

What do the quality grades of rotary-cut veneers indicate about their internal structure in correlation to their mechanical properties?

Beate Buchelt¹ <https://orcid.org/0000-0003-4671-0852>*

Robert Krüger¹ <https://orcid.org/0009-0006-6024-4471>

¹ TUD Dresden University of Technology. Institute of Natural Materials Technology. Chair of Wood Technology and Wood-based Bioeconomy. Dresden, Germany.

*Corresponding author: beate.buchelt@tu-dresden.de

Abstract:

The quality grading of rotary-cut veneers, as defined by various standards, considers the quality features and surface appearance of plywood or molded plywood. This grading primarily focuses on visual surface characteristics, such as knots, cracks, and discoloration. However, the correlation between these quality grades and the internal structural features, such as fiber deviations, lathe check depth, and frequency, and their impact on mechanical properties remains unexplored. This study investigates the relationship between the quality grades (A, B, and C) of *Fagus sylvatica* (European beech veneers) and their mechanical performance, as represented by the modulus of elasticity and the tensile strength. Structural features were quantitatively analyzed. Tensile tests revealed that veneers of quality grade C exhibited significantly lower modulus of elasticity (10737 MPa) and tensile strength (78,2 MPa) than grades A and B. Grade B veneers showed comparable modulus of elasticity values of 13500 - 13800 MPa but differing tensile strengths of 88,3 MPa for grade A and 116,8 MPa for grade B on average.

Structural analysis indicated that grade C veneers exhibited the highest fiber deviations in the thickness direction (up to 20 %) and the highest lathe check depths (46 %), suggesting a qualitative alignment between grading and structural integrity. However, the structural differences between grades A and B did not consistently reflect their mechanical performance.

Keywords: *Fagus sylvatica*, mechanical properties, rotary-cut veneer, structural features, tensile strength, veneer grading.

Received: 18.12.2025

Accepted: 28.07.2026

Introduction

The quality and properties of veneers as a single layer of various veneer-based products, including plywood, laminated veneer lumber, and molded plywood have a significant influence on the composite properties and their quality (Wang *et al.* 2001, Çolak *et al.* 2007, Pramreiter *et al.* 2020a). The quality of veneer is influenced by various factors, including lathe checks, surface roughness or thickness variation, which are based on the manufacturing process (Rohumaa *et al.* 2016, Rahayu-Sekartiing 2016). Knots and discoloration are also influencing factors on veneer quality, based on the natural wood itself (Wang *et al.* 2001).

The quality of rotary-cut veneers is the subject of a number of scientific studies. The objective of these studies is different. A recent study considered the veneer quality optimization in plywood using machine learning to grade grain pattern, and defects such as knots or discoloration (Ramos-Maldonado *et al.* 2025). This work emphasizes the actuality of the topic. The surface roughness is a quality criterion interesting for bonding and surface quality and was topic of several studies (Daoui *et al.* 2011, Kamperidou *et al.* 2020, Kamperidou *et al.* 2022). The standards DIN EN 635-2 (1995) and DIN 68707 (2016) give a regulation for the quality of rotary-cut veneer, processed in plywood, wherein only the surface appearance is regarded. The main characteristics of a surface veneer are determined by factors such as knots, cracks, discoloration and holes. DIN EN 635-2 (1995) classifies into five different grades (E; I to IV); where grade E is the best without any flaw, and grade IV the worst one allowing a lot of and large knots and cracks. DIN 68707 (2016) grades the face veneers for molded plywood similar to DIN EN 635-2 (1995) using only three grades A; B and C. Grade A has the highest quality standards. Only slight discolorations and no mechanical damage are allowed. The B grade allows slight discoloration. However, cracks are not allowed and only small, strongly adnate knots with a maximum diameter of 6 mm are permitted. In the last grade C, cracks and flaws are permitted as long as they do not affect the strength. Figure 1 shows examples for each grade.

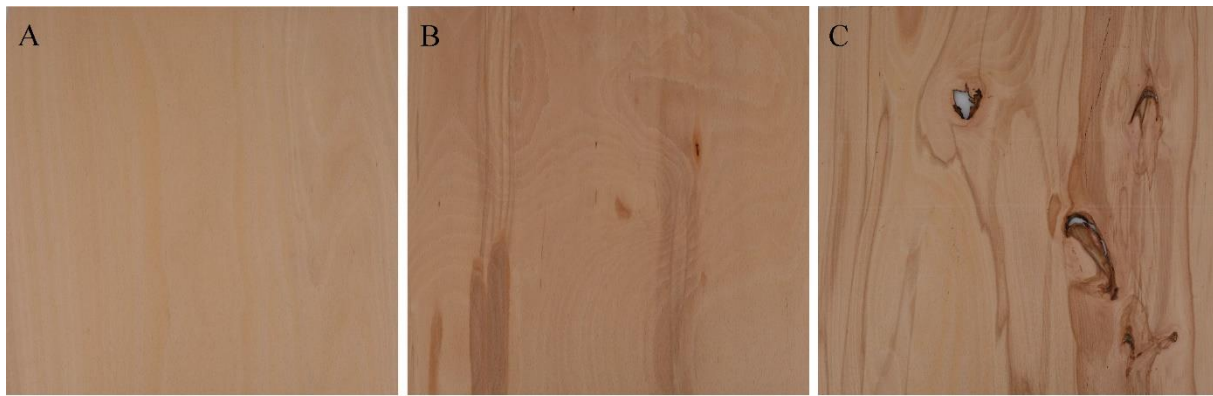


Figure 1: Examples of veneer grades A, B, and C (from left to right), according to DIN 68707 (2016); size approximately 500 mm x 500 mm.

