signals, a difference of each deflection was not admitted. In AE average signals, the maximum value showed the tendency to increase with increasing the deflection. However, in the cases of 4 mm and 5 mm in deflection, the rupture in the starved joints part of NH-laminae was often occurred. It is considered that AE signals in the case of 4 mm and 5 mm were remarkably generated because of these ruptures. Therefore, it became clear that the optimum deflection in this test with evaluation system is 3 mm. Moreover, a remarkable difference between the maximum values of AE average signal at the deflection of 3 mm and 4 mm was admitted. These results were suggested to be able to detect the starved joints part with evaluation system by setting the deflection to 3 mm and the threshold to 0.1 V in the AE average signal. Therefore, in experiment 2, the deflection and the feed speed were set to 3 mm and high speed (480 mm/s), respectively.

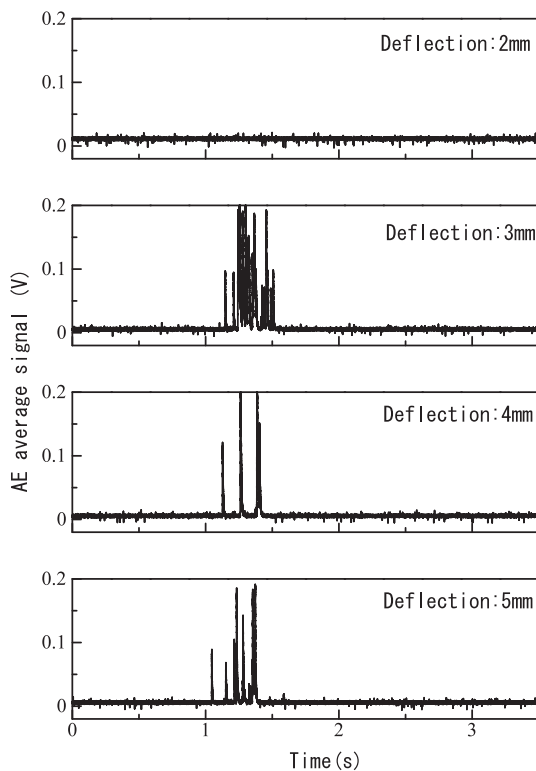


Fig. 4. Typical waveforms of AE average signal in NH-laminae within the range of deflection from 2 to 5 mm.

Wood failure proportion

Figure 5 shows the wood failure proportion of each laminae after the bending test (experiment 2). The wood failure proportion of both the finger-jointed laminae without the open assembly time and the other finger-jointed laminae with the open assembly time of 20 minutes in jointing at the temperature of 20 degrees showed the large value. These destruction forms in the section of finger-jointed part were also measured in wood part of finger, and the pull out of finger was not admitted. On the other hand, the wood failure proportion of I-laminae with the open assembly time of 20 minutes in jointing at the temperature of 40 and 60 degrees showed the small value, and the destruction in the interface or the adhesion layer of finger-jointed part were occurred. It was considered that the surface hardening of spread adhesive advanced due to the open assembly time and the adhesive did not shift on non-spreading side. The wood failure proportion of R-laminae with the open assembly time of 20 minutes in jointing at the temperature of 40 and 60 degrees showed the very small value because the pull out of the finger-jointed part under the evaluation test was occurred. In both of R- and I-laminae without the open assembly time in jointing at the temperature of 20 degrees, the wood failure proportion could not be measured because the destruction in the defaults such as loosed grain and knots was occurred.

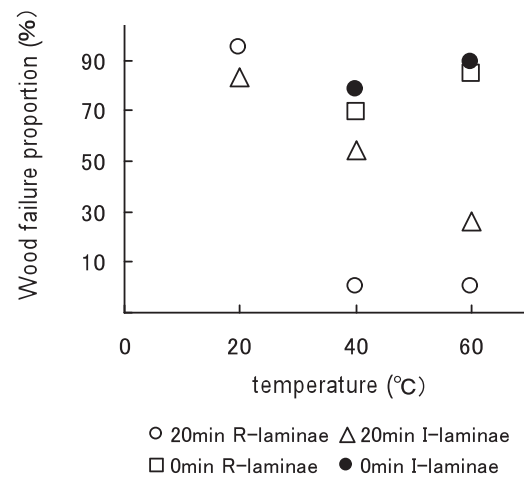


Fig. 5. Relationship between wood failure proportion and temperature.

