J. Agric. Sci., Tokyo Univ. Agric., 52 (1), 39–44 (2007)
東京農大農学集報, 52（1），39–44（2007）

Observation of Crack Propagation in Wood at the Cellular Level Considering the Occurrence of Lathe Checks

By

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(Received October 26, 2006/Accepted March 15, 2007)

Summary : In veneer production, lathe checks created during the cutting process affect the veneer qualities. Previous studies have clarified that lathe checks are generated due to tensile stress in bending at the rake face of the knife. To compare lathe checks propagated inside veneers in orthogonal cutting, small thin wood specimens with minute cracks inserted beforehand on the tension side were bended. Deformation and fracture of the wood structures due to propagation of the cracks were observed continuously through a digital microscope at the cellular level. The modes of crack propagation on early wood and late wood of Japanese cedar, sugi, (*Cryptomeria japonica* D. Don) were differed due to the difference in hardness between early wood and late wood, and classified into three patterns in early wood and twos in late wood according to the anatomy of the wood. The results obtained in this study were as follows ;

1) Crack propagation in early wood showed any one or a combination of the following characteristics in both the radial and tangential directions : (1) Propagation by separation between cells ; (2) propagation by partial splitting of cell walls ; and (3) propagation by rupture of cell walls.
2) Crack propagation in the radial direction in late wood almost always proceeded by separation between cells. This was also true in the tangential direction, but in rare cases, cracks propagate by the rupture of cell walls.
3) The mode of crack propagation differed with propagation direction.
4) The development of lathe checks in orthogonal cutting of wood perpendicular to grain, lathe checks developed chips inside from the loose side of the chips almost same modes as crack propagation observed in fundamental bending tests.

Key words : crack, crack propagation, lathe checks, cell walls

1. Introduction

In veneer cutting, the workpiece deforms elastically under the force in the vicinity of the knife-edge. When this force exceeds a certain value, the workpiece ruptures at the knife-edge. Separated portion is removed from the workpiece and flows out on the rake face as a veneer. Under the complicated stresses occurring near the knife edge during veneer cutting, lathe checks are generated from the loose side of a veneer, and develop inside the veneer during the veneer cutting. Lathe checks are awkward in that they lower the strength of the veneer or plywood which consists of multiple layers of veneers.

Aiming for the precision machining of wood, many cellular-level observations have been made on deformation of wood cells and fracture behaviour of wood structures. The behaviours of wood tissues were observed under high magnification through the optical microscope in the past studies[1–6]. The authors observed behaviours of wood tissues in veneers in the preliminary studies[7–9]. However, the generating mechanism of a lathe check is complicated and still unclarified because wood is a complex aggregate of tis-

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sues with different order of strength.

Therefore, we assume that one of the main causes for lathe checks is the tensile stress in the bending of a veneer, which occurs on the rake face of the knife in the neighbourhood of the cutting edge. In order to investigate the mechanisms of lathe checks, the authors attempted to observe microscopically the crack propagation and the deformation and rupture processes of wood structures in the cross section of the wood sample while the wood sample was subjected to a lateral bending stress.

2. Experiments

2.1 Procedure of bending test

Air-dried wood block of Japanese cedar, sugi (*Cryptomeria japonica* D. Don) was used to prepare samples to be subjected to bending stress on their tangential- or radial section. After the samples were saturated in water, the cross section, which was the plane of observation, was sliced smoothly by a sliding microtome. The samples were re-dried in air, and the experiment was carried out. For the bending test, a minute crack (1.0 mm of depth) was inserted by razor blade beforehand in the centre of the tension side of the wood sample. The sample size was 45×10×2.5 (thickness) mm.

The wood samples were subjected to a 3-point bending load on the compact device shown in Fig. 1. This device has a rectangular aluminium frame (60×100×30 mm) and a micrometer (1/1000 mm precision) was placed at the centre of one side. Supports were placed on the opposite side of the frame and the sample was fastened to the supports. The spindle was moved linearly against the sample to apply the bending load by turning the ratchet of the micrometer. The tip of the spindle had an angle of 90°. For observation of deformation and rupture of wood cells under the bending load, the compact bending device was placed on the platform of a digital microscope, and the cross section was continuously observed during the three-point bending test.