The quality of veneer in relation to its mechanical properties was mostly objective of research for laminated veneer lumber (LVL) or laminated composites in general. Purba *et al.* (2019) investigated the influence of lathe checks and knot proportion on the mechanical properties of hardwood LVL. They found out that deeper lathe checks and higher check intervals generate a lower shear modulus of the LVL beam, but no correlation was found between the lathe checks properties and the bending modulus of elasticity of the LVL beams. Similar results were found by Rohumaa *et al.* (2016).

Recent studies have explored the use of veneer grading parameters and fiber orientation measurements to estimate the mechanical properties of laminated veneer lumber (LVL). These approaches demonstrate the potential of online grading systems for predicting the modulus of elasticity from measured veneer characteristics. However, their validation remains limited because the predicted values were not systematically compared with experimental mechanical measurements, leaving the relationship between grading parameters and actual mechanical performance insufficiently verified (Duriot *et al.* 2021).

The influence of veneer quality on the mechanical properties of layered wood composites has been examined using established timber classification systems. In a study, veneers were graded according to the softwood round timber classification (iTeh Standards EN 1927-2 2008) into four quality categories—A to D—ranging from defect-free material at the highest grade to

heavily knotted veneers at the lowest, and plywood panels assembled from each grade were subsequently tested in bending. The results indicate that plywood produced from grade A veneers exhibits the highest mechanical parameters, while panels from grades B through D show comparably reduced performance with no significant differences among them, suggesting that the beneficial effect of high veneer quality does not translate proportionally across intermediate and lower grades (Burawska-Kupniewska *et al.* 2011).

The available literature demonstrates the significance of veneer quality on the properties of products and composites based on veneers. The peeling industry as well as the manufacturer of veneer-based products has implemented quality grading processes for their veneers. Visual defect analyzers based on microwaves are common, as is manual grading of veneers. Visual defect analyzers identify defects such as discolorations, rot, heartwood, and open defects effectively (Wagenführ *et al.* 2023). Whether or not a machine is used for grading depends on the manufacturer. However, the grading process is conducted independently of the application of veneer in molded plywood or composites for constructive purposes.

It seems to be plausible that lower-grade veneers lead to inferior veneer properties, and, consequently, inferior properties in the products and composite materials manufactured from these veneers. This assertion can be partially supported by the literature presented. But is this assertion true? Does the visual classification of veneers into quality grades also reflect their mechanical properties?

This study utilizes tensile tests on veneers to assess the mechanical performance of the different quality grades. Additionally, further structural features are provided for a more comprehensive description of the veneer properties. The objective is to answer the question asked in the headline: What information can the quality grades of rotary-cut veneers provide regarding their mechanical properties? This study seeks to establish a connection between visual quality grading and mechanical performance by offering a deeper understanding of the structural

features of rotary-cut veneers, which can serve as a foundation for optimizing veneer-based products in both structural and non-structural applications.

Materials and methods

1,2 mm-thick, rotary cut european beech veneer (*Fagus sylvatica* L.) of the quality grades A, B and C according to DIN 68707 (2016) was used for the investigations. European beech is a widely available and common wood species, particularly for molded wood applications. The veneers were produced under industrial conditions, and the grading was performed manually during the production process. The sheets were randomly selected from the production line. From each quality grade, twenty sheets were available, each measuring 500 x 500 mm². Table 1 shows the density and the moisture content (EMC) of the material at 20 °C / 50 % relative humidity. Six samples were analyzed for each value. These conditions were also used as the testing conditions for the tensile tests and structural feature analyses.

Table 1: Equilibrium moisture content (EMC) and density (standard deviation in brackets).

Veneer quality grade	EMC	Density
A	8,6% (0,2%)	585 kg/m ³ (33 kg/m ³)
B	8,7% (0,2%)	621 kg/m ³ (17 kg/m ³)
C	9,0% (0,1%)	639 kg/m ³ (16kg/m ³)

Tensile tests

The tensile tests were conducted according to Krüger *et al.* (2025). Rectangular veneer samples with a length of 200 mm and a width of 20 mm were tested in fiber direction (0°-direction) with a universal testing machine (Inspekt 10, load capacity 10 kN, Hegewald and Peschke, Nossen, Germany). The test speed was strain-controlled and was 1 % min⁻¹. For the strain measurement, a stereo camera system (Aramis adjustable 12M, Carl Zeiss GOM Metrology, Braunschweig, Germany) was used, which applies the principles of digital image correlation (DIC). A contrast speckle pattern was applied to the area of interest (AOI), which measured 100 mm in length and 15 mm in width, on the closed side of the veneer surface. In order to evaluate the mechanical performance, the modulus of elasticity (MOE) and the tensile strength were considered. The orthotropic material wood, as well as veneer, have different properties in the three anatomical directions: longitudinal, radial and tangential. In veneer, however, only two directions can be considered: the longitudinal direction, also referred to as the fiber direction, and the perpendicular direction. The perpendicular direction represents a combination of radial and tangential orientations; however, due to the peeling process, the tangential direction tends to dominate. Due to the directional nature of wood's structure, both the MOE and tensile strength are strongly dependent on fiber direction. As known by Hankinson's equation (Figure 2), even

small deviations in fiber angle clearly influence the mechanical properties. Figure 2

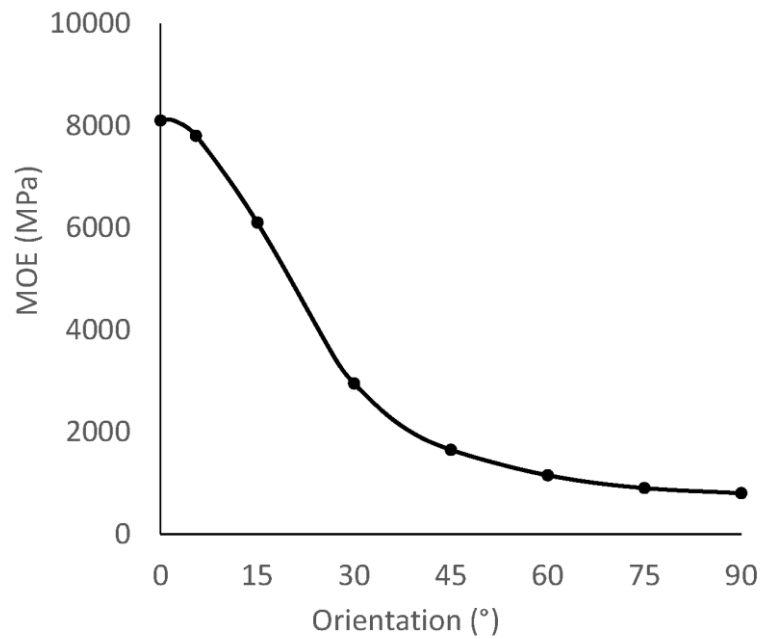


Figure graphically illustrates this dependence.

