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LATHE CHECK FORMATION AND THEIR IMPACT ON EVALUATIONS OF VENEER-BASED PANEL BOND QUALITY

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ABSTRACT: During the peeling of veneer, lathe checks as deep as 70 to 80% of the veneer thickness are formed. This study showed that during adhesive testing according to EN 314 deep lathe checks in birch (*Betula pendula* Roth) veneer significantly reduced the shear strength of phenol-formaldehyde (PF) bonded plywood, even though these checks are not mentioned in the standard. In addition, we show that specimens tested open can fail by a different mechanism than those pulled closed, especially when checks are deep. Lathe checks were also shown to influence bond strengths when using the Automated Bonding Evaluation System (ABES). These findings stress the importance of measuring lathe check depth and considering the orientations of checks during testing to get a better understanding of bond quality in veneer-based products.

KEYWORDS: bond quality; lathe checks; plywood; shear strength; percent wood failure

1 INTRODUCTION

During peeling, lathe checks form on the veneer surface curving away from the knife and move through the veneer at an angle to the surface. The checks side of veneer has been named the 'loose side' and the opposite side is the 'tight side' (Figure 1). Lathe check parameters, their formation and measurement during peeling have attracted significant research interest [1-7]. It is known that the peeling settings are very important in obtaining high quality veneer [8,9] and the optimum settings can vary depending on the raw material [10].

Lathe check depth and frequency are correlated; deeper checks tend to be less frequent than shallower checks [12-14]. Compression of the log just in front of the knife impacts the depth and frequency of lathe checks [11], and heating logs before peeling reduces the formation of deep lathe checks [5,15], which is beneficial since it has been shown that shallower checks are less detrimental to veneer strength perpendicular to grain [16].

Roughness of wood has been frequently used as a parameter to predict adhesive bond formation and quality, though measurement of the true topography taking part in bonding is ambiguous and the optimum surface topography for bonding varies also with adhesives [20]. Wood surfaces that are too rough sometimes prevent intimate contact between the adhesive and with wood surface [17]. There is no clear limit for surface roughness, but according to Sellers [10], cited in [22], the maximum roughness depth for acceptable veneer bonding is about 0.5 mm. Traditional surface roughness measurement techniques might not adequately characterize the surface roughness of wood material relevant to bonding, because of a weak boundary layer [23], which is a result of wood processing and which can limit adhesive bond formation with intact wood. In this study we were interested in the weak boundary layer created by deep lathe checks or surface fractures, which prevent the surface from being well anchored to the bulk veneer.

Wood processing parameters play an important role in the surface roughness and other parameters that ultimately impact bond performance [17]. Some studies have demonstrated that heating logs by soaking in hot water before peeling will decrease surface roughness [18,21], while at least one shows the reverse [19]. In general, the effects of log soaking prior to peeling have received little attention.

Generally, the quality of an adhesive bond in plywood is evaluated by testing saw kerfed specimens in tensile shear. In the European Standard EN 314 "Plywood Bonding Quality" percentage wood failure (PWF) and shear strength are used in assessing adhesive bond

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performance, but the orientation and depth of lathe checks are not taken into the account.

According to the standard, if the product failure occurs in the wood, it most likely will be accepted. Unfortunately, PWF is commonly evaluated by visual observation and the results are highly evaluator dependent, as it is very hard to determine whether the bond failed at the adhesive-wood interface or slightly below the wood surface.

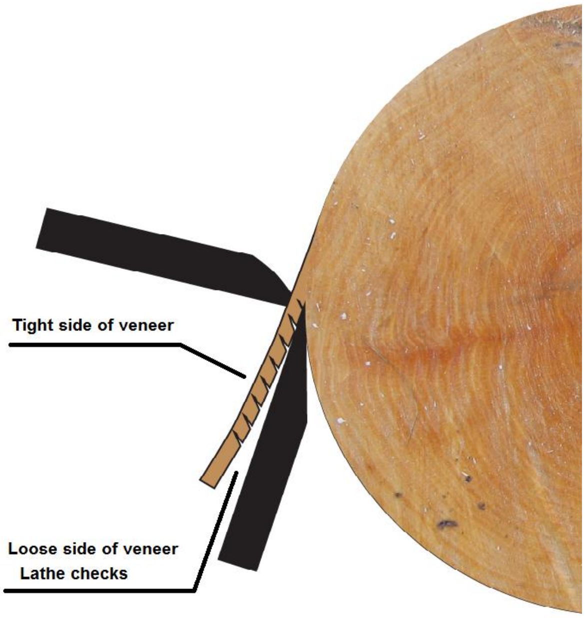

Figure 1: *Veneer peeling and lathe checks formation*

The strength values obtained with the EN 314 test differ depending on whether the checks are pulled open or closed. Testing plywood with the checks closed results in higher shear strength than when checks are pulled open, however, the magnitude of the strength difference varies from 14 up to 94% [24-27]. The variation in strength might be due to check depth, but in most published reports, the depth of checks is not presented.

