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STRENGTH GRADING OF TIMBER IN EUROPE WITH REGARD TO DIFFERENT GRADING METHODS

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ABSTRACT: Structural timber in Europe is either graded visually or by machine. Both grading methods are applied to limit the variation in engineering properties of sawn timber. The obtained grading results are largely dependent on the method chosen. In addition, parameters such as species, source, and cross-section of the timber, as well as the applied grading rules also play a role. To what extent these parameters - depending on the chosen grading method - actually affect timber properties and yields is of interest for both producers and users of sawn timber.
For analysing the different grading results, laboratory data of 10704 spruce specimens were evaluated.
The used cross-section has a major influence on the grading result. Furthermore, the used grading rule and the method applied to determine characteristic values are essential for the grading result. The origin of the timber influences the grading results of both grading methods. While the yields for machine grading are always higher than for visual grading, both grading methods are prone to fall short of the declared properties. It is recommended to adjust the normative framework as well as to regulate both grading procedures similarly.

KEYWORDS: Visual grading, Machine grading, Growth areas, Test procedures

1 INTRODUCTION

The mechanical properties of timber need to be assessed before the material can be used in structural applications. As a consequence, the variation in the properties needs to be controlled by grading of the raw material. Timber characteristics influencing the performance are estimated visually, by machine or by a combination of the two. The prediction quality depends on the chosen methods. Knowing the differences between and within the two methods is of high interest for several stakeholders: grading machine producers, structural engineers and the sawmilling industry. The knowledge of the resulting engineering properties and of the share of useable material is useful in the marketing process of machines, design processes for buildings and managerial decisions in the industry. Besides these economic interests, effective grading procedures contribute to a sustainable use of wood.

The major part of structural timber on the European market is graded visually. While for machine graded timber European standards are commonly used, visual grading is done mainly based on national standards. The harmonized European standard for strength grading of structural timber with rectangular cross section EN 14081-1 [1] lists some of the parameters which can influence grading results: different species or groups of species, geographic origin, different dimensional requirements, varying requirements for different uses, quality of material available, and historic influences or traditions. Substantial test programs have been carried out trying to cover these influences in order to establish machine settings and to check the applicability of visual grading standards. All major species can be CE-marked and the accessibility to the European market is given [2][3]. Characteristic values for the mechanical properties and density are currently guaranteed for the material.

The current status quo in the grading scene is unsatisfactory as different requirements for machine and visually graded timber exist. This is partly caused by the history. Visual grading and corresponding rules have been used since centuries. As a next step many countries standardized these rules for wood quality. Germany, for example, has introduced its first standard, DIN 4074, in 1939. Later in this century, machine strength grading has been developed. The commercial use of grading machines started in the USA in 1963 [4]. Decades later, first national standards followed in Europe. Under these preconditions separate European standards have been developed for visual and machine grading that provide different rules for initial type testing and factory production control.

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Depending on the grading method, different characteristic values can be expected.

The presented work considers the latest developments in the field of strength grading in Europe. Its focus is on the effect of different grading methods on timber properties. As a second parameter yields are compared in order to judge the efficiency of the different methods. Different parameters influencing the grading results are considered.

The latest developments in standardization are considered as well as their influence on the grading results.

2 MATERIAL AND METHODS

2.1 MATERIAL

The test data of 10704 specimens of the major European softwood species Norway spruce (Picea abies) have been analysed for the present work (Table 1). After determining parameters which can be used for the grading procedure, all of the pieces have been destructively tested in edgewise bending or in tension parallel to the grain. Depending on the data availability some timber collectives can only be used for analysing either machine or visual grading methods. However, data which can be used for a rough visual classification of the specimen is available in all cases. This does not include exact knot sizes, over a longer span of the pieces, which are needed for visual grading.

Table 1: *Summary of the timber data used*

Testing	Data availability		
	N	Machine	Visual
Bending			
	2116	x	x
	3360	x	-
	407	-	x
Tension			
	2555	x	x
	1601	x	-
	665	-	x

Most samples were tested in the laboratory of Technische Universität München. The remaining softwood data originates from European research partners which made their data available within the Gradewood Project [5].

