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Ohuchi, Takeshi
Faculty of Agriculture, Kyushu Unviersity

Suzuki, Nobuhiko
Graduate School of Bioresource and Bioenvironmental Sciences, Kyushu Unviersity

Murase, Yasuhide
Faculty of Agriculture, Kyushu Unviersity

Studies on Axial Deviation of Hole in Deep Machine–Boring of Wood

Takeshi OHUCHI*, Nobuhiko SUZUKI[1] and Yasuhide MURASE

Laboratory of Wood Material Technology, Division of Biomaterial Science,
Department of Forest and Forest Products Sciences,
Faculty of Agriculture,Kyushu University,
Fukuoka 812–8581, Japanese

Many deep holes for bolt joints are often required for construction using a large dimension structural glued laminated timber. In deep machine–boring of this type of timber, axial deviation of the hole frequently occurs, and causes difficulty in the bolt joint operation. Therefore, the development of machine boring which prevents axial deviation of hole is important. The objective of this study was to obtain basic information on axial deviation of the hole in the deep machine–boring of wood. In this experiment, the effects of knots and bit wear on axial deviation of the hole were examined, and acoustic emission (AE) and power consumption were also measured during the boring process. The main results obtained are as follows: Axial deviation of hole was affected by the annual rings, and became larger with increasing bit wear. In workpieces which had a loose knot, all deep holes deviated in the direction of the loose knot. The average value of both the AE and power consumption became larger with increasing feed per revolution. For the other hand, the average value of the AE were almost unaffected by bit wear, and the average value of power consumption increased slightly by bit wear. A correspondence between axial deviation of hole and the AE or power consumption was not recognized.

INTRODUCTION

Recently, large dimension structural glued laminated timber has been widely introduced for many buildings. Bolt joints have been chiefly adopted in these structural materials. In machine–boring of bolt joints, it is demanded to be able to process many borings in not only high accuracy but also speedy. In some factories, the introduction of an automatic boring–machine or the robot that replaces workers who bore by hand had been attempted. However, even when boring processes are performed with these machines, axial deviation of hole frequently occurs. In addition, a problem that joint positions become disagreements occurs. Therefore, the development of machine–boring which prevents axial deviation of the hole is greatly needed.

A technique for monitoring the wood machining process is important for the automation and automating. Acoustic emission (AE) is one method used as a monitoring technique, and is promising for the monitoring of chip formation (Kato and R. L. Lemaster, 1991; Sadanari *et al.*, 1991), tool wear (Dornfeld and R. L. Lemaster, 1981; Murase *et al.*, 1988; Tanaka *et al.*, 1992), and surface roughness (Zhao *et al.*, 1993;

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[1] Laboratory of Wood Material Technology, Division of Biomaterial Science, Department of Forest and Forest Products Sciences, Graduate School of Bioresource and Bioenvironmental Sciences, Kyushu University, Japanese.
* Corresponding author (E–mail: tohuchi@agr.kyushu–u.ac.jp)

Aguilera *et al.*, 2001). However, these target AE generated in the planing and sanding, the investigation on the AE generated in the machine–boring of wood is hardly conducted.

In this study, the objective was to obtain the basic information on axial deviation of the hole in the deep machine–boring of wood. In this experiment, the effects of knots and bit wear on axial deviation of the hole were examined and the acoustic emission (AE) and power consumption were also measured during the boring process.