2.2 Procedure of orthogonal cutting of wood

To compare the crack propagation in bending and lathe checks occurred in the cutting of wood, a modified shaping machine was adapted to obtain orthogonal cutting without a pressure bar. Orthogonal cutting of wood was undertaken to feed a wood block linearly against the stationary knife. The knife used for orthogonal cutting (SKH 51) had a sharpness angle of 20° and a clearance angle of 45′. Depth of cut was 0.5 mm and feed speed was 12 mm/s (hand feed). The

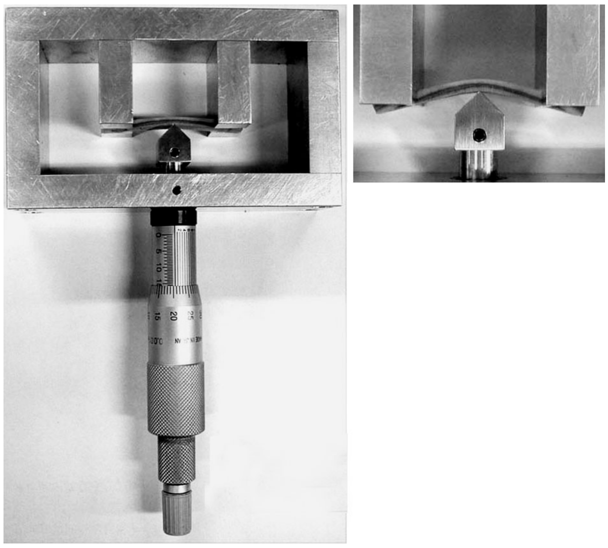

Fig. 1 Side view and a close up view of device for three-point bending test.

cutting surface was the radial section. The direction of feed was perpendicular to grain from the bark side to the pith side.

Quick curing bond was applied on the radial section of the obtained chip immediately after the cutting process. After embedding the chip in melted paraffin (m.p. : 68–70℃), the thin sections having thickness of 40 μm were taken from the cross section of the paraffin-embedded block by a sliding microtome. The prepared slide samples were observed through an optical microscope and the deformation and rupture of cell walls were evaluated at the cellular level.

3. Results and Observations

3.1 Crack propagation in bending load

3.1.1 Crack shape

In early wood, when a crack propagated in radial direction, a crack advanced straight mainly by separating between cells as shown in Fig. 2A. Sometimes a crack advanced by splitting of cell walls (refer Fig. 2B). However, when a crack propagated in a tangential direction, crack propagation was often observed to advance in a zigzag. In those cases, the crack mainly propagated by splitting cell walls or completely opening cell walls (refer Fig. 2C). Therefore, the typical modes of crack propagation in early wood were classified into three patterns according to the anatomy of the wood : separation between cells, partial splitting of a cell wall, and rupture of a cell wall. Thus, propagation of cracks in early wood occurs by any one or a combination of these.

Figure 3 shows the crack propagation observed in late wood. In nearly all cases, cracks advanced in the radial direction by separating between the cells (Fig. 3 A). In rare cases, splitting of cell wall in the tangential direction was observed (Fig. 3B).

3.1.2 Relation between angle to annual ring and crack propagation mode

Modes of crack propagation also varied with the inclination angle of annual rings to the direction of the bending load. In many cases where the crack propagated roughly perpendicular to the annual ring, it continued linearly in the radial direction (Fig. 4).

In contrast, two modes were seen when the crack propagated with some angle to the annual rings and particularly the crack formed a roughly around 45° angle to the annual ring. In some cases, the crack propagated straight in the radial direction (Fig. 5). In other cases, the crack propagated temporarily in the radial direction, then the crack changed the direction near the middle of the wood sample. In the latter case, the crack mainly propagated in a tangential direction by separation of cells, but the crack propagation by partial or complete rapture of cell walls was also observed. When a crack propagated almost parallel to an annual ring (the inclination angle between a crack and an annual ring became about 0°), crack propagation was often observed to proceed in a zigzag (Fig. 6). In this case, the crack mainly propagated by separation of cells, but sometimes by splitting cell walls or complete rupture of cell walls.

3.1.3 Relation between radial tissue and crack propagation mode

Figure 7 shows crack propagation by separation of tracheids from rays in early wood. This mode of crack onset was observed in many cases. This indicates that the bonding strength between tracheids and rays is less strong than the mutual bonds between tracheids. Three modes of crack propagation in the radial direction were observed : separation between rays and tracheids (refer Fig. 8A) ; separation within rays (Fig. 8 B) ; and rupture of rays (Fig. 8C). These modes would be explained by the differences in the crack's progressed direction in rays and the gap bonding strength between rays and tracheids described above, in combination with other factors.

