RADIAL SPLIT RESISTANCE OF CHESTNUT EARLYWOOD AND ITS RELATION TO RING WIDTH

Patrick Fonti

Ph.D. Student
WSL Swiss Federal Research Institute
Sottostazione Sud delle Alpi
Via Belsoggiorno 22
Casella postale 57
CH-6504 Bellinzona, Switzerland

and

Juergen Sell†

Professor and Head
EMPA, Swiss Federal Laboratories for Materials Testing and Research
Wood Department
Ueberlandstrasse 129
CH-8600 Duebendorf, Switzerland

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ABSTRACT

New equipment was developed to measure the maximal radial split resistance of individual annual rings in green European chestnut wood (*Castanea sativa* Mill.). This equipment was then used to compare the split resistance in chestnut trees with and without ring shake taken from three differently managed coppices from the southern part of the Swiss Alps. Results indicate that within these stands radial split resistance and annual ring width are positively correlated, and that the rates of ring-shake occurrence increase with narrow and weak growth rings. Forest management of chestnut coppices that leads to an increase in growth thickness might, therefore, be a way of reducing the risk of ring shake.

Keywords: *Castanea sativa,* European chestnut, radial split resistance, ring shake.

INTRODUCTION

Chestnut wood (*Castanea sativa* Mill.) is commonly affected by ring shake, a serious problem reducing the use of this wood for high-added-value products (Bourgeois 1992). Ring shake is a type of wood crack that develops in the tangential plane of the trunk growing parallel to the annual ring (Chanson et al. 1989). Because of the high incidence of ring shake and difficulties in processing, the demand for this wood is limited.

Chestnut wood research has been principally aimed at avoiding the damage caused by ring shake, either by improving wood processing and uses or by identifying the factors controlling the development of failures. In particular, research focused on the causes leading to the more problematic ‘‘healthy’’ type (as defined by Chanson et al. (1989)), whose fracture appears to be unrelated to any anomalies of the wood tissue (discoloration or decay due to trauma, fungal or bacterial activity). Fonti et al. (2002b) recently reviewed the state of the art on chestnut ring shake. Of particular interest is Ferrand’s theory (Ferrand 1980), advancing the hypothesis that chestnut wood is prone to developing ring shake because of its structure that forces the propagation of tangential rather than radial cracks. It is proposed that the earlywood structure with its ring porosity and large vessels generates a plane of weakness along the annual ring, while the thin uniseriate wood rays have a limited ability to

† Member of SWST.

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resist crack openings in the tangential plane (Tschegg et al. 2001; Burgert et al. 1999; Eckstein et al. 1998; Beery et al. 1983; Keller and Thiercelin 1975; Schniewind 1959; Kollmann 1956). In addition, radially growing cracks, which usually form along the radial rays, have to cross both the weak earlywood and the tough latewood, which offers resistance to the fracture propagation without finding preferential paths (along large radial rays). Despite this high propensity of the species, not every tree is affected by ring shake. Intra-specific variability in the wood structure may affect radial tensile strength properties regulating individual (or even annual ring) susceptibility. Even if earlywood specific gravity and growth rate of ring porous hardwood do not seem to change with ring width (Zobel and van Buijtenen 1989), experimental data on earlywood radial strength in relationship with the growth rate are still inadequate.

Many earlier studies on radial strength have revealed that trunks affected by ring shake usually display lower average strength values than those without ring shake (Macchioni 1995; Frascaria et al. 1992; Leban 1985) although, because of the wide variability observed, it was not possible to find a significant relationship between radial weakness and ring shake. Nevertheless, these earlier studies suffer from some limitations in the testing methods because they do not allow either comparable data to be collected or the earlywood radial cohesion strength of wood to be properly characterized. Tensile radial tests performed by Leban (1985) allowed only one measurement per radial specimen, without it being known exactly where the specimen would break. Bending tests carried out by Frascaria et al. (1992) permitted several measurements along the same radial specimen, but it was not possible to check the exact crack location in this case. Macchioni (1995) developed a testing method based on torsion load on wood cores. This method permitted multiple measurements along the same cores and enabled the load location to be checked. However, the fracture displayed features differing from ring shake, not occurring precisely in the tangential plane. The wedge-splitting technique patented by Tschegg (1986) permits the radial split resistance to be determined while avoiding previous limitations. However, the shape and dimensions of the test specimens are unsuitable for easy measurement of the split resistance of annual rings positioned in close proximity.