MATERIALS AND METHODS

Testing machine

The deep boring–machine apparatus used in this test is shown in Figure 1 (Ohuchi *et al.*, 2003). The workpiece on the stage driven by a pulse motor was fixed using a vise in this figure. A mechanism of the testing machine is to perform boring by sending the workpiece to a bit that is installed in chuck of spindle point of the motor. The feed speed and moving distance of the stage can be adjusted by controlling the pulse motor. An AE transducer was mounted on the side of the vise with a magnet holder, and silicon grease was spread between the vise and the AE transducer. The output signal from the AE transducer was inputted to a personal computer through the AE tester. A wattmeter was installed in the motor, and power consumption was then measured. In addition, the output signal from the AE transducer was amplified by 54 dB using the AE tester, then high–pass filtered over 100 kHz; the average signal rectified in a half wave was then
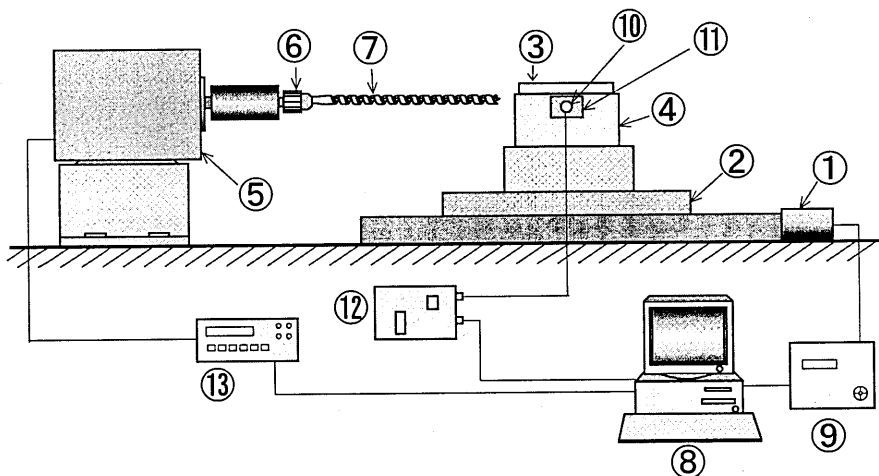

Fig. 1. Schematic diagram of the experimental apparatus.
Legend: ① Pulse motor, ② Stage, ③ Workpiece, ④ Vise, ⑤ Motor, ⑥ Chuck, ⑦ Bit,
⑧ Personal computer, ⑨ Controller, ⑩ AE sensor, ⑪ Magnetic holder, ⑫ AE tester,
⑬ Wattmeter

sampled.

Auger bits

Auger bits had a spur edge, a cutting edge, and a center drill which had a feed–screw. In this study, auger bits that were killed a feed–screw by grinding were used as shown in Figure 2 (Banshoya *et al.*, 2001). The tool material was alloy tool steel. The diameter was 9 mm and an overall length was 240 mm. Bits in which the spur edge recessions reached to 100, 200 and 400 microns by continuous boring of particleboard were prepared. In this test, these worn bits and a non–cutting bit were used.
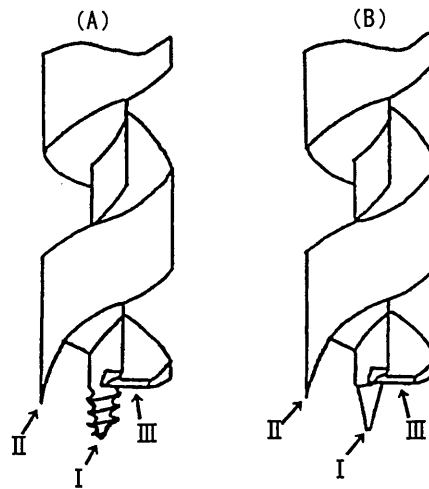
Fig. 2. Drawing of tools used in this experiment.
Legend: I: Center drill, II: Spur edge, III: Cutting edge