There is no robust understanding of how the depth of checks affects the bonding quality of plywood. Also, there is a lack of consensus as to the role that both the PWF and the shear strength values play in determining bond quality. A better understanding of the effect of peeling parameters on the veneer surface and the resulting bond properties is needed for the development of more durable wood-based materials.

This paper summarizes some findings of a multi-year study of the complex process of plywood bonding. The effect of lathe check depth and check orientation on failure stress and PWF according to EN 314 was evaluated. In this paper we also report the impact of log soaking temperature on surface quality. In the regime of relatively smooth veneers, we found lathe checks, and the weak boundary layer they generate, to be a critical factor in understanding adhesive bond strength.

2 MATERIALS AND METHODS

2.1 VENEER FOR PLYWOOD PREPARATION

Fresh birch (*Betula pendula* Roth) logs were soaked in water at 20°C prior to rotary peeling on an industrial size lathe (Model 3HV66, Raute Oyj, Finland). The target thickness of the veneer was 2 mm and the average lathe check depth was 50%. After peeling, the veneers were dried at 160°C in a laboratory scale veneer drier and conditioned at 20°C and 65% RH. Finally, the veneer sheets were sanded (180 grit) on both sides to achieve 1.4 mm thickness. With sanding, three groups of veneer were formed with lathe checks depth nominally 25, 50, and 75% of veneer thickness (Figure 2).

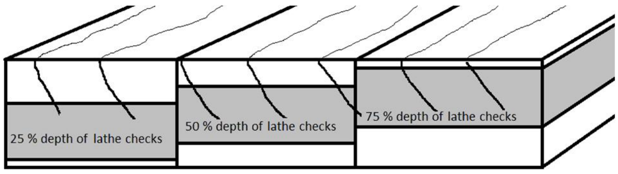

Figure 2: *Schematic representation of the three veneer groups to control check depth. Shaded area is the final veneer after sanding (adapted from Rohumaa et al. [28])*

In this way, individual veneer sheets with actual lathe check depth ranging from approximately 30 to 90% of the veneer thickness were produced. This approach was first used by Rohumaa et al. [28].

2.2 VENEER FOR SURFACE INTEGRITY MEASUREMENTS

Veneers for use in surface integrity testing were peeled with thickness 0.8 mm, at two different temperatures. Bolts from the same tree were cut to a nominal length of 1.2 m and completely immersed in water tanks heated to either 20ºC or 70ºC. Then the logs were rotary peeled on an industrial scale lathe (Figure 3) manufactured by the Raute Corporation (Model 3HV66; Raute Oyj, Finland). All other peeling conditions were kept constant.

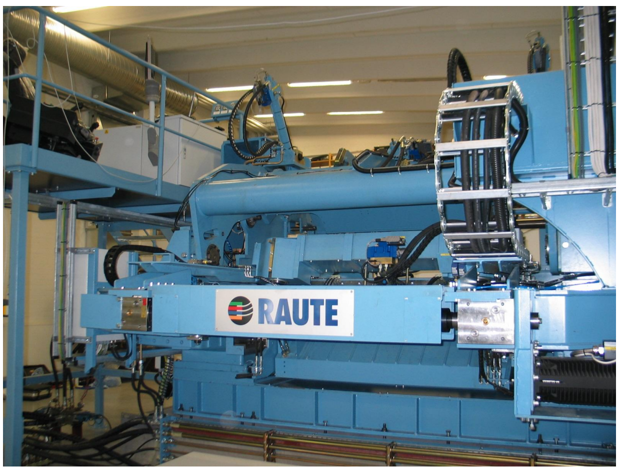

Figure 3: *Industrial scale lathe used in present study.*

The veneers were dried at 160ºC in a laboratory scale veneer dryer (Figure 4) (Raute Oyj, Finland). Prior to testing, the veneers were conditioned to constant mass at 20ºC and 65% RH.