In the present study, an effort was made a) to develop a split testing procedure to obtain comparable earlywood split resistance measurements for as many annual rings belonging to the same radial wood specimen as possible. The hypothesis is that the split resistance is a good indicator of the radial cohesion strength of wood within single growth rings. In addition, a preliminary study was performed b) to verify whether there is a relationship between radial wood strength, ring width, and ring shake.

MATERIALS AND METHODS

Wood materials

Overstory trees were selected in three chestnut coppice stands managed with different intensity and located in the Swiss canton of Ticino south of the Swiss Alps: 5 trees from a regularly and intensively thinned stand (Gorduno, 29-year-old stands), 21 trees from an occasionally and partially managed stand (Brione, 26–45 years old), and 24 trees from an unmanaged and abandoned stand (Bedigliora, 62 years old). From each of the selected trees, a 30-cm-thick stem disk was cut at 1.3 m above ground stem height. Since green wood was needed for the splitting test, these disks were immediately taken to the preparation laboratory. There, every thick wood disk was further sawn in order to obtain 3 to 5 green wood disks (3 cm thick). One of these was used for ring-shake observations, one for the preparation of the wood specimens for the mechanical test, and the remaining disks were either stored as reserve or used for repeated measurements in order to verify the consistency of the method used. From the disks for the mechanical testing, two pith-to-bark radial strips

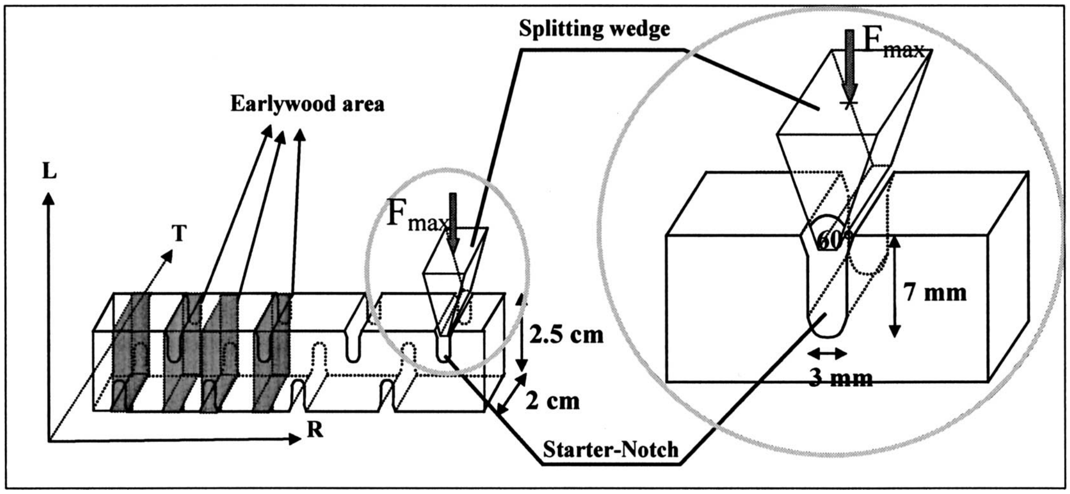

FIG. 1. Specimen details and test facilities used for the splitting test.

(2 cm wide × 2.5 cm high × disk radius length) that displayed the annual rings well disposed perpendicular to the radius axis were sawn for measurement of the annual ring width. Since the mechanical tests were performed later in a second test stage, all these still green wood strips were wrapped in aluminum paper and stored in a freezer at −17°C in order to prevent desiccation. Prefreezing should not have affected results; as observed by Stanzl-Tschegg et al. (1994) the fracture toughness between spruce wood with and without prefreezing did not change significantly.

The splitting test

Device and procedure settings.—The splitting test device consists of a universal testing machine (ZWICK type 1474) provided by a wedge with an angle of 60° and a side length of 2.5 cm and employed in its compression mode (Fig. 1). The load capacity of the machine is 100 kN and the capacity of the load cell used was 100 kN. The loading speed was set up to 50 N/s for all tests.