Work materials

The work materials used in this test were Hemlock (air–dried specific gravity : 0.47, moisture content : 12.8%). Workpiece A (Fig. 3A), which was assumed to be non knot, workpiece B (Fig. 3B), which was assumed to be loose knot and workpiece C (Fig. 3C), which was assumed to be live knot were prepared, respectively. In workpiece B, material that performed boring at a diameter of 12 mm was inserted in a position from 20 to 40 mm in the depth of the hole. In workpiece C, Ramin (diameter : 12 mm, air–dried specific gravity : 0.7, moisture content : 10.6%) of column type was buried under the loose knot of workpiece B. Here, let α be the angle between the boring direction and annual ring, and α of all workpieces was measured as shown in Figure 4. When α was positive, it meant that the direction of the annual ring was to the right of the boring direction. When α was
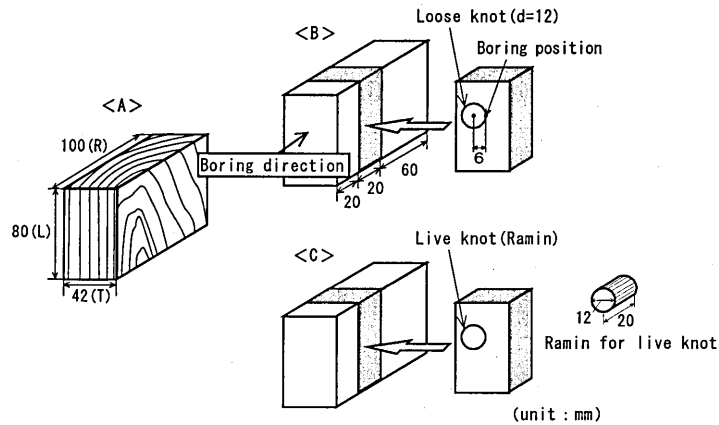
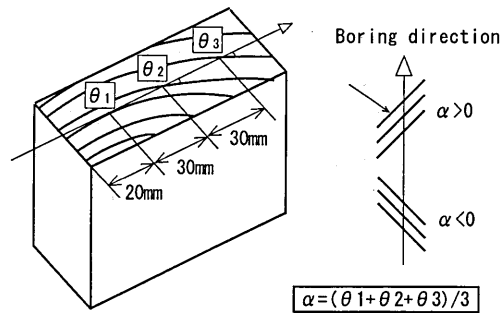**Fig. 3.** Drawing of workpieces used in this expriment.

Fig. 4. Measuring method of α.

negative, it meant that the direction of annual ring was to the left of the boring direction. The range of α of all workpieces used in this test were from −25.5 to 37.0 degrees.

Deep boring conditions and measurement method

The feed per revolution of 0.1, 0.4 0.7, 1.0 mm/rev were tested while keeping the spindle speed at 1700 rpm. In each experiment, through–hole borings of 100 mm in depth were performed, and were repeated three times per test condition. In the measurement of the axial deviation of the hole, the edge distance (Xin, Xout) and end distance (Yin, Yout) in the hole on the entrance and the exit side were measured by using image analysis software, as shown in Figure 5. The difference (ΔX, ΔY) in the distance between the entrance and the exit side was calculated, and the axial deviation of the hole was evaluated with these values. Therefore, when ΔX is positive, it means that the hole turns right with respect to the boring direction. When ΔX is negative, it means that the
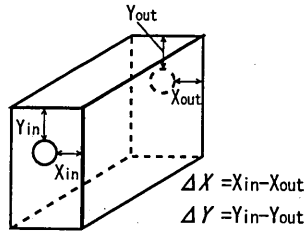
Fig. 5. Measuring method of axial deviation of hole.

hole turns left with respect to the boring direction. Moreover, when ΔY is positive, it means that the hole bends up with respect to the boring direction. When ΔY is negative, it means that the hole bends down with respect to the boring direction.