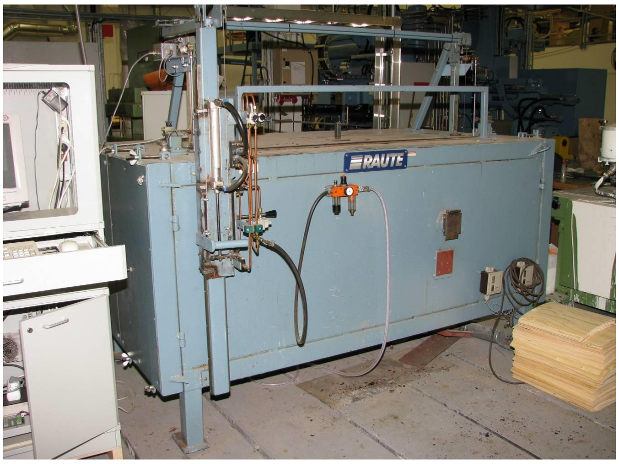

Figure 4: *Laboratory scale veneer dryer used in present study.*

2.3 BONDING PROCESS

Adhesive: A liquid phenol-formaldehyde (PF) resin (Prefere 14J021, Dynea Chemicals Oy, Hamina, Finland) with 49% solids content was used throughout this work.
Plywood manufacturing: 7-ply plywood was produced in a laboratory hot press. The approximate spread rate of the adhesive on each layer of the veneer was 155 g m^{-2}. After lay-up, the panels were pre-pressed for 8 min at 0.8 MPa prior to hot pressing. The hot press time was 7 min, the platen temperature 128°C, and press pressure 1.8 MPa. In total, 18 panels were produced. Following hot pressing, the panels were conditioned at 20°C and 65% RH for one week prior to machining the specimens. The specimens were produced according to SFS-EN 314-1 [29].
ABES: Matched veneer specimens with dimensions 20 x 117 mm^2, were cut from conditioned veneer sheets. Resin was applied by a micropipette (HandyStep electronic, BRAND GMBH + CO KG, Wertheim, Germany) to an area of 5 x 20 mm^2 at one end of the veneer specimens to give a resin spread rate of ~100 g m^{-2}.

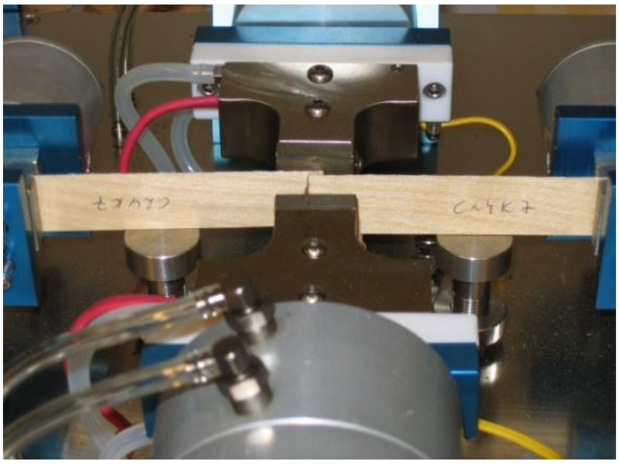

Figure 5: *Bond preparation and testing with ABES*

After adhesive application, the veneer-resin assembly was placed in the ABES equipment (Adhesive Evaluation Systems, Inc., Corvallis, Oregon, USA) and hot pressing started almost immediately (Figure 5). The assembly time for specimens was approx. 5 s.

2.4 EVALATION AND TESTING

2.4.1 Lathe check depth

All specimens used in lathe check depth measurements were treated with the textile dye "Tulip red" (Dylon, UK) to make the checks visible under an optical microscope.
The checked side (loose side) of the veneer sample was exposed to the dye and then conditioned at 20^{0}C and 65% RH for 12 h. The veneer specimens were cut across the grain direction to reveal the checks in the transverse direction. The depth of all checks in specimens were measured (Figure 6) and the average check depth percentage (%) was calculated for each group, using a stereo microscope (Wild MZ8, Leica, Wetzlar, Germany) and National Instruments, Vision Assistant 7.1 image processing software.

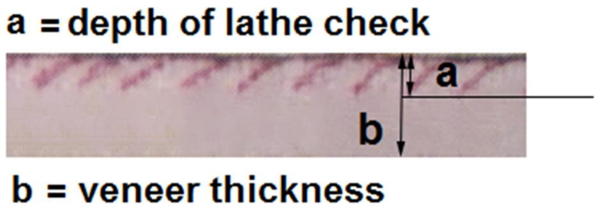

Figure 6: *Measurement of lathe checks*

Plywood specimens were treated with the same dye on one edge of test specimen (SFS-EN 314) so as to make the checks visible under the microscope. To reveal the checks, a slice approx. 0.5 mm thick was removed from the coloured edge by sawing. The depths of all checks occurring between the saw kerfs were measured and the average check depth (% of veneer thickness) was calculated for each specimen.

2.4.2 Plywood bond strength

Plywood bond quality was evaluated using the standards SFS-EN 314-1 [29] and SFS-EN 314-2 [30]. Half of the specimens were tested according to SFS-EN 314-1 [29] class 1 and the other half of the specimens were tested without pre-treatment in water. Additionally, shear strength was measured both with the checks pulled open (Figure 7a) and pulled closed (Figure 7b).