Set-up of wood specimen.—The previously collected pith-to-bark radial strips were set up in order to perform a maximal number of tests on the same radial strip. Since a minimal distance between two consecutive splitting tests is needed in order to avoid wood structural damage, we arbitrarily decided to perform the measurements, when possible, on every fourth annual ring. For every selected annual ring, a 7-mm-deep and 3-mm-thick starter notch was cut in the earlywood zone using a special milling head, alternatively changing from the top to the bottom of the wood-strip specimen (Fig. 1). Annual rings displaying either (partial) failures or an excessive curvature, i.e., these rings where the starter notch did not entirely cover the earlywood area, have not been considered. Finally, in order to reduce inelastic compression on the upper edge of the notch during load transmission, the upper side of the starter notch was slightly rasped with a triangular lime (60° angle) to increment the contact surface between wedge and wood. Before running the test, wood strip specimens were stored at room temperature for a few hours for thawing. Splitting tests were performed only on water-saturated wood samples.

Estimation of the splitting resistance.—Using the TestXpert software (Version 6.01, produced by Zwick GmbH & Co., Germany) connected with the device, we recorded the wedge load-displacement curves. Then the splitting resistance (R_{split}) was calculated according to Stanzl-Tschegg et al. (1995) as:

TABLE 1. *Disk classification according to stand, growth rate, and shake incidence. SG = slow-growing, i.e., average disk ring width <4 mm; FG = fast growing, i.e., average disk ring width >4 mm, Icip = ring shake index. Shake incidence groups do not statistically differ in disk diameter (ANOVA, p = 0.98).*

Stand/no. of disks	Growth rapidity	Shake-free (Icip = 0–30 cm)	Slightly shaken (Icip 30–150 cm)	Strongly shaken (Icip) >150 cm)
Bedigliora	SG	8	8	8
Brione	SG	2	8	5
Brione	FG	4	—	2
Gorduno	FG	5	—	—
Total		19	16	15

$$R_{split} = (F_{max} \times 0.5 tg\alpha)/A \quad [N/mm^2] \qquad (1)$$

where F_{max} is the maximal load of rupture, α the wedge angle and A the fractured surface.

Ring-shake observation

Ring-shake incidence was surveyed taking into account all failures (healthy ring shake) longer than 1 cm noted on the green wood disks. The length of the failure, its location on the wood disk, and the year of the fractured annual ring were recorded for each ring shake. Then a ring-shake index (Icip) based on ring-shake failure length was calculated for the whole wood disk.

RESULTS

Growth characteristics and ring-shake incidence of the disks

As expected, all trees from Bedigliora showed slow growth (average disk ring width <4 mm) in contrast to those from Gorduno, which have grown faster, whereas in Brione both classes are present: 17 slow-growing trees and 6 fast-growing ones (Table 1).

Among the disks selected, we observed that 19 (38%) are shake-free (Icip < 30 cm), 16 (32%) are slightly ring-shaken (Icip 30–150 cm), while 15 (30%) are strongly ring-shaken (Icip > 150 cm). Ring shake was located mainly in the middle third of the radius. It is interesting to note that shake-free disks are present in all growth categories, whereas fast-growing trees are only rarely ring-shaken.

Radial split resistance

Radial split resistance tests were performed in the earlywood area of 1,076 annual rings from 50 trees collected in 3 differently managed coppice stands. Radial split resistance values generally exhibited wide variability, ranging from a minimum of 0.06 N/mm^2 to a maximum of 2.55 N/mm^2, with an average value of 0.86 N/mm^2 (q_{25} = 0.55 N/mm^2; q_{75} = 1.10 N/mm^2).

In order to validate the experimental method, split-test measurements were replicated in the same annual rings of three adjacent pith-to-bark radial wood specimens from 8 trees. Altogether 110 replicas were tested. The average standard deviation within replicas was 0.11 N/mm^2. Compared to the variability between annual rings belonging to the same radial strip (average standard deviation = 0.32), the variability within the replicas was significantly smaller (one-sided, paired t-test, $P < 0.001$). This result suggests that the splitting method used is consistent and sensitive enough for such kind of measurements.