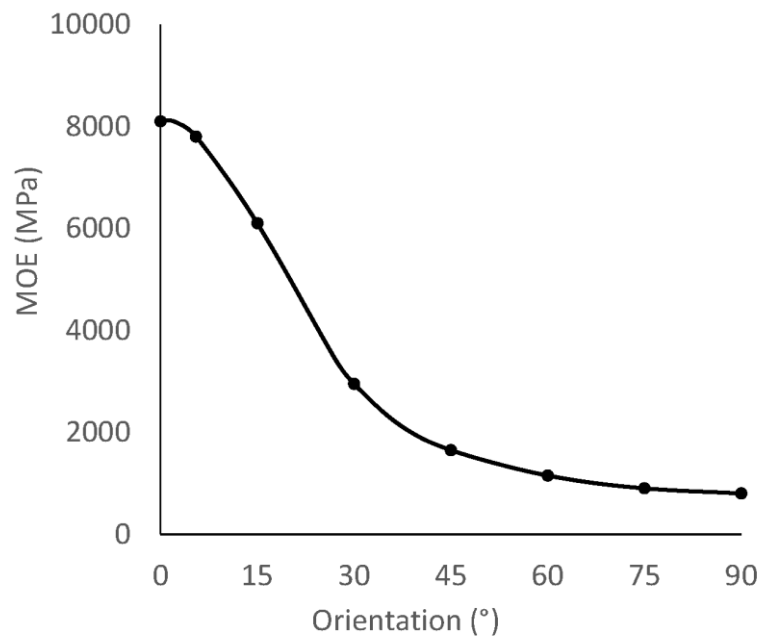


Figure 2: MOE in different planes under tension load, according to Clauß *et al.* 2014.

Due to the peeling process and the natural variation in wood growth, fiber deviations within a veneer sheet are to be expected. To account for these conditions, various structural features are examined to improve understanding of the results of tensile tests.

Twenty replicates were tested for each quality grade. Two different veneer sheets from each quality grade were randomly selected to prepare the samples: grade A sheets A3 and A13; grade B sheets B3 and B10; and grade C sheets C3 and C8. The samples were cut as parallel as possible to the fiber direction, but not parallel to the outer edge of the veneer sheet.

Structural features

Various structural features of the available veneer sheets were regarded. Mechanical parameters are mostly determined in a defined fiber direction. In reality, veneer sheets are processed during the production process, during which other conditions are more significant than the fiber parallelism. Additionally, the trunk grows conically and the peeling process is cylindrical. Thus, the fiber direction in the veneer sheets vary to some extent. Following the peeling process, the veneers are cut into the required fixed dimensions for the subsequent production process. Thereby often an angle is formed between the outer edge of the sheet and the fiber direction. This angle is illustrated in Figure 3 together with the anatomical directions within the wood: R is radial, T is tangential and L is longitudinal. This angle, termed fiber angle in plane of the sheet, was measured with a simple method. To determine the fiber direction in the veneer, a corner of each veneer sheet was ripped. This resulted in a crack following the fiber direction. Hence, the angle between the outer edge of the veneer sheet and the fiber direction could be measured using a photo and a vector-oriented drawing program (AutoCAD) for its determination. The determination of these angles gives an impression of the parallelism of the fiber to the outer line of the veneer sheet and can support the quality assessment of the different quality grades. Altogether twenty sheets and angles were determined for each quality grade.

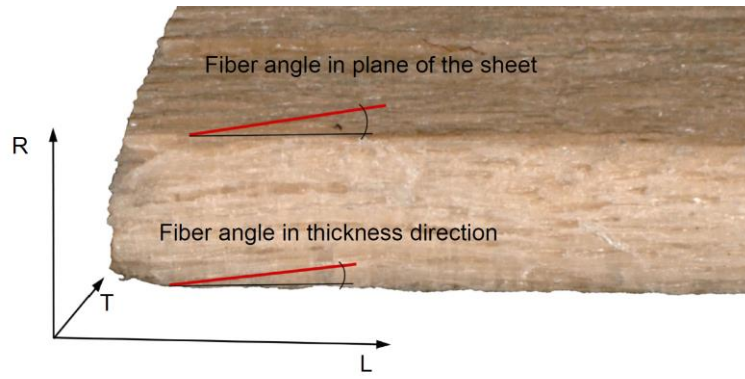


Figure 1: Fiber angles in the veneer, red lines symbolizes a fiber.

Another angle variance is possible in the thickness direction of the veneer. With the idea that lower-grade veneer qualities allow more flaws, such as knots, deviations of the fiber direction in the thickness direction could be different for the quality grades and thus, influence the mechanical performance of the veneer. The fiber deviation in thickness direction was defined as the angle between the veneer surface and the direction of single fibers in the cross-section (Figure 3) and determined microscopically. For each quality grade, four 20 mm-long stripes were prepared in the radial – longitudinal cross-section and investigated. The stripes were taken from the same veneer sheets from which the tensile samples were taken. In addition to the fiber angle in the thickness direction, as illustrated in Figure 4, two other criterions were considered to describe and evaluate the structural features in the thickness direction of the veneer. Figure 4 shows a schematic (left) and a microscopic image (right) of the criterions that were considered and measured in the R-L cross-sections. Altogether twenty angles were determined for each quality grade.