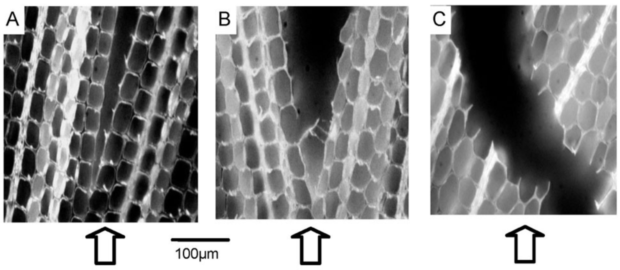

Fig. 2 Typical patterns of crack propagation in early wood, **A** : separation between cells, **B** : partial splitting of a cell wall, **C** : rupture of a cell wall.
Note : Bold arrows represent the loading direction in bending.

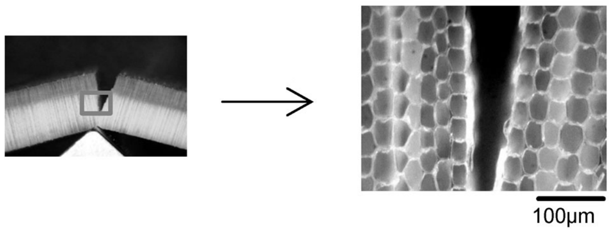

Fig. 4 Crack propagation in radial direction.
Note : in a case of a crack propagates perpendicular to the annual rings.

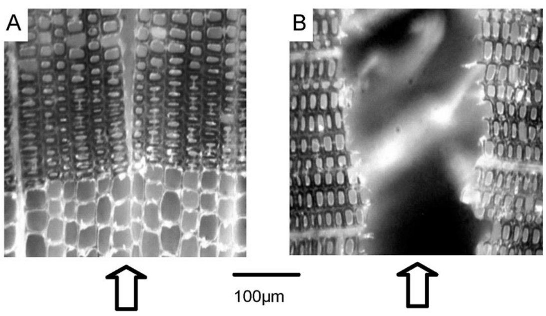

Fig. 3 Typical patterns of crack propagation in late wood, **A** : separation between cells proceeded in the radial direction, **B** : splitting of cell wall in the tangential direction.
Note : refer Fig. 2.

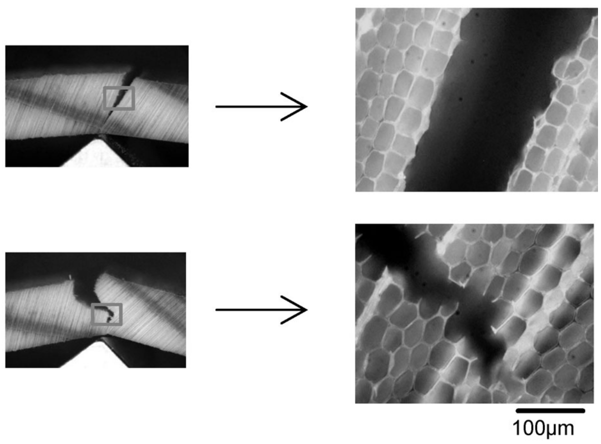

Fig. 5 Crack propagation in radial direction.
Note : in a case of a crack propagated with low angle to the annual rings.

3.2 Comparison of crack propagation in bending load and lathe checks in orthogonal cutting

In the initial stage of bending of wood sample with a minute crack, a buckling line appeared on the compression side of the wood sample as shown in Fig. 9A. As the bending load increased, a crack was propagated and grew into the vicinity of the extension of the buckling line on the tension side of the wood sample. In orthogonal cutting of wood, a buckling line was also observed in the tight side of the chip obtained. After the appearance of the buckling line, a lathe check was generated from the loose side of the chip (refer Fig. 9B).

Modes of lathe checks were different when lathe checks grew to radial direction and to tangential direction ; i.e. lathe checks progressed to the radial direction by separating wood cells mainly, but sometimes progressed with partial splitting of cell walls as shown in Fig. 10A (refer Fig. 4), and progressed to the tangential direction by separating cell walls accompanying the splitting of cell walls and rupture of cell walls as shown in Fig. 10B (refer Fig. 6). However, modes of lathe checks were concluded to be coincidental to the modes of crack propagation under bending loads.