RESULTS AND DISCUSSION

Axis deviation of hole

The axis deviation of the holes in workpiece A, workpiece B, and workpiece C are shown in Figures 6, 7, and 8 respectively as typical examples of the result. In the case of
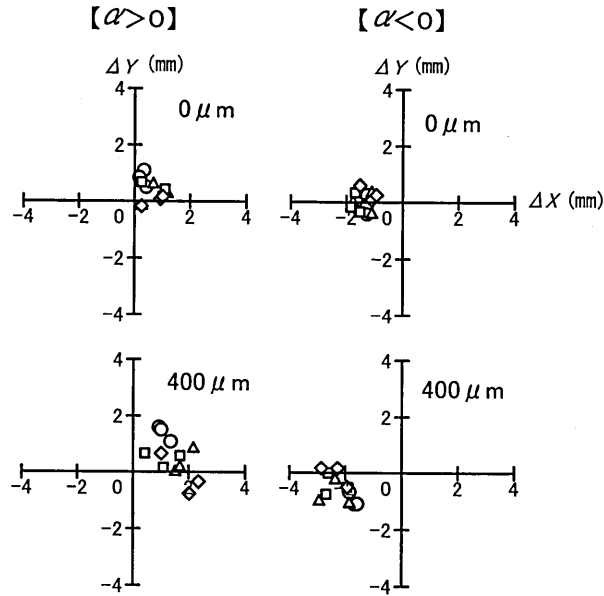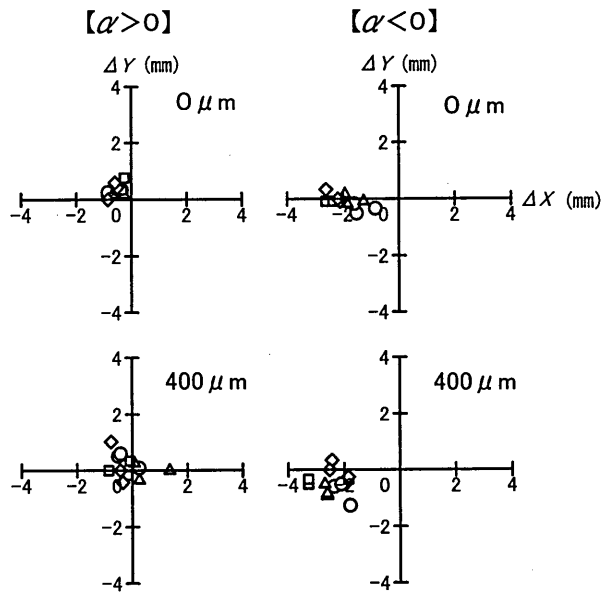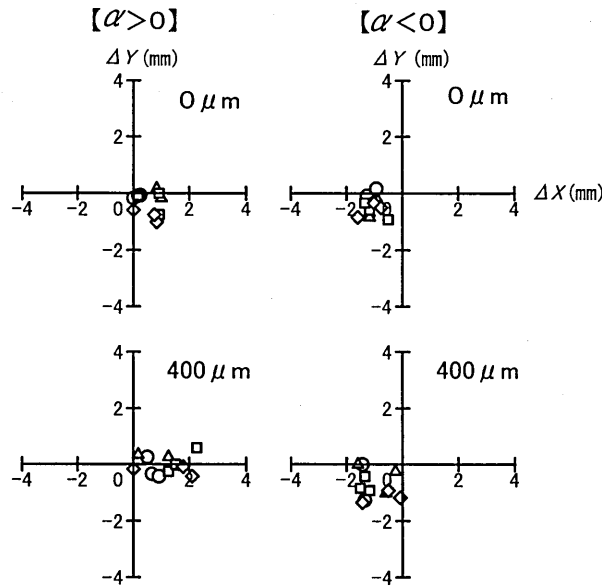

Fig. 6. Axial deviation of hole (workpiece A).
Legend: Feed per revolution (mm/rev)
○: 0.1, △: 0.4, □: 0.7, ◇: 1.0

【α>0】　　　　　【α<0】

ΔY (mm)　　　　　ΔY (mm)

0 μ m　　　　0 μ m

ΔX (mm)

400 μ m　　　　400 μ m

Fig. 7. Axial deviation of hole (workpiece B).
Legend: Symbols are as shown in Fig. 6.

workpiece A (Fig. 6), ΔX had positive values when α was positive, and ΔX had negative values when α was negative. From these results, it was found that the hole deviated along the annual ring. ΔY had smaller values than ΔX, except for in one condition that in which the annual ring influences the axis deviation of the hole. Moreover, axis diviation of the holes became larger with increasing bit wear. The tendencies mentioned above were similar for workpiece B and workpiece C. In the case of workpiece B (Fig. 7), ΔX was nearly zero when α was positive, and ΔX had negative values when α was negative, and these negative values was larger than those for workpiece A. These results mean that many holes deviated great deal in the direction of the loose knot. This deviation is considered to occur when the cutting resistance becomes small in machine–boring to loose knot. However, axis deviation of the hole became small when α was positive, because the annual ring direction is the opposite direction to the position of the loose knot. In contrast, when α was negative, the axis deviation of the hole became large, because the annual ring direction is the same direction as the position of loose knot. Moreover, the axis deviation of the hole showed a tendency to increase with increasing bit wear when α was negative. However, when α was positive, the tendency was hardly recognized. In the case of workpiece C (Fig. 8), the hole deviated along the annual ring, and the axis deviation of the hole was smaller than workpiece A when α was negative. In machine–boring to a live knot with large specific gravity, the cutting resistance became large, and the axis deviation of the hole was suppressed because the resistance acted on