Relationship between radial split resistance, ring width, and ring-shake incidence

Figure 2 summarizes radial split resistance, ring width, and ring-shake incidence measurements performed in a single tree (Brione no. 3). On this disk, it is possible to qualitatively observe that:

- wider annual rings show higher values of radial split resistance;

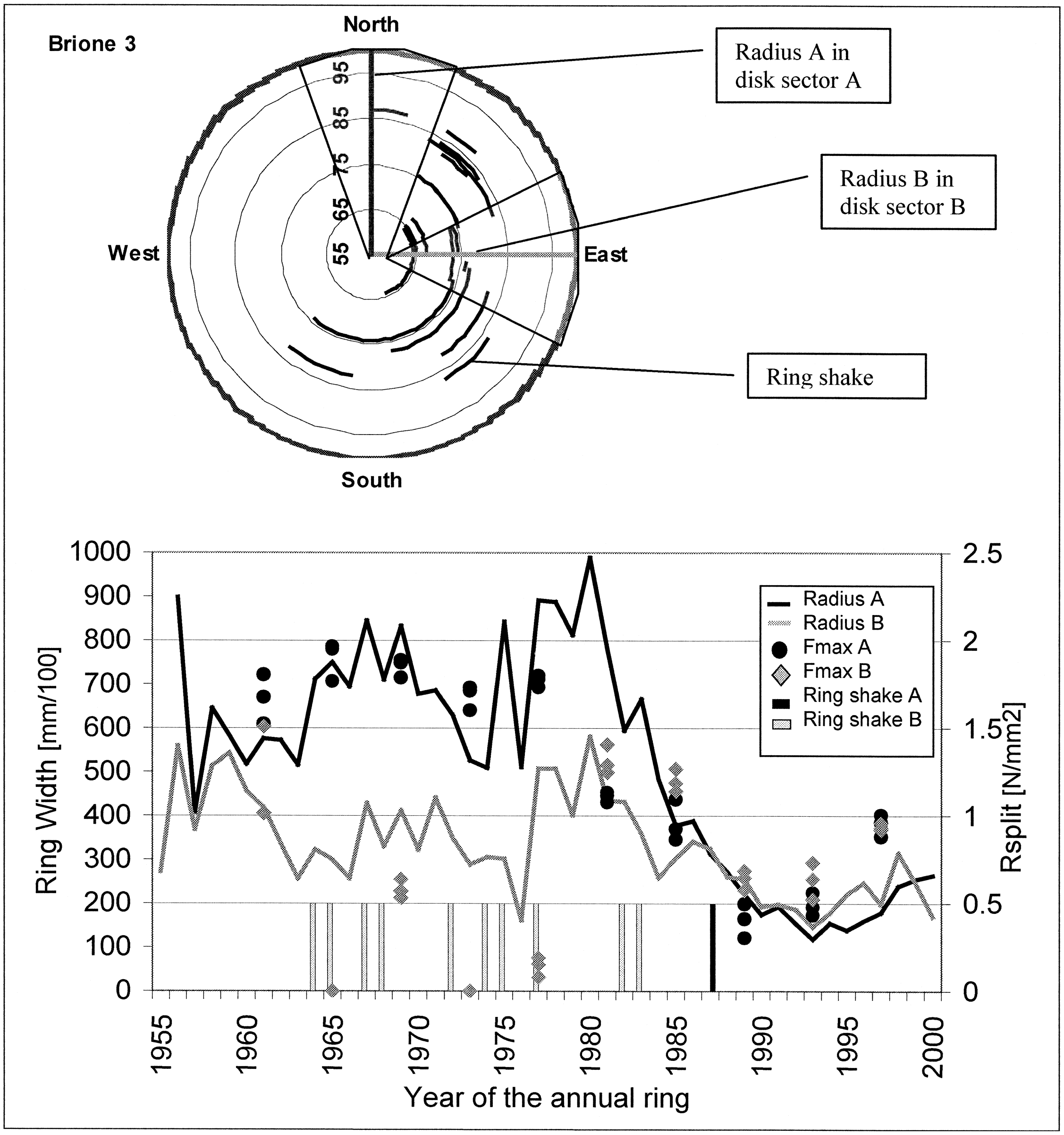

FIG. 2. Example of measurement performed on a single wood disk. Above a schematic disk representation with ring shake and wood specimen location identified. Below the graph shows ring width, split resistance, and ring shake presence of the two wood disk sectors of the specimens considered.

- ring shake occurs mainly in the central part of the radius and is more frequent in sector B, which is characterized by rings displaying narrower and lower radial cohesion strength than those of sector A.