4. Conclusions

Wood samples were subjected to bending loads, and the deformation and fracture processes of cells were observed in the cross section. The following conclusions were obtained :

1) Crack propagation in early wood showed any one or a combination of the following characteristics in both the radial and tangential directions : (1) Propagation by separation between cells ; (2) propagation by partial splitting of cell walls ; and (3) propagation by rupture of cell walls.

2) Crack propagation in the radial direction in late wood almost always proceeded by separation between cells. This was also true in the tangential direction, but in rare cases, cracks propagate by rupture of cell walls.

3) The mode of crack propagation differed with propagation direction. During propagation in the

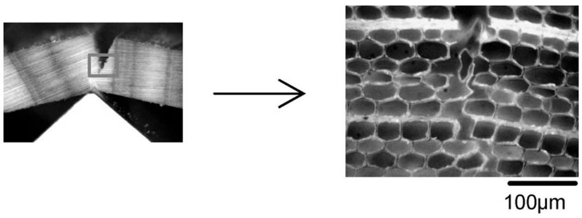

Fig. 6 Crack propagation in radial direction.
Note : in a case of a crack propagated parallel to the annual rings.

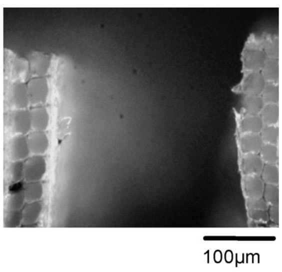

Fig. 7 Separation of tracheids from rays in early wood.

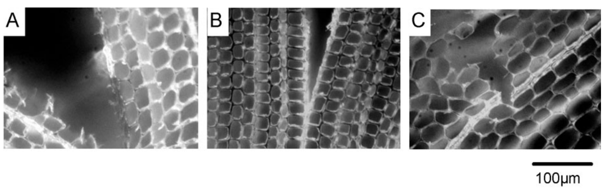

Fig. 8 Crack propagation in rays.
Notes : (**A**) separation between rays and tracheids, (**B**) separation within rays, (**C**) rupture of rays.

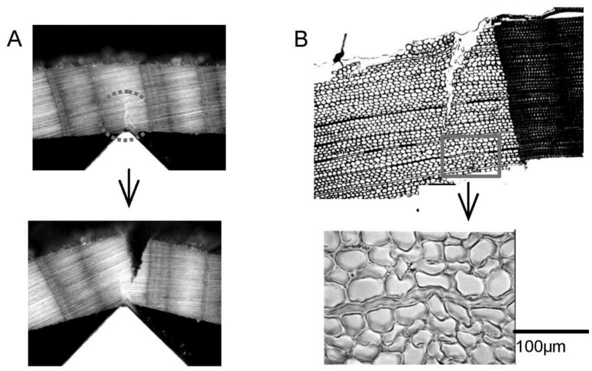

Fig. 9 Comparison of crack propagation in bending (**A**), and a lathe checks in a chip (**B**).

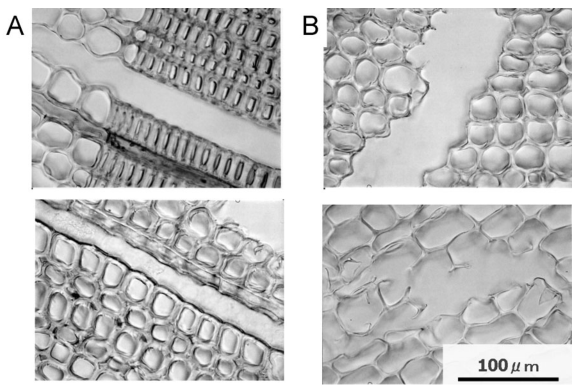

Fig. 10 Modes of lathe checks progressed to radial (**A**) and tangential (**B**) directions.

radial direction, the main mode was the separation between cells, but partial or complete rupture of cell wall also occurs. Separation between cells was also the main mode during propagation in the tangential direction, but partial or complete rupture of cell wall occurred somewhat more often.

4) Cracking was often observed to be initiated between rays and tracheids, and usually progressed within rays.