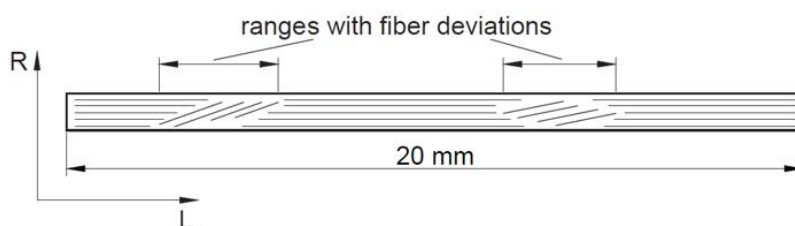


Figure 4: Veneer cross-section with considered criterions. Left: ranges with deviations, right: an example of a fiber exit.

To evaluate the fiber deviation in the thickness direction, the maximum fiber angle found from all the angles measured within each veneer sample was used. Since there were obvious differences in the proportion of areas with fiber deviations, the percentage of the overall length of each sample with fiber deviations was used as a further evaluation criterion. Figure 4 (left) illustrates a principle schematic with these ranges. Assuming that leaking fibers cannot transfer forces in the event of a mechanical stress, the presence of fiber exits on the veneer surface was used as a third evaluation criterion. Figure 4 (right) shows an example of a fiber exit.

The measured values were averaged for each quality grade. When assessing veneer quality in relation to its mechanical performance it is essential to consider the depth and frequency of the lathe checks (Bekhta *et al.* 2009, Rohumaa *et al.* 2018). In the peeling industry, it is usual practice to use fresh, sharp knives in order to achieve high quality veneers. For the production of lower-grade veneers in general already used knives are used. For this reason, differences in lathe check depth and frequency are probable. Lathe check depths and frequencies were determined microscopically. Samples from the same veneer sheets used for the tensile tests were taken for these measurements. Two 20 mm-long stripes of each veneer quality grade were selected to prepare a R-T cross-section. The veneer surface was colored with black ink to make the lathe checks visible. Figure 5 shows a cross-section with the lathe checks and the measuring parameters.



Figure 5: Cross-section with measuring parameters (lathe checks).

Altogether six stripes and 156 checks were measured. Thus, an average of 50 checks were measured for each quality grade. The lathe checks were evaluated using the percentage check depth, i.e. the depth of the lathe check in relation to the 1,2 mm veneer thickness. The frequency was evaluated in terms of the number of lathe checks per mm. All values were averaged.

Results and discussion

Fiber angle in plane of the sheet

The frequency of the measured angles was used to evaluate the fiber orientation in the plane of the sheets. The deviations were classified into three groups. According to Pramreiter *et al.* (2020b), deviations in fiber orientation from 0° to 2° do not affect the mechanical properties of the veneers. Deviations within this range form the first group. Another group was formed based on the evident decrease in strength observed at fiber deviations greater than approximately 5° (Kollmann 1951, Clauß *et al.* 2014). The third group was defined between these two limits (more than 2° until 5°). Table 2 shows the frequencies of the deviations of the fiber angle in the plane of the sheet for all quality grades.

Table 2: Frequencies of deviations of the fiber angle in the plan of the sheet for all grades and groups.

Veneer quality grade	Deviation group		
	0° - 2°	>2° - 5°	>5°
A	60%	30%	10%
B	75%	25%	0%
C	50%	35%	15%

The majority of the veneers have a small deviation of fiber orientation of 0° to 2°. More than 5 % deviation only occurs at quality grades A and C. The differences between the quality grades are clearly visible. Veneers of quality C has clearly the highest deviations.

Considering the veneer sheets used for the tensile tests, all of them have fiber deviations of 2° or 3° in the plane of the sheet, except for sheet C8, which has a deviation of 4°. However, it should be noted that all samples were cut as close as possible to the fiber direction and not parallel to the veneer border. The influence of the fiber angle on the mechanical properties is sufficiently known (Kollmann 1951, Clauß *et al.* 2014). Therefore, it is unnecessary to prove its validity. For this reason, the results of the deviations of the fiber angles in the plane of the sheet are only used to evaluate of the veneer grading.

Fiber deviations in thickness direction

Table 3 shows the results of the measurements of fiber deviation in the thickness direction. The given values represent the average and the range of all the measured values of all the samples.

Table 3: Results of fiber deviations in thickness direction for all qualities, (average, range in brackets).

Veneer quality grade	Maximum fiber angle	Percentage of fiber deviations	Fiber exits on the surface
A	16° (9° - 28°)	24,8% (18,5% - 36,5%)	not present
B	12° (9° - 17°)	37,0% (23,5% - 51,2%)	not or occasional present
C	20° (11° - 26°)	52,0% (32,0% - 73,0%)	are always present

The results should be considered as a whole. Clearly, deviations of more than 5° can occur in veneers of all quality grades. The average of the maximum fiber angle shows high deviation in all quality grades. Together with the percentage of fiber deviations, it can be assumed that the samples of quality grade C have the highest and greatest number of fiber deviations in the thickness direction. Samples of quality grades A and B follow this trend, but grade B has slightly lower maximum fiber angle deviations and a smaller range of maximum fiber angles. However, grade B shows a clearly higher percentage of fiber deviations. However, the percentage captures all ranges of deviation, including those with very small fiber deviations. Fiber exits on the surface indicate whether the veneer sample has continuous fibers. All fiber exits identified in the microscopic images are present on only one side of the surface. All fibers that end with their lumen at the surface run into the veneer as they continue. One veneer grade C sample is an exception. Therefore, it can be assumed that these fibers do not cross the veneer, thereby causing a change in fiber direction. With these criteria and considerations concerning the thickness direction, it can be concluded, that veneer grading reflects the fiber orientation and its disorders very well and it can be assumed that lower veneer quality grades have more and greater fiber deviations and exits.