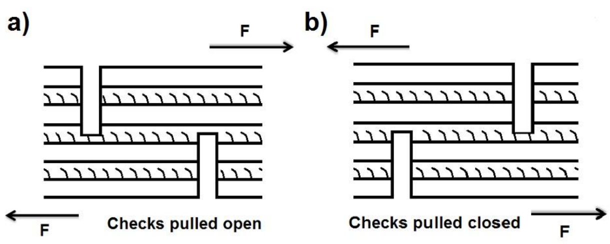

Figure 7: *Visualisation of lathe check direction in plywood testing. a) Middle ply with lathe checks pulled open. b) Middle ply with lathe checks pulled closed.*

In this manner, the following four test groups were prepared: a) water soaked samples with open checks, b) water soaked samples with closed checks, c) dry samples with open checks and d) dry samples with closed checks. Bond quality testing was performed on a Zwick universal tester (type 147570, Zwick Roell, Ulm, Germany). PWF was determined automatically by means of a CCD camera and image processing software.

2.4.3 Automated bonding evaluation system (ABES)

ABES shear strength was measured after 120 s pressing times. The platen temperature was 130°C and press pressure was 2.0 MPa. The bonds were tested immediately after pressing and were not cooled prior to strength testing. At least 7 bonded specimens were tested for each group and pressing time.

2.4.4 Veneer surface integrity

A standardised test method does not exist for veneer surface integrity measurements, but Rohumaa et al. [31] developed a procedure to evaluate integrity of the veneer surface. Veneer surface integrity was tested with a Huygen internal bond tester (model 1314, Huygen Corporation, Wauconda, IL USA) by first attaching double-sided tape (P-02, Nitto Denko Corporation, Osaka, Japan) to the veneer surface with constant pressure and then using the same device to separate the tape from the veneer surface. This internal bond tester is generally used to produce a high speed Z-direction rupture in paper and paperboard. In this study, the test veneer was fixed between a stainless steel sample base and an aluminium angle using the double-sided tape by applying a constant pressure of 0.12 MPa for 5 s. After pressing, a pendulum is released and strikes the vertical leg of the aluminium angle. The impact separates the tape from the veneer (Figure 8) allowing an observation of the attached wood particles on the tape surface, with area 25.4 x 25.4 mm^2. The veneer surface destined to be visualized was previously dyed with a 1% solution of the fluorescent dye acridine orange.

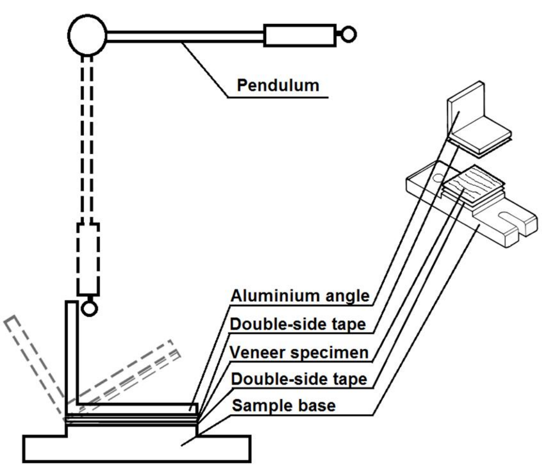

Figure 8: 8 Sample preparation for integrity testing and separation of tape from the veneer surface (adapted from Rohumaa et al. [31])

After tape removal, fluorescence images of the particles adhering to the tape (quantity and size) were obtained using a Leica DMLAM (Leica Microsystems GmbH, Wetzlar, Germany) microscope modified by installing a TV zoom lens and removing the objective. The specimens were illuminated with a blue LED (wavelength 470 nm) and the fluorescent emission passed through a Leica L4 filter set. A Leica DC300 colour digital camera captured the images and processing was done in the Leica Application Suite software. Because of the acridine orange stain, wood showed up as bright particles, allowing the number and size of particles to be calculated in each 6 x 6 mm^2 image based on bright pixels, using MATLAB 2013b software. To improve consistency of results, only earlywood regions were included in the analysis presented here.

2.4.5 Microscopy and microtensile testing

Small plywood shear specimens with dimensions of 80 mm length × 9 mm depth × 3 mm width were prepared and tested in tension in a bespoke microtensile tester operated under a Leica Wild MZ8 dissecting microscope, which is suitable for the visualization of the failure mechanism during testing.

3 RESULTS AND DISCUSSION

3.1 LATHE CHECK DEPTH AND PLYWOOD BONDING QUALITY

Lathe check depth was found to have a strong influence on the measured shear strength when the checks were pulled open, since the shear strength dropped by approx. 40% when the check depth increased from 40 to 80% (Figure 9). On the other hand, when the checks were pulled closed, limited strength loss was noted over the same interval. The results also show that soaking of test specimens prior testing, required in standard testing, universally lowered shear strength values.

As shown in Figure 9, the strength difference observed in the different pulling modes is mainly affected by the depth of the checks. The shallower the checks, the smaller the difference between the open and closed pulling modes. This is also in agreement with previously presented results by Korpijaakko [14] and Marra [17], where the shallower checks are less detrimental to the strength properties of plywood.