2.2 METHODS

In order to judge the applicability and quality of a grading method or a grading rule, the relationship between the non-destructive assessment and the destructive tests needs to be addressed. The destructive test results are characterized by bending or tension strength, modulus of elasticity and density. Additionally, information about how the datasets are grouped and about applied mathematical models is needed.

2.2.1 Visual Grading

Knots are the most important criterion for visual grading. Still, additional parameters have to be considered in all accepted national grading rules. These requirements are listed in Annex A of EN 14081-1.

For the majority of the specimens used here, all important strength reducing characteristics have been recorded under laboratory conditions [6][7][8]. The knot sizes and positions have been determined with an accuracy of 1 mm. Knots smaller than 5 mm were not recorded. Knots are only considered in the critical test range of the specimen. In addition to knots, the recorded data covers growth ring width, the proportion of compression wood and the appearance of pith. Grading according to DIN 4074-1 [9], BS 4978 [10], INSTA 142 [11] and NF B 52-001-1 [12] is based on this information. Differences between grading rules are partly due to knot measurements, which can be done by determining the minimum knot diameter, the knot projected on the end grain of the board, or the knot size measured parallel to the edge of the board. Not only single knots but also knot clusters are considered in all of the standards. The differences between grading standards are not only caused by different ways of determining knot sizes but also because the number of classes vary. Where BS has two classes, INSTA and NF have four, not counting the reject. This fact influences the assignment of visual grades to strength classes in EN 338 (C-classes) [13].

The information about the largest knot cluster appearing in the test range of a specimen was recorded in the same way for all specimens. From this data a parameter called total knot area ratio (tKAR) is derived. The tKAR is defined as the knot area that results from a projection of the knots on the end grain divided by the area of the cross section. Knots are considered within a length of 150 mm. Overlapping areas are only counted once. As mentioned before, based on tKAR only it is not possible to predict real grading results as all national grading rules require more than just one parameter. The tKAR information is mainly used to analyse visual grading efficiency.

Based on the estimation for the MOR, settings are derived for a machine controlled system in accordance with EN 14081-2 [14]. These settings match settings which would result from a grading measuring only the tKAR values.

2.2.2 Machine Grading

A variety of parameters can be measured by grading machines. The dynamic modulus of elasticity is the parameter which is most frequently used in Europe. High end machines do add knot data as an additional predictor.

Depending on the algorithm used in a grading machine differences between the visually determined knot value and the knot value used by the machine can occur. Applying the tKAR value in addition to the dynamic MOE an accuracy is reached that is comparable to machines combining knot measurements and dynamic MOE.

The tKAR value used for machine grading was determined visually as described above. The dynamic MOE is calculated from the eigenfrequency and the density. For the frequency, the resonance frequency of a longitudinal oscillation was recorded. Based on the weight and dimension of the piece of timber, the density is calculated. As the dynamic MOE is influenced by the moisture content the value was corrected complying with the standard. Here, linear regression model were used to calculate the estimated bending strength (also referred to as IP - Indicating Property) values [15][8].

The calculation of these values is only the first step during the process of deriving settings for a grading machine. For a so called “machine controlled” system it is necessary to compare the IP to the test values for MOR, MOE and density. This method is used in EN 14081-2 and also known as the "cost matrix method" [16], a risk assessment method that compares the costs of the grading results to assignments that would have been obtained by a fictitious perfect grading machine. Settings are derived for several combinations of C-classes.

2.2.3 Testing

The destructive test procedure itself is independent of the used grading method. The timber was tested either in edgewise bending or tension. A symmetrical two point loading was used for the determination of bending strength, usually over a span of 18 times the height h (Figure 1).

All destructive tests were per-formed according to EN 408 [17]. The factors k_h and kl, used for adjusting assumed size effects, given in EN 384 [18] were applied. The MOE value was calculated using the global MOE measurements [19] based on the total deflection of the specimen covering a length of 18 times the height. The orientation of the board in edgewise bending tests was chosen randomly.

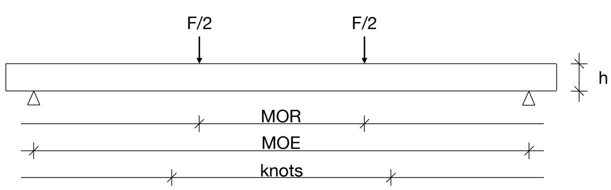

Figure 1: *Illustration of the range used for the determination of the bending strength (MOR), the global modulus of elasticity (MOE) and the knots for edge wise bending tests.*

For tension tests usually a span of 9 times the height is used (Figure 2). MOE is measured in the centre of the test range over a span of 5 times the height. Whenever possible the weakest section along the beam axis is tested. This requires the defect to be placed in the middle third for bending tests and between the grips for tension.