The fiber deviations in the thickness direction are clearly higher than those in the plane of the sheet. However, the deviations in the thickness direction are not as continuous as they are in the plane of the sheet.

Regarding the results of considering the fiber orientation in both directions (in plane and in thickness), it can be assumed the quality grades reflect the fiber orientation well.

Depth and frequency of lathe checks

These values are shown in Table 4. The lathe check depth and the check frequency vary between the quality grades.

Table 4: Lathe check depths and check frequencies for all measured veneer sheets, standard deviations in brackets.

Veneer quality grade	Lathe check depth	Lathe check frequency
A	43% (12,2%)	1,2 per mm
B	31% (10,5%)	1,3 per mm
C	46% (10,8%)	1,1 per mm

The differences in lathe checks are obvious in the different quality grades. However, the deviations are partly high. On average, samples of quality grade C tend to have the highest lathe check depths, while samples of the quality grade B tend to have the lowest. All values fall within the expected range for 1 mm thick veneers (Krüger 2022). The lathe check depths of the quality grade B are unexpectedly lower than that of the quality grade A.

There is only a slight difference in the lathe check frequency within the different quality grades. This result does not align with the literature. Rohumaa *et al.* (2018) and Krüger (2022) found that there is a relationship between lathe check depth and frequency, in that the deeper the lathe checks, the greater the frequency. However, the veneers investigated here do not support this relationship. Possibly the results of these investigations differ from the other results because the veneers were taken from ongoing production.

Evaluation of the structural features

A qualitative method was used to evaluate the structural features. Figure 6 shows how these features change with each quality grade according to the determined values. The objective of this visualization is not to prove dependence; but rather to demonstrate a trend. The qualitative depiction shows whether a feature behaves consistently across the grades. Thus, it is possible to evaluate qualitatively how the quality grading reflects the veneer quality.

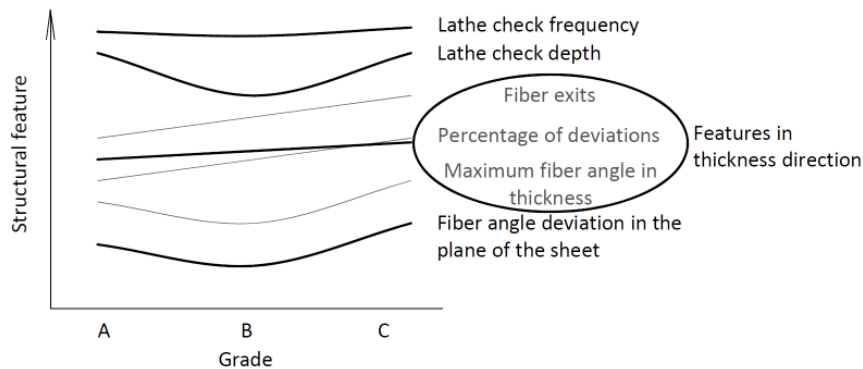


Figure 2: Qualitative progress of the structural features.

A higher value at the ordinate in Figure 6 indicates worse structural features. As discussed above, the three features of the measurements in thickness direction are summarized and evaluated as a whole. Clearly, quality grade C always has the worst structural features. While the difference between quality grades A and B is obvious, the trend is not uniform overall. There are clear discontinuities in fiber angles in the plane of the sheet, and in the lathe check depth. Overall, it can be assumed that the veneer grading properly reflects structural features.

However, a clear relationship between grades A and B regarding structural features fiber angle deviation in the plane of the sheet and lathe check depth is not always apparent.

MOE and tensile strength

Figure 7, Figure 8 and Table 5 show the results of the tensile tests to evaluate the mechanical performance of the different veneer quality grades. The MOE values (Figure 7) are with an average between 10737 MPa and 13825 MPa basically within the range of the values available in the literature. Krüger *et al.* (2025) estimated 13488 MPa for 1 mm thick rotary-cut beech veneer. The average of quality grades A and B veneers are in a comparable range of 13532 MPa and 13825 MPa, respectively, with no significant difference (ANOVA test, $p < 0,05$). The average of quality grade C veneer has with 10737 MPa MOE a significant lower MOE.

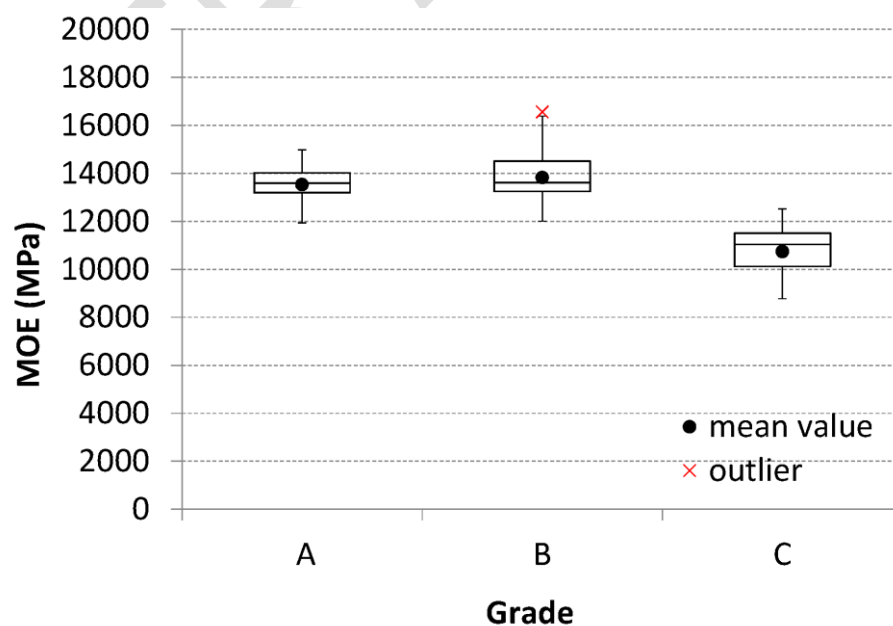


Figure 7: MOE of the different veneer quality grades.