【α>o】 **【α<o】**

Fig. 8. Axial deviation of hole (workpiece C).
Legend: Symbols are as shown in Fig. 6.

the direction of X axis. Moreover, the axis deviation of the hole became larger with increasing bit wear when α was positive. However, this tendency was hardly recognized when α was negative. All of the workpieces were almost unaffected by the feed per revolution.

Waveforms of AE and power consumption

The typical waveforms of AE and power consumption obtained in this test are shown in Figure 9. The X axis in these graphs showed the depth of the hole, and the time at which the point of the center drill entered into the workpiece was assumed to be 0 mm. The section from 25 to 45 mm in the dept of the hole was assumed to be section. The section from 70 to 90 mm in the dept of the hole was assumed to be section. The waveforms of AE in workpiece A became larger within 5 mm in the depth of the hole after the center drill entered into the workpiece, and became constant on average after that. The waveforms of power consumption increased from a depth of 5 mm in the hole, and became constant after that. In workpiece B, the waveforms of AE and power consumption within 25 mm in the depth of the hole showed a similar tendency to those of workpiece A. However, both waveforms decreased in section. For the other hand, both waveforms in workpiece C became larger in section. The difference in these tendencies depended on whether the workpiece had a knot or not. Therefore, it is clear that the processing of the knot can be monitored using waveforms of AE and power consumption.
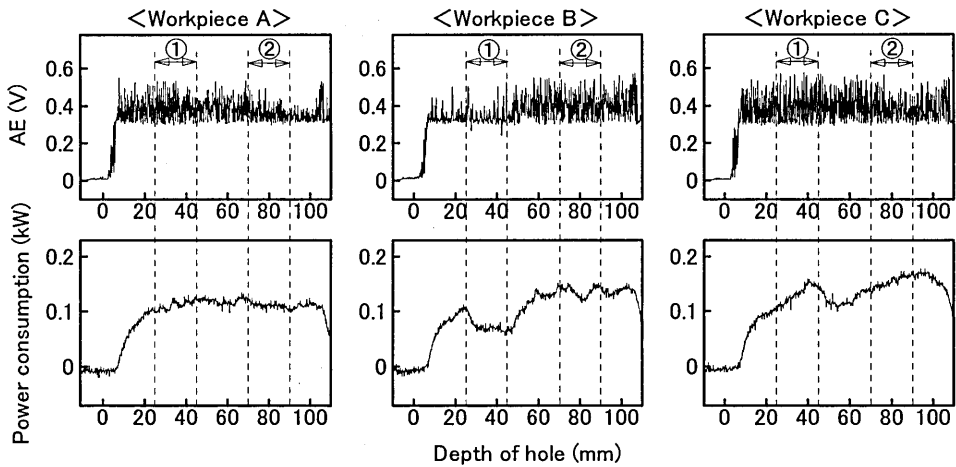
Fig. 9. Typical waveforms of AE and power consumption.
Notes: Workpiece B, $\alpha > 0$, 0μm, 0.7 mm/rev