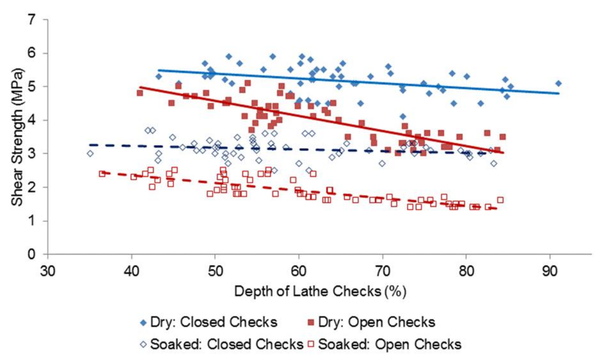

Figure 9: Shear strength values of plywood tested under dry and wet conditions, with checks pulled open or closed [28]

These results also explain the differences in open and closed strength values presented by other authors [13, 24-26] who did not measure the depth of checks in their studies.

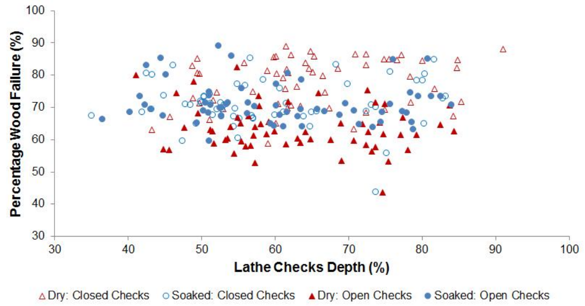

Figure 10: *Effect of lathe checks depth on PWF evaluated by automated image analysis for checks pulled open and closed under wet and dry conditions.*

The PWF results show that there is no correlation between the PWF and lathe check depth tested wet or dry, when bonds are pulled in the same direction (Figure 10). Similar results were obtained also by DeVallance et al. [26], where they did not observe any statistical differences between wet and dry bonds in terms of PWF.
However, there are statistical differences in PWF between the open and closed specimens, which explains the contradictory results reported in the literature [25-27]. The extreme scattering of PWF was also confirmed.

3.2 PLYWOOD FAILURE MECHANISMS

The plywood failure mechanisms were observed under a microscope during testing. In Figure 11a it can be seen that pulling the checks open leads to a localized mode I (opening mode) failure type resulting in the middle ply "rolling" off from the bondline. This would suggest that larger checks would allow an easier movement and thus provide a mechanism explaining the lower failure load.

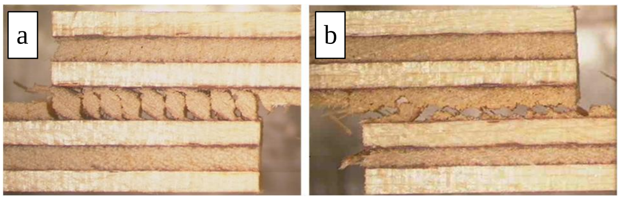

Figure 11: *Deep lathe checks. a) Plywood failure when tested open. (b) Plywood failure when tested closed. The loose sides of the tested veneers are at the bottom*

As indicated in Figure 11b, specimens that are pulled closed fail primarily due to global in-plane shear (mode II), resulting from the propagation of fracture within the bulk veneer itself. Therefore, the observations that strength is almost independent of check depth (Figure 9) when the checks are pulled closed is understandable. This difference in failure mode also suggests that larger checks would allow an easier movement and thus provide a mechanism explaining the lower failure load. This hypothesized mechanism would also support the observations of Korpijaakko [14], namely that a few deep checks are more detrimental to bond strength than many shallow checks.
This mechanism also explains why shallow lathe checks pulled open (Figure 12a) approach the value of specimens pulled closed in Figure 9. Shallower checks are less effective at instigating mode I failures (Figure 12a), and therefore specimens with shallow checks pulled open behave very much like specimens pulled closed (Figure 12b).

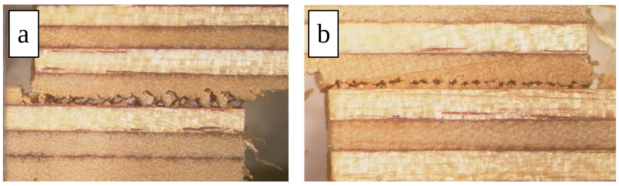

Figure 12: *Shallow lathe checks. a) Plywood failure when tested open. (b) Plywood failure when tested closed. The loose sides of the tested veneers are at the bottom*

In light of these observations of failure mechanism, the large scatter in the published data and some apparently contradictory findings are not surprising. Our findings not only confirm the importance of minimizing the depth of lathe checks for product quality, but also demonstrate how check depth could influence a standard bonding quality test (SFS-EN 314), which was designed mainly for testing adhesive properties and evaluating adhesive cure. As demonstrated, the lathe check depth has a very large impact on the results of tests carried out according to EN 314.