Table 2. Maximum value of AE signal in NH-laminae

Deflection (mm)	AE average signal (V)			AE accumulated signal (V)		
	low speed	middle speed	high speed	low speed	middle speed	high speed
	155 (mm/s)	280 (mm/s)	480 (mm/s)	155 (mm/s)	280 (mm/s)	480 (mm/s)
3	0.03	0.08	0.02	0.01	0.04	0.09
4	0.12	0.11	0.13	0.04	0.03	0.08
5	0.28	0.07	0.24	0.08	0.04	0.09

Effect of difference of jointing conditions on bending strength properties of laminae

Figure 6 shows MOE and MOR for the finger-jointed laminae with the open assembly time of 20 minutes. Both MOE and MOR showed the tendency to decrease with higher temperature in jointing. It was considered that the adhesive was not shifted on non-spreading side as well as the case of the wood proportion as shown in Fig. 5. Figure 7 shows the MOE and MOR for the finger-jointed laminae without the open assembly time. The MOE and MOR were unaffected by the temperature in jointing.

In the range of this experiment condition, the strength properties of the finger-jointed laminae in jointing at the temperature of 20 degrees were unaffected regardless of the presence of open assembly time. The strength properties of the finger-jointed laminae with the open assembly time showed the tendency to decrease with higher the temperature in jointing. Therefore, it became clear that the high temperature in jointing was the condition that the starved joint part was caused.

Correspondence of AE signals and strength properties of laminae

The maximum value of the peak in the typical waveform of AE signals for I-laminae with the open assembly time in jointing at the temperature of 40 and 60 degrees were examined referring to the results of Figure 2. In addition, the correspondence between these maximum values and the strength properties was examined. The results in AE accumulated signal are shown in Fig. 8. The MOE and MOR showed the tendency to

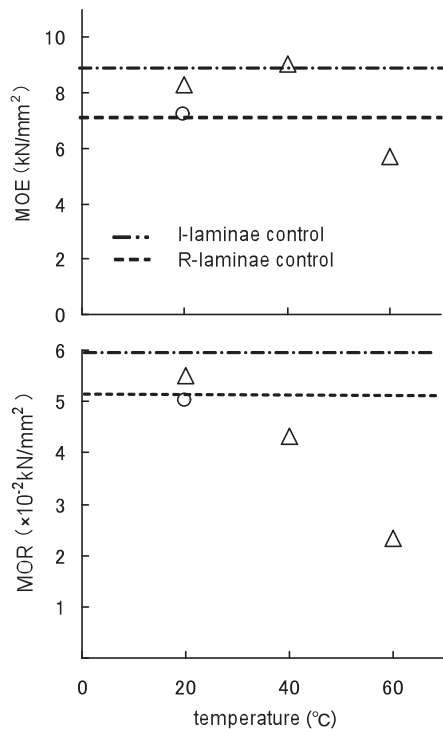


Fig. 6. MOE and MOR with open assembly time of 20 min.
Legend: symbols are shown in Fig. 5.