Effect of bit wear on the average value of AE and power consumption

The relationships between the average values of AE, power consumption in the section from 70 to 90 mm within the hole and bit wear are shown in Figures 10 and 11. In all the workpieces, the average value of the AE were almost unaffected by the bit wear,
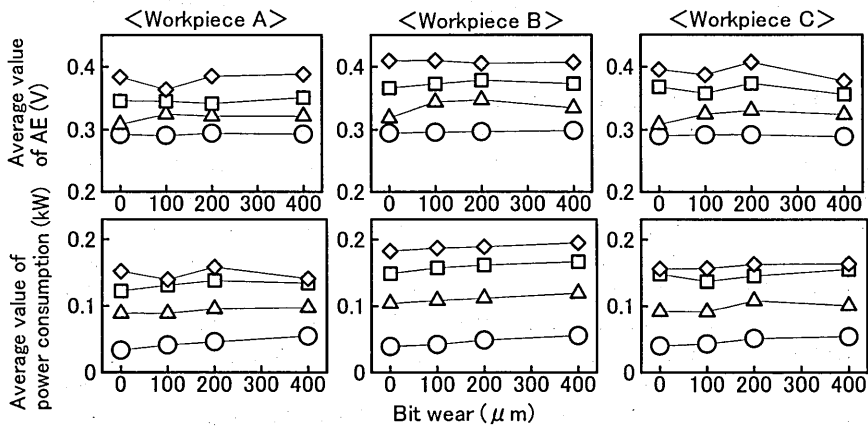
Fig. 10.   Relationships between the average values of AE, power consumption and bit wear ($\alpha > 0$).
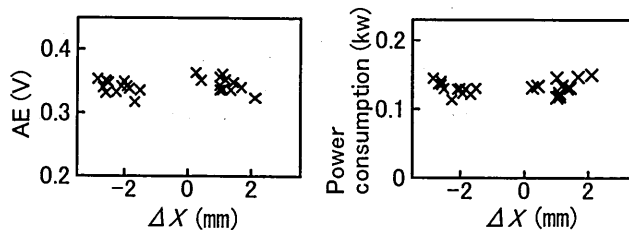Legend: Feed per revolution (mm/rev) ○: 0.1, △: 0.4, □: 0.7, ◇: 1.0
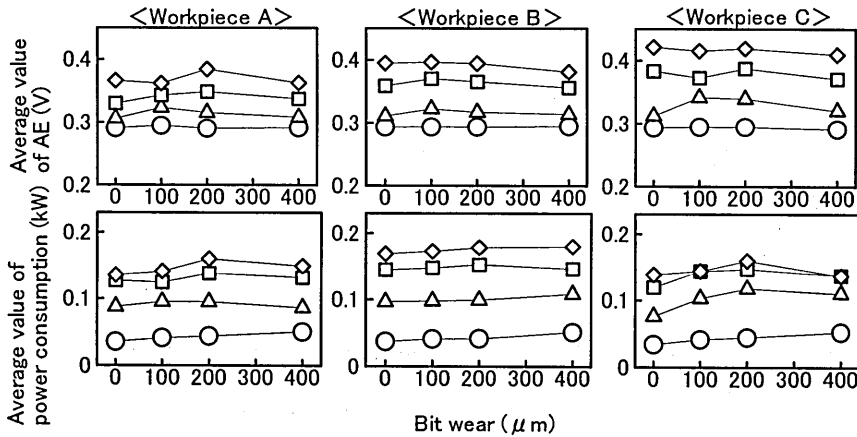
Fig. 11. Relationships between the average values of AE, power consumption and bit wear ($\alpha < 0$).
Legend: Symbols are as shown in Fig. 10.

but the average value of power consumption increased slightly by bit wear in some conditions. Moreover, the average values of AE and power consumption became larger with increasing feed per revolution.

Relationships between AE, power consumption and axial deviation of hole

Figure 12 shows the relationships between the average value of AE, power consumption in the section from 70 to 90 mm within the hole in workpiece A and ΔX, respectively. Thus, the average values of the AE and power consumption were almost unaffected by ΔX. That is, it was clear that a correspondence between the axial deviation of the hole and the AE or power consumption was not recognized.

Fig. 12. Relationships between the average values of AE, power consumption and ΔX.
Notes: Workpiece A, Feed per revolution:0.7 mm/rev

CONCLUSIONS

The objective of this study was to obtain basic information on axial deviation of the hole in the deep machine–boring of wood. In this experiment, the effects of knots and bit wear on axial deviation of hole were examined, and the acoustic emission (AE) and power consumption were also measured during the boring process. The main results obtained are as follows:

1) Axial deviation of the hole was affected by the annual rings and became larger with increasing bit wear.
2) In workpieces which had a loose knot, all deep holes deviated in the direction of the loose knot.
3) The average value of the AE and power consumption became larger with increasing feed per revolution.
4) A correspondence between axial deviation of the hole and the AE or power consumption was not recognized.

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