3.3 LATHE CHECKS AND ABES

Traditional standard bond quality tests on plywood specimens such as SFS-EN-314 are time consuming and require a lot of test material. Less labour and material is needed for the Automated Bonding Evaluation System (ABES), where the adhesive is cured under controlled conditions in an integrated miniature hot-press, while the lap-shear bond strength is measured within the same unit after pressing [32]. The advantages of the ABES are that small and smooth veneer specimens are tested with a small overlap area and in a parallel-ply assembly where the effect of lathe checks could be minimized. Previously, ABES was used successfully in studies on the development of the adhesive bond for modelling the hot-pressing process of panel products [33,34], in the optimisation of resin formulations [35], and in estimating the impact of veneer processing and material properties on bond strength [36]. However, the effect of lathe checks on bond strength development in ABES have not been reported previously.

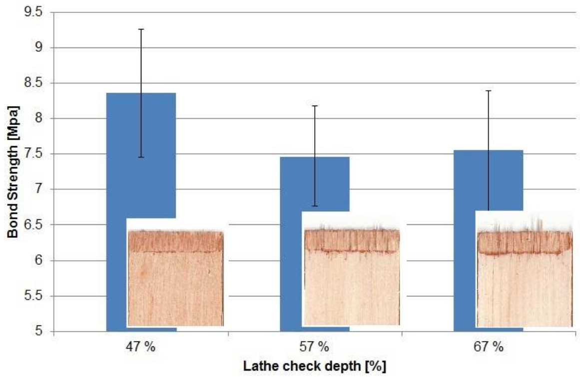

Figure 13: *Effect of lathe check depth on bond strength evaluated with ABES. Error bars represent a standard deviation*

Figure 13 shows the impact of lathe check depth on ABES strength values, using the loose side of the same veneers described in Figure 2. We found that the bond strength values obtained with ABES dropped remarkably when the check depth exceeded 50%, though the errors are quite large. This data suggests that lathe checks may have an influence during ABES testing, as well as in plywood shear tests. Note that the surfaces of these veneers were all identically sanded, so that surface properties other than check depth were identical.

A reason for lower bond strength with deeper lathe checks is shown in the inset images of Figure 13, where fibre pull-out is visible in samples with deeper lathe checks. It appears that even in ABES testing, deep lathe checks form the locus of failure if the check depth exceeds a critical value and adhesive does not penetrate into the checks. Thus, deep lathe checks not only decrease the bonding strength of plywood, but may also affect the results obtained with ABES if not controlled.

3.4 INTEGRITY OF VENEER

Traditionally surface roughness measurements have been conducted to evaluate surface bondability. However, surface roughness measurement techniques like stylus often largely miss lathe checks, in part because checks curve underneath the veneer surface. The checks are in essence creating a weak boundary layer of loosely attached particles on the surface. To evaluate the role of these loosely attached particles on bond quality an integrity test was developed by Rohumaa et al. [31].

Results of the integrity test show that the impact of deep lathe checks appears to be on the ability of the tape to remove large bundles of fibres from the surface [28]. The tape pulled off of the veneer peeled at 20°C with deeper checks (Figure 14a, check depth 23.7%) contains much larger wood particles than veneer surfaces peeled at 70°C with shallower checks (Figure 14b, check depth 16.0%). Because they can be removed by tape, they are clearly not well connected to the rest of the veneer substrate, and if an adhesive fails to "heal" these checks by flowing deeply into them, they could form the locus of failure. [28]

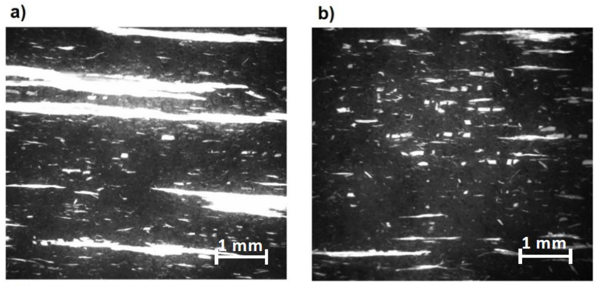

Figure 14: *The effect of soaking temperature on surface quality measured by fluorescence microscopy Log soaked at a) 20°C, b) 70°C*

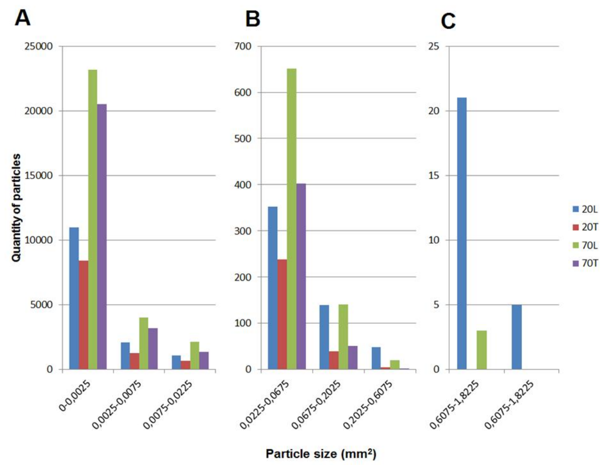

Figure 15: *Effect of veneer side and soaking temperature on particle size and quantity. Results from the integrity test. (L – loose side and T – tight side)*