Similar results are even more apparent when considering all the samples. As illustrated in Fig. 3, which shows the relationship between ring width and radial strength, the splitting resistance within the 3 stands is sig-

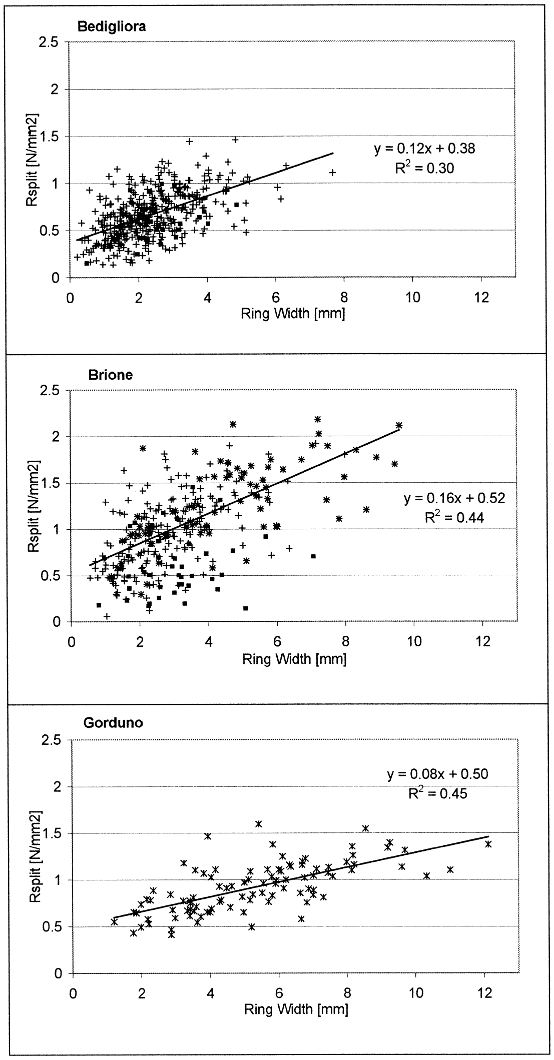

FIG. 3. Relationship between radial split resistance and ring width according to stand origin. + = slow-growing tree values; * = fast-growing tree values; ■ = split measurements performed in proximity of ring shake. If in the disk sector ring shake occurred in the annual ring preceding and following the annual ring to be measured, then this measurement has been classified as "in proximity of ring shake." Regression lines do not consider split measurements performed in proximity of ring shake. The slope of the regressions are high significantly different from zero (*P*-value <0.001).

nificantly related to the width of the annual ring. The larger the annual ring, the more split-resistant the earlywood is in its tangential plane. In line with a 1-mm radial growth increment, the split resistance increases from 0.08 N/mm^2 for the Gorduno disks to 0.16 N/mm^2 for the samples from Brione. In Fig. 3, it is also possible to observe that in the majority of the cases the strength values of the annual rings located in the proximity of ring-shake failure are among the weakest values measured in rings with similar width. However, this does not mean that all growth rings that showed lower strength values are in the proximity of ring-shaken areas, also because there are some areas where ring shake only rarely occurs (near the pith and close to the bark). It has also been observed that within the same disk, ring shake is predominantly located in the sector with narrower rings. From a selection of the disks where the mean ring width rate between the 2 selected disk sectors was clearly detectable (i.e., mean ring width differing for more than 0.5 mm), it was observed that in 14 out of 18 cases the narrower and also weaker radius showed a higher incidence of ring shake. According to the binomial distribution $\beta(18, 0.5)$ with a significance level of 0.05, this rate has a probability *P* significantly different from 0.5. An analogous trend was also detectable when considering wood disks with different ring-shake severity. Figure 4 shows the relationship between radial split resistance and annual ring width calculated for each wood disk. Among the faster-growing trees (average ring width > 4 mm), there are no ring-shaken disks, whereas with slow-growing trees the frequency of ring-shaken disks increases.

DISCUSSION AND CONCLUSIONS

The splitting method used may not be ideally suited to an absolute and accurate characterization of the wood split resistance. More sophisticated testing devices, such as that patented by Tschegg (1986), are more effective in reducing wedge friction during load transmission. As the purpose of the study was to compare the radial cohesion of different annual rings, the device used was sufficiently sensible and consistent, as demonstrated with