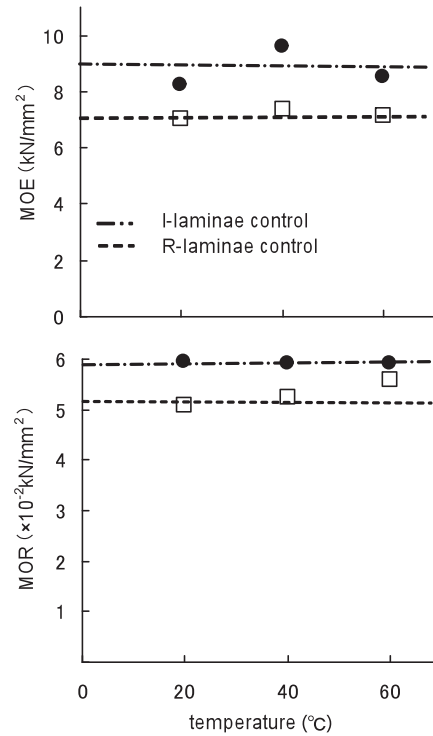


Fig. 7. MOE and MOR without open assembly time.
Legend: symbols are shown in Fig. 5.

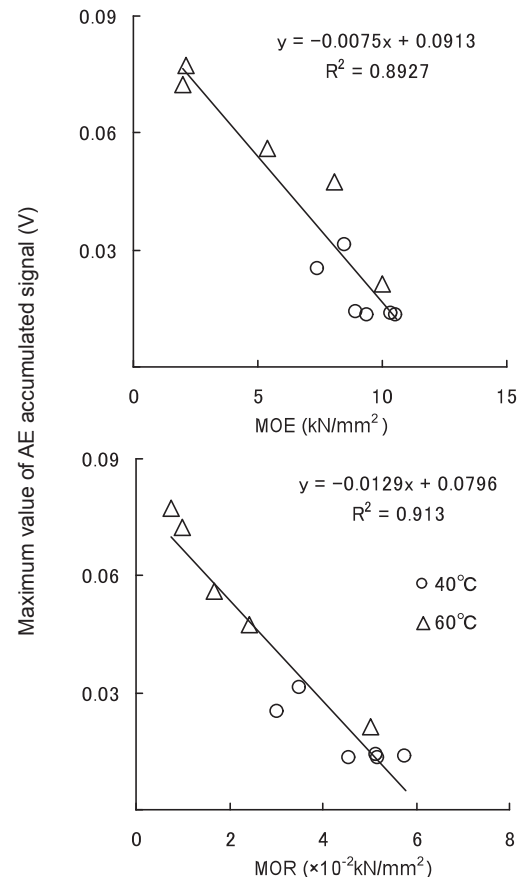


Fig. 8. Relationship between maximum value of AE accumulated signal and MOE, MOR.

decrease with increasing the maximum value of the AE accumulated signal. Thus, it became clear that there was a high correlation between the maximum value and the strength properties.

From these results, this evaluation system was promising for the detection of the difference of the bonding performance caused by the influence of bonding conditions such as the temperature and the open assembly time in jointing.

CONCLUSIONS

In this study, the optimum condition needed in the evaluating test with this evaluation system was examined. In addition, the effects of the temperature and the open assembly time in finger jointing on the strength properties of the finger-jointed laminae with this evaluate system were examined. The main results are summarized as follows:

- 1) The peak in the waveform of AE signals obtained by the evaluation system was recognized in the laminae with starved joint. The peak and the starved joint part were corresponded. From the results, this system was promising for detecting of the starved joints.
- 2) In evaluation test of the finger-jointed laminae with this system, the necessary conditions set in this test were the deflection and the feed speed. From the results of the test under various conditions, it was found that these optimum conditions were set to 3 mm and high speed (480 mm/s), respectively.
- 3) The strength properties of the finger-jointed laminae in jointing at the temperature of 20 degrees were unaffected regardless of the presence of open assembly time. The strength properties of the finger-

jointed laminae with the open assembly time showed the tendency to decrease with higher the temperature in jointing. Therefore, it became clear that the high temperature in jointing was the condition that the starved joint part was caused.

- 4) The MOE and MOR of the finger-jointed laminae showed the tendency to decrease with increasing the maximum value of the AE accumulated signal. Thus, it was clear that there was a high correlation between the maximum value and the strength properties. Therefore, this evaluation system was promising for the detection of the difference of the bonding performance caused by the influence of bonding conditions such as the temperature and the open assembly time in jointing.

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