The tensile strength (Figure 8a, Table 5) have with the average values of 88,3 MPa for quality grade A, 116,8 MPa for quality grade B and 78,2 MPa for quality grade C significant different strength values (ANOVA test, $p < 0,05$). The available literature value from Krüger *et al.* (2025) is 93 MPa. To exclude the influence of density on the results, the specific strength was considered. The specific strength is calculated as the quotient of the strength and the density. Figure 8b shows the values of specific strength, which also differ significantly. Therefore, the relationship between the strength values is independent of density. Thus, it can be assumed that there are clearly different strength values for the three qualities.

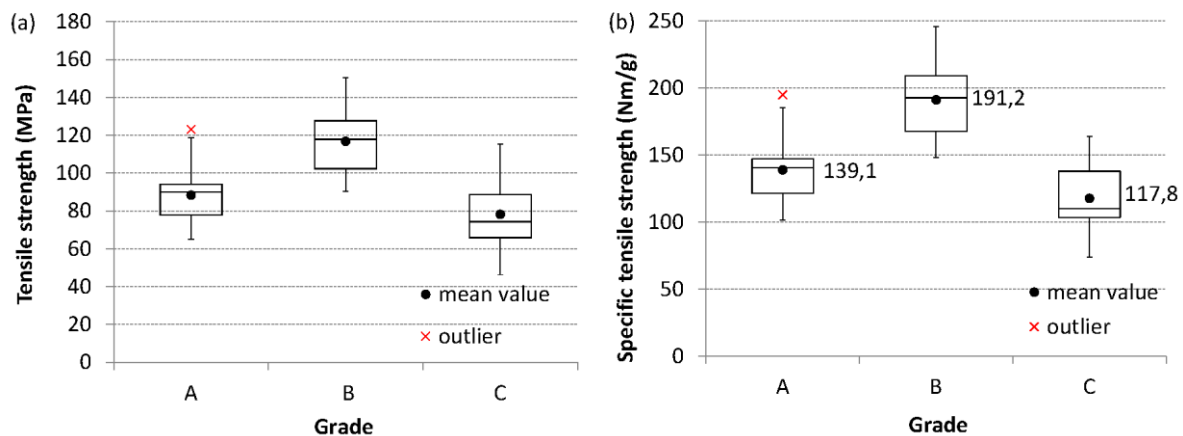


Figure 8: (a) tensile strength and (b) specific tensile strength of the different veneer quality grades.

Table 5: MOE and tensile strength of the different quality grades, standard deviation in brackets.

Veneer quality grade	MOE (MPa)	Tensile strength (MPa)
A	13532 (888)	88,3 (12,3)
B	13825 (957)	116,8 (16,8)
C	10737 (1091)	78,2 (18)

The significantly lower MOE and lower tensile strength for quality grade C indicates a poorer mechanical performance for this quality grade. The strength values are partly below and partly above the literature value. The amount of strength values does not follow the quality grade. However, the lowest quality C has the lowest tensile strength.

It is worth mentioning, that the standard deviation increases for both, MOE and tensile strength, with lower veneer grading (Table 5). This means that the lower the veneer quality grade, the greater the variation in the parameters. This suggests that veneers of a higher quality grade are more consistent.

Influence of the structural features on the mechanical properties

The dependence of the mechanical properties, represented by MOE and tensile strength, are discussed similar to the structural features in a qualitative way. Figure 9 shows the trends for MOE and strength for the veneer quality grades. Thereby, the progresses reflect the significant differences determined by ANOVA analyses.

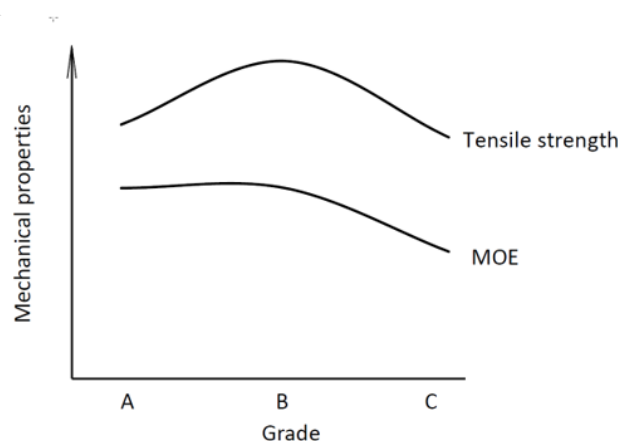


Figure 9: Qualitative progress of the MOE and the tensile strength.

Regarding the evaluations of the structural features, it is reasonable that quality grade C has the worst MOE and tensile strength. It is remarkable that quality grades A and B have comparable MOE values but different tensile strengths. As these two parameters are independent of each other, this seems possible. Nevertheless, this observation is a limitation of the current understanding of how the material behaves in relation to its structural features, and may be a topic for future research.

However, the difference in tensile strength between grades A and B remains unexplained. According to the evaluation discussion of the structural features (Figure 6), considering the features in thickness direction as a whole, and given that the fiber deviation in the plane direction does not have much influence because the samples were cut as close to the fiber direction as possible, the lathe checks remain the feature with a discontinuous trend.

Regarding the lathe checks depth (Figure 5) and the mechanical properties (Figure 9) it is apparent that the quality grade B veneers have the lowest lathe check depth and the highest tensile strength. Based on this observation, the average values of the percentage of lathe check depth and MOE and tensile strength, respectively, were combined in Figure 10 and differentiated for each veneer sheet used.