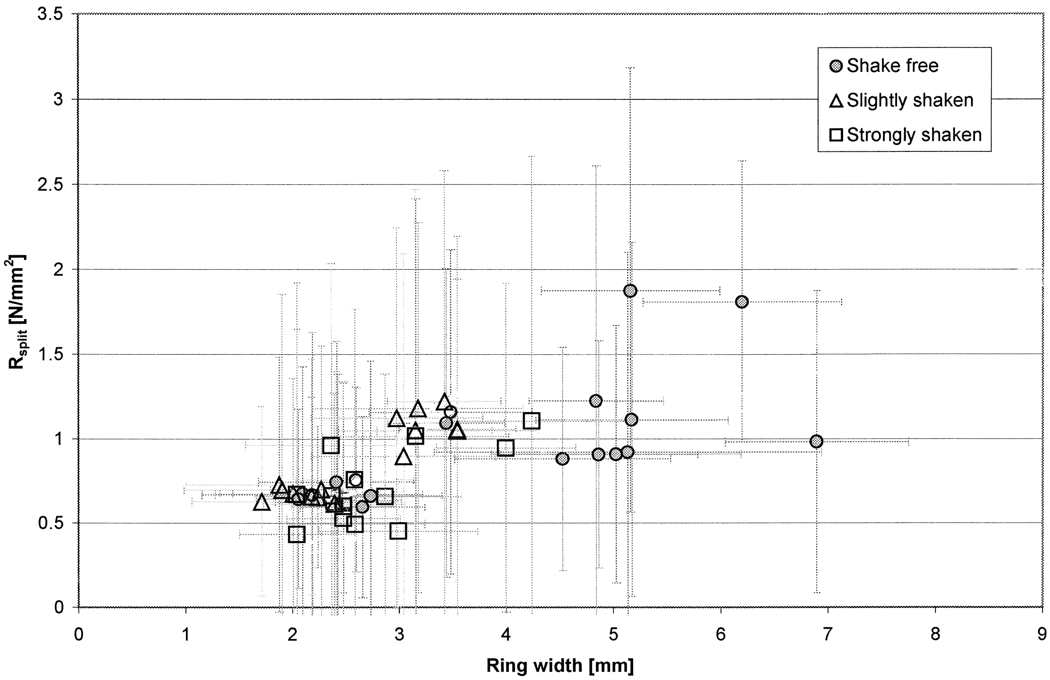

FIG. 4. Relationship of the radial split resistance and ring width. $R^2 = 0.53$. Each point corresponds to mean values measured for each wood disk. Bars indicate the standard deviation of values. Disks have been classified in three ring-shake incidence groups: ○ = shake-free (Icip 0–30 cm); △ = slightly shaken (Icip 30–150 cm); □ = strongly shaken (Icip > 150 cm).

the 110 triple replication tests performed on 8 different trees.

The results provided clear evidence of a positive correlation between the annual ring width and radial wood strength. This trend was supported by the comparison between wood disks, by the pith-to-bark wood specimens belonging to the same disk, and also by the comparison of single growth rings. The fact that wider rings seem to be less prone to shake might suggest that growth rate affects earlywood (anatomical) characteristics. Nevertheless earlywood width of ring-porous species does not change with ring width (Zobel and van Buijtenen 1989). Whereas considering earlywood vessels and radial rays features, it has been observed that, although an increase in vessel lumina and ray volume with mean ring width of the stand has been observed, the differences between ring-shaken and shake-free disks are not as we initially expected: in fact ring-shaken disks displayed significantly smaller earlywood vessel lumina (Fonti et al. 2002a) and a higher amount of rays (Fonti and Frey 2002) than the unshaken ones. However, ring-shake development was directly related to weak radial cohesion and narrow annual growth rings. Ring shake can also develop in wood with high radial cohesion as well as in large growth rings, but the frequency of shakes tends to be lower in those rings. In particular, we observed that ring shake very rarely occurred in rings wider than 4 mm. This does not, however, mean that all narrow rings or slow-growing trees are always affected by ring shake. In addition, near the pith and close to the bark ring shake only rarely occurs as observed both in this and in previous studies (Fonti et al. 2002b). In fact, most narrow rings and about 25 percent of all slow-growing trees considered for this study are shake-free. As well as radial strength, growth stresses in wood are also very important with respect to the development of ring shake (Fonti et al.

2002b). It may, therefore, happen that ring shake occurs in wood with a high radial strength and vice-versa.

An increase in radial growth corresponds to an improvement in the radial split resistance, which plays an important role in the development of ring shake. Enhancement of the radial wood cohesion strength should therefore help to reduce the risk of the occurrence of ring shake.

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