Figure 15 quantitatively shows the number of particles of each size class. As previously discussed, large loose particles 0.6 mm^2 and larger were mainly present on the loose side of veneers peeled at 20°C (Figure 15c), and to a lesser extent the loose side of veneers peeled at 70°C. The lack of large particles removed from the tight side again implicates checks in their formation.

In contrast, the smallest particles (less than 0.005 mm^2) are twice as abundant on 70°C peeled veneer compare to 20°C peeled veneer (Figure 15a), with only minor differences between the tight and loose side. These small particles form a "hairy" surface from the tearing of cell walls through ductile failure during peeling. The veneer surface peeled at 20°C seemed to have more brittle failures and less fine particles.

4 CONCLUSIONS

Check depth and pulling direction were found to have a strong influence on the measured shear strength of plywood tested according to SFS-EN 314, even though this is a test of adhesive bonding and not intended to measure wood quality. As lathe check depth increased from 40 to 80%, plywood shear strength decreased by ca. 40% when tested open. In contrast, check depth had almost no effect on strength when plywood was tested closed. In addition, failure when testing closed involved a predominantly mode II (shear) mechanism, whereas testing open involved more of a mode I (cleavage) failure type, especially with deeper checks. Shallower checks are less effective at instigating mode I failures and therefore specimens with shallow checks pulled open behave more like specimens pulled closed.

The reported findings not only confirm the importance of minimizing the depth of lathe checks for product quality, but also demonstrate how check depth could influence a test (SFS-EN 314) which was designed mainly for testing adhesive properties and evaluating adhesive cure.

Deep lathe checks also seem to affect the results of ABES testing, where they can form the locus of failure if the check depth (with this adhesive) exceeds 50%. Because of this, we suggest bonding only the tight sides of veneers in ABES and/or sourcing veneers with minimal checking.

The weak boundary layer of veneers was probed with the newly described surface integrity test. Lathe checks resulted in large fibre bundles that were easily removed from the wood surface, and could serve as failure initiation sites. In addition, very small, loosely bound particles on the veneer surface from fracture of individual cells was quantified.

This series of studies clearly show that lathe checks can have a dramatic impact on veneer bonding, and suggest that controlling them could result in much lower variability in wood bonding tests, allowing researchers to more easily identify the other factors influencing bond quality.

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REFERENCES

[1] Denaud L.E., Bléron L., Eyma F., Marchal R.: Wood peeling process monitoring: a comparison of signal processing methods to estimate veneer average lathe check frequency. European Journal of Wood and Wood Products 70:253-261, 2012.

[2] Denaud L.É, Bléron L., Ratle A., Marchal R.: Online control of wood peeling process: acoustical and vibratory measurements of lathe checks frequency. Ann. For. Sci. 64:569-575, 2007.

[3] Tomppo, L., Tiitta, M., Lappalainen, R.: Ultrasound evaluation of lathe check depth in birch veneer. European Journal of Wood and Wood Products 67:27-35, 2009.

[4] Pałubicki B., Marchal R., Butaud J., Denaud L., Bléron L., Collet R., Kowaluk G.: A Method of Lathe Checks Measurement; SMOF device and its software. European Journal of Wood and Wood Products 68:151-159, 2010.

[5] Dupleix A., Denaud L., Bleron L., Marchal R., Hughes M.: The effect of log heating temperature on the peeling process and veneer quality: beech, birch, and spruce case studies. European Journal of Wood and Wood Products 71:163-171, 2013.

[6] Antikainen T., Eskelinen J., Rohumaa A., Vainio T., Hughes M.: Simultaneous measurement of lathe check depth and the grain angle of birch (Betula pendula Roth) veneers using laser trans-illumination imaging. Wood Sci. Technol. 49:591-605, 2015.

[7] Darmawan W., Nandika D., Massijaya Y., Kabe A., Rahayu I., Denaud L., Ozarska B.: Lathe check characteristics of fast growing sengon veneers and their effect on LVL glue-bond and bending strength. J. Mater. Process. Technol. 215:181-188, 2015.

[8] Siimes F., Liiri O.: Technical investigation of plywood I. VTT Publications 95, 1951.

[9] Palka L.C.: Veneer cutting review - factors affecting and models describing the process. Canadian forest service. Vancouver BC Information report VP-X-135:54, 1974.