5) Three modes of cracking were observed in rays : (1) Separation between rays and tracheids, (2) separation within rays ; and (3) rupture of rays.

6) From the observation of development of lathe checks in orthogonal cutting of wood perpendicular to grain, lathe checks developed chips inside from the loose side of the chips in almost the same modes as crack propagation observed in fundamental bending tests, even though lathe checks and propagated cracks under bending loads grew to the radial direction or to the tangential direction.

Acknowledgements

Authors wish to express their appreciation to Mr. Takanori Hatayama, a former undergraduate student of Laboratory of Wood Science and Technology, Department of Forestry, Faculty of Regional Environment Science, Tokyo University of Agriculture, for his assistance throughout the experiment.

Literature cited

1) LENEY, L., (1960). Mechanism of veneer formation at the cellular level. *Research Bulletin* **No. 744**, College of Agriculture, University of Missouri, 1–111.

2) HAYASHI, D., TOCHIGI, T., YAMAZAKI, M., (1970). Studies on veneer cutting at the cellular level —Rupture formation of cell walls—. *Mokuzai Gakkaishi,* **16** (2), 70–75.

3) HAYASHI, D., TOCHIGI, T. and INOUE, H., (1971). Observation on rupture formation of cell walls at the cellular level in the wood cutting process (1). —Effects of inclination angle of rays upon cutting resistance and ratio of U-shaped cells—. *Wood Industry,* **26** (7), 306–312.

4) HAYASHI, D., TOCHIGI, T. and INOUE, H., (1971). Observation on rupture formation of cell walls at the cellular level in the wood cutting (0–90) process (2). —Effects of inclination angle of rays upon previous checks, lathe checks and characteristics of cutting surface—. *Wood Industry,* **26** (8), 358–363.

5) HAYASHI, D., TOCHIGI, T. and INOUE, H., (1972). Microphotograph of rupture formation of cell walls at the cellular level in the wood cutting (0–90) process. *Wood Industry,* **27** (5), 242–245.

6) HAYASHI, D., TOCHIGI, T., INOUE, H. and OGASAWARA, K., (1975). Observation on rupture formation of cell walls at the cellular level in the wood cutting (0–90) process (III). —Effects of setting condition of nosebar upon characteristics of cutting surface—. *Wood Industry,* **30** (12), 544–548.

7) OHBAYASHI, H., YOSHIZAWA, M., YABE, K., KOBAYASHI, J., SHIOKURA, T., TOCHIGI, T. and TADOKORO, C., (2003). Veneer cutting of frozen Japanese cedar, sugi. *Abstracts of the 53rd annual meeting of the Japan Wood Research Society, Fukuoka.* p.155.

8) NAKANO, H., MOMOI, T., OHBAYASHI, H., TOCHIGI, T and KOBAYASHI, J., (2005). Orthogonal cutting of the thermo-compressed Japanese cedar, sugi —Observation at cellular level—. *Abstracts of the 55th annual meeting of the Japan Wood Research Society, Kyoto.* p.77.

9) OHBAYASHI, H., TOCHIGI, T., MOMOI, T. and KOBAYASHI, J., (2005). The orthogonal cutting of frozen Japanese cedar (SUGI, *Cryptomeria japonica* D. DON). *Proceedings of COST Action E35, Workshop on Processing of Frozen Wood, Lappeenranta, Finland.*

単板中の裏割れの発生を想定した木材中の亀裂伝播の細胞レベルでの観察

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（平成 18 年 10 月 26 日受付/平成 19 年 3 月 15 日受理）

要約：単板切削において単板に生ずる裏割れは単板の品質に，また単板をエレメントとする合板の品質に大きく影響を及ぼす。裏割れの発生は切削に伴って工具刃先近傍に発生する諸切削応力のうち，主として引張応力に起因することが明らかになっている。

単板内での裏割れの発生および成長過程を細胞レベルにおいて検証するべく，小さい試験片（厚さ 2.5 mm）の曲げ試験を実施した。試験片の引張側に亀裂を事前に施し，負荷に伴う亀裂の伝播を細胞の変形および破壊挙動を観察した。また，二次元切削を実施し，得られた切屑の横断面（木口面）で確認できる裏割れの微視的観察を行い，曲げ試験による亀裂の伝播状況と比較した。

キーワード：亀裂，亀裂伝播，裏割れ，細胞壁，細胞レベル

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