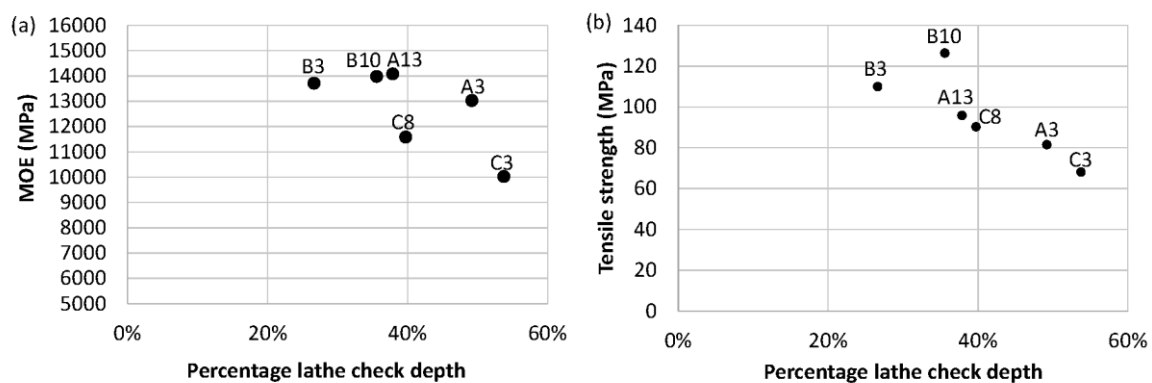


Figure 10: MOE (a) and tensile strength (b) relation to lathe check depth.

Figure 10a shows the average MOE values and Figure 10b shows the tensile strength values in relation to the lathe check depth and the corresponding veneer sheet numbers. When discussing the lathe checks in relation to the mechanical properties in the fiber direction, it should be noted that the lathe checks run parallel to the fiber orientation. Thus, they should barely affect the properties in the fiber direction.

The MOE values of quality grades A and B veneers are at the same level. Only the quality grade C veneers have significantly lower MOE values. The MOE is determined in the elastic range. Thus, the acting forces are not that high, so that the material damages resulting from the lathe checks do not greatly affect the elastic material behavior. Possibly, the notable fiber deviations and fiber exits of quality grade C veneers may influence the MOE more because they partially change the fiber orientation. This may be a possible reason for the reduced MOE for grade C veneers.

The influence of the lathe check depth on the strength seems to be obvious, though values for sheet B 10 do not confirm this trend. Lathe checks are material damages that run parallel to the fiber. Thus, it is not obvious that these affect the strength in the fiber direction. However, these checks may cause notch stresses, which may lead to stress concentrations. These stress concentrations may lead to an uneven stress distribution and stress peaks in the cross section. The deeper the lathe checks, the higher the stress peaks, which could explain the lower tensile strength.

Conclusions

The quality grades of veneer, as described in DIN 68707 (2016), reflect a number of structural features, investigated in this study. The fiber angle deviation in the plane of the veneer sheet is

moderately reflected. Although differences are demonstrable, the trend does not clearly follow the grading. The fiber deviations in the thickness direction were described with three structural features: the maximum fiber angle in the thickness direction, the percentage of fiber deviations, and the presence of fiber exits on the surface. These structural features were regarded as a whole and were accurately reflected by the veneer grading. The lathe checks as another structural feature, described by the lathe check depth and the lathe check frequency, were also moderately reflected. The differences are similar to the fiber deviations in the plane of the sheet. Overall, it can be assumed that the veneer grading properly reflects structural features. However, a clear relationship between grades A and B regarding structural features is not always apparent.

The results show that lower quality grades do not necessarily indicate lower mechanical performance, as represented by the MOE and tensile strength of the veneer. However, it can be stated that veneers of quality grade C have clear limitations. Furthermore, the standard deviations of the mechanical values demonstrate that veneers of a higher quality grade are more consistent. A remarkable finding is that veneer grades A and B exhibit different tensile strengths but similar MOE values. This difference could not be explained by the evaluated structural parameters.

A qualitative reflection between the structural features and the mechanical properties should clarify whether the grading can be used for mechanical evaluation. The correlation between the fiber orientation, as one regarded structural feature, and the mechanical properties is well-known, and was not proven in this study. The influence of the structural features in the thickness direction, considering all features as a whole, on the mechanical properties could not be proven qualitatively. The same is true for the lathe check frequency. A connection was found between the lathe check depth and the tensile strength: veneers with deeper lathe checks had a lower strength. It should be noted, however, that all investigations conducted can only show trends. No statistical investigations were conducted. One trend demonstrated that lathe checks may influence strength independently of load direction.

Altogether it can be assumed, the grading after DIN 68707 (2016) is not suitable for a classification in stiffness classes or similar classifications for applications with mechanical demands. However, it could also be shown, that relationship between structure and mechanical performance is inconsistent and requires further investigation to achieve a comprehensive understanding.

Author contributions

B. B.: Conceptualization, Data curation, Investigation, Writing – original draft. R. K.: Methodology, Visualization, Writing – review & editing.

Acknowledgements

The research project entitled “Software-supported evaluation of the dimensional stability of veneer plywood materials” these investigations are based on was financially supported by the Federal Ministry of Agriculture, Food and Regional Identity of Germany (grant reference 2222HV035B). Beate Buchelt is receiving financial support for this project.

Declaration of conflict of interest

The authors declare no competing interests.