[10] Sellers T.: Plywood and adhesive technology. CRC Press, 1985.

[11] Lutz J.F.: Techniques for peeling, slicing and drying veneer. USDA Forest Service. Research Paper FPL 228, 1974.

[12] McMillin C.W.: The relation of mechanical properties of wood and nosebar pressure in the production of veneer. Forest Products Journal 8(1):23-32, 1958.

[13] Koch P.: Effects of seven variables on properties of southern pine plywood. Part II, Maximizing wet shear strength. Forest Prod. J. 15:463-465, 1965b.

[14] Korpijaakko S.: Koivuviilun lujuuteen vaikuttavat tekijät erityisesti raskaan kuljetusvälineteollisuuden lattiavanerien valmistuksen kannalta. Helsinki University of Technology, Department of Forest Products Technology Espoo 112, 1999.

[15] Meriluoto J.: Raaka-ainetekijöiden vaikutus sorvatum koivuviilun màäràän ja laatun-the influence of raw material factors on the quantity and quality of rotary cut brick veneer, 1965.

[16] Kontinen P., Kivistö A., Söyrilä P., Usenius A.: Automation of plywood manufacturing. VTT Publications 756, 1992.

[17] Marra A.A.: Technology of wood bonding, 1992

[18] Aydin I, Colakoglu G, Hiziroglu S.: Surface characteristics of spruce veneers and shear strength of plywood as a function of log temperature in peeling process. Int J Solids Structures 43:6140-6147, 2006.

[19] Corder SE, Atherton GH.: Effect of peeling temperature on Douglas-fir veneer. Information circular 18, Oregon State University, Corvallis, 1963.

[20] Baldan A.: Adhesion phenomena in bonded joints. Int J Adhes Adhes 38:95-116, 2012.

[21] Lutz J.: Heating veneer bolts to improve quality of Douglas-fir plywood. Tech. Rep. No 2182. U. S. Department of Agriculture, Forest Service, Forest Products Laboratory. Madison, USA, 1960.

[22] Walser D.C., McLauchlan T.A.: A new development in veneer peeling. FPRS Annual Meeting, Denver, 1977.

[23] Stehr M, Johansson I.: Weak boundary layers on wood surfaces. J Adhes Sci Technol 14:1211-1224, 2000.

[24] Bethel J.S., Huffman J.B.: Influence of lathe checks orientation on plywood shear test results. Technical

Report no. 1 School of Forestry, North Carolina State College, Raleigh, 1950.
[25] Chow S.: Lathe-check influence on plywood shear strength. Canadian forest service. Vancouver BC Information report VP-X-122:24, 1974.
[26] DeVallance D.B., Funck J.W., Reeb J.E.: Influence of several preparation conditions on Douglas-fir plywood gluebond quality test results. For. Prod. J. 56:47-50, 2006.
[27] Neese J.L., Reeb J.E., Funck J.W.: Relating traditional surface roughness measures to gluebond quality in plywood. For. Prod. J. 54:67-73, 2004.
[28] Rohumaa A., Hunt C.G., Hughes M., Frihart C.R. and Logren J.: The influence of lathe check depth and orientation on the bond quality of phenol-formaldehyde bonded birch plywood Holzforschung, 67(7):779–786, 2013
[29] SFS-EN 314-1.: Plywood. Bonding quality. Part 1: Test methods. Finnish Standards Association SFS, Helsinki, Finland, 2005.
[30] SFS-EN 314-2.: Plywood. Bonding quality. Part 2: Requirements. Finnish Standards Association SFS, Helsinki, Finland, 1993.
[31] Rohumaa A., Antikainen T., Hunt C.G., Frihart C.R. and Hughes M.: The influence of log soaking temperature on surface quality and integrity performance of birch (Betula pendula Roth) veneer. Wood Science and Technology, 50(3):463-474, 2016.
[32] Humphrey P.E.: A device to test adhesive bonds. US patent number 5,176,028 (and other patents). US Patent Office, Washington, DC. USA, 1993.
[33] Humphrey P.E.: Adhesive bond strength development in pressing operations: some considerations. Proceedings of the First European Panel products Symposium, Llandudno, Wales9:145-155, 1997
[34] Stöckel F., Konnerth J., Kantner W., Moser J., Gindl W.: Tensile shear strength of UF-and MUF-bonded veneer related to data of adhesives and cell walls measured by nanoindentation. Holzforschung 64:337-342, 2010.
[35] He G., Feng M., Dai C.: Development of soy-based adhesives for the manufacture of wood composite products. Holzforschung, 66(7):857–862, 2012
[36] Rohumaa A, Hunt CG, Frihart CR, Saranpää P, Ohlmeyer M, Hughes M.: The influence of felling season and log-soaking temperature on the wetting and phenol formaldehyde adhesive bonding characteristics of birch veneer. Holzforschung 68:965-970, 2014.