References:

- Bekhta, P.; Hiziroglu, S.; Shepelyuk, O. 2009.** Properties of plywood manufactured from compressed veneer as building material. *Materials and Design* 30(4): 947–953. <https://doi.org/10.1016/j.matdes.2008.07.001>
- Burawska-Kupniewska, I.; Mycka, P.; Beer, P. 2021.** Influence of Scots Pine (*Pinus sylvestris* L.) veneers quality on selected properties of layered composite for flooring materials. *Forests* 12(8). e1017. <https://doi.org/10.3390/f12081017>
- Clauß, S.; Pescatore, C.; Niemz, P. 2014.** Anisotropic elastic properties of common ash (*Fraxinus excelsior* L.). *Holzforschung* 68(8): 941–949. <https://doi.org/10.1515/hf-2013-0189>

Çolak, S.; Çolakoğlu, G.; Aydın, I. 2007. Effects of logs steaming, veneer drying and aging on the mechanical properties of laminated veneer lumber (LVL). *Building and Environment* 42(1): 93–98. <https://doi.org/10.1016/j.buildenv.2005.08.008>

Daoui, A.; Descamps, C.; Marchal, R.; Zerizer, A. 2011. Influence of veneer quality on beech LVL mechanical properties. *Maderas. Ciencia y Tecnología* 13(1): 69–83. <https://doi.org/10.4067/S0718-221X2011000100007>

Duriot, R.; Pot, G.; Girardon, S.; Roux, B.; Marcon, B.; Viguier, J.; Denaud, L. 2021. New Perspectives for LVL Manufacturing from Wood of Heterogeneous Quality—Part 1: Veneer Mechanical Grading Based on Online Local Wood Fiber Orientation Measurement. *Forests* 12(9).1264. <https://doi.org/10.3390/f12091264>

German Institute for Standardization. 1995. Plywood—Classification by surface appearance—Part 2: Hardwood. DIN EN 635-2. DIN: Berlin, Germany.

German Institute for Standardization. 2016. Molded plywood and laminated wood for furniture—Requirements for dimensions and quality features. DIN 68707. DIN: Berlin, Germany.

Kamperidou, V.; Aidinidis, E.; Barboutis, I. 2020. Impact of structural defects on the surface quality of hardwood species sliced veneers. *Applied Sciences* 10(18). e6265. <https://doi.org/10.3390/app10186265>

Kamperidou, V.; Aidinidis, E.; Barboutis, I. 2022. Surface roughness of sliced veneers in terms of defects and wood structure variability—Impact of mild hydrothermal treatment. *Drvna Industrija* 73(2): 177–191. <https://doi.org/10.5552/drwind.2022.2129>

Kollmann, F. 1951. *Technologie des Holzes und der Holzwerkstoffe*. 1st edition. vol. 1. Springer: Berlin, Germany. 1051p. ISBN 978-3-642-49474-1.

Krüger, R.; Buchelt, B.; Zauer, M.; Wagenführ, A. 2025. Veneer composites for structural applications—Mechanical parameters as basis for design. *Forests* 16(4). e617. <https://doi.org/10.3390/f16040617>

Krüger, R. 2022. Untersuchungen an Rotbuchenschäl furnier zur Anwendung furnierbasierter Werkstoffe im Maschinenbau (Investigations on beech rotary cut veneer for use in veneer-based materials in machine construction). PhD Thesis. Dresden University of Technology. 196 p. <https://doi.org/10.25368/2024.324>

Purba, C.Y.C.; Pot, G.; Viguier, J.; Ruelle, J.; Denaud, L. 2019. The influence of veneer thickness and knot proportion on the mechanical properties of laminated veneer lumber (LVL) made from secondary quality hardwood. *European Journal of Wood and Wood Products* 77(3): 393–404. <https://doi.org/10.1007/s00107-019-01400-3>

Pramreiter, M.; Stadlmann, A.; Linkeseder, F.; Keckes, J.; Müller, U. 2020a. Non-destructive testing of thin birch (*Betula pendula* Roth.) veneers. *BioResources* 15(1): 1265–1281. <https://doi.org/10.15376/biores.15.1.1265-1281>

Pramreiter, M.; Bodner, S.; Keckes, J.; Stadlmann, A.; Kumpenza, C.; Müller, U. 2020b. Influence of fiber deviation on strength of thin birch (*Betula pendula* Roth.) veneers. *Materials* 13(7). e1484. <https://doi.org/10.3390/ma13071484>

Rahayu-Sekartingsih, I. 2016. Characteristics of lathe check and surface roughness of fast growing wood veneers and their performance on laminated veneer lumber. PhD Thesis. École Nationale Supérieure des Arts et Métiers. 110 p. <https://pastel.hal.science/tel-01399983/file/RAHAYU.pdf>

Ramos-Maldonado, M.; Gutiérrez, F.; Gallardo-Venegas, R.; Bustos-Avila, C.; Contreras, E.; Lagos, L. 2025. Machine learning and industrial data for veneer quality optimization in plywood manufacturing. *Processes* 13(4). e1229. <https://doi.org/10.3390/pr13041229>

Rohumaa, A.; Hunt, H.G.; Hughes, M.; Frihart, C.R.; Kers, J. 2016. Lathe check formation and their impact on evaluations of veneer-based panel bond quality. In: Proceedings of the World Conference on Timber Engineering. Vienna, Austria, 22–25 August 2016.

Rohumaa, A.; Viguier, J.; Girardon, S.; Krebs, M.; Denaud, L. 2018. Lathe check development and properties: effect of log soaking temperature, compression rate, cutting radius and cutting speed during peeling process of European beech (*Fagus sylvatica* L.) veneer. *European Journal of Wood and Wood Products* 76(6): 1653–1661.

<https://doi.org/10.1007/s00107-018-1341-9>

Wagenführ, A.; Buchelt, B.; Kairi, M.; Weber, A. 2023. Veneers and Veneer-Based Materials. In: *Springer Handbook of Wood Science and Technology*. Springer Handbooks. Springer: Cham, Switzerland. https://doi.org/10.1007/978-3-030-81315-4_26

Wang, J.; Biernacki, M.; Lam, F. 2001. Nondestructive evaluation of veneer quality using acoustic wave measurements. *Wood Science and Technology* 34(6): 505–516.

<https://doi.org/10.1007/s002260000069>

PAPER ACCEPTED