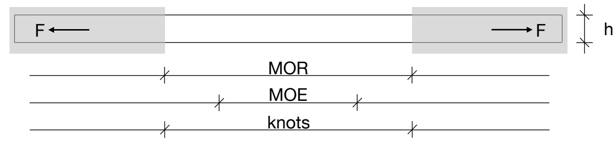

Figure 2: *Illustration of the range used for the determination of the tensile test data.*

Moisture content and density (ρ) measurements were carried out on small samples, free of defects and cut out close to failure location, using the oven dry method according to EN 13183-1 [20]. The resulting moisture content was used for the correction of the MOE value to the reference value set at 12% moisture content.

2.2.4 Secondary calculations and analysis of test data

Based on the testing results, characteristic values of the graded timber samples have to be calculated in order to allocate the timber to a strength class. For the properties of interest the characteristic value is defined as the 5^{th} percentile (MOR, ρ) or the mean value (MOE).

A number of methods is available for the determination of the mentioned characteristic values [21]. Here, in most cases, the 5^{th} percentile is determined by using the ranking method as this is the standardized method in EN384:2010. As a change away from this ranking method is intended, we briefly highlight how assumed normal and log-normal distributions of timber properties can influence the grading results [15].

While the density value resulting from this calculation corresponds to the declarable value, this is not necessarily for MOR and MOE. These characteristic values which may be assumed for the timber sample are influenced by additional factors. For the calculated MOR value the factors k_v and k_s [18] have to be considered. A k_v-factor of 1.12 has to be applied for bending strength of machine graded timber if a bending strength below 30 MPa is reached. The factor is supposed to allow for the lower variability of machine graded timber. Whether this factor is justified is respected by evaluating material safety factors for different timber samples. The average MOE value is also not directly compared to the grade requirement. A characteristic mean modulus of elasticity of bending is acceptable if it reaches 95% of the required value for a class. Although, EN338 [13] restricts this factor to bending, it is also used for tension.

The results have been analysed separately for the type of loading, the grading method, the grading standard and of course the resulting grade. Depending on the aim of the respective question aspects, such as cross-section and origin were also analysed. Due to the nature of visual grading, usually considering the relative size of a knot, the cross-section is of special importance for visually graded timber. The influence caused by the origin of the timber was and is of special interest in the field of timber grading. As described above the origin of the timber has to be and is usually known. It gives condensed information about several important factors that influence timber quality. The information about the growth origin is of special interest when new grading machines shall be approved or the applicability of a visual grading standard needs to be shown. Typically, in both cases destructive tests from a representative sample are required. Since destructive tests are time consuming for machine producers and the sawmilling industry, it is often questioned how many tests are actually needed for a specific growth area. Currently, the growth area definition is linked in most cases to national borders. Although, it is recognized that the country definition is not the best solution large scale testing programs [5] did not succeed in overcoming this difficulty. Different approaches were followed to find out more about the influence from the origin on the grading results.

3 RESULTS AND DISCUSSION

3.1 VISUAL GRADING

3.1.1 Grading rule

The used grading standard itself directly influences the grading results. In addition to the measuring instructions the results are mainly influenced by the number of grades. The major European grading rules allow a visual classification up to strength class C30 for spruce. The British Standard is an exception. Table 2 compares the obtained characteristic properties and the resulting yield for spruce tested in bending for British (BS), German (DIN), Scandinavian (INSTA) and French (NF) rules.

Table 2: *Visual grading results for the major European rules for spruce tested in bending. [6]*

Rule	Strength class	n	$f_{m,k}$ [MPa]	$E_{0,mean}$ [MPa]	ρ_k [kg/m³]	Yield [%]
BS	C24	1503	25.6	12600	373	61
	C16	457	18.9	10700	361	19
DIN	C30	287	28.7	13200	387	12
	C24	1225	22.8	12100	363	50
	C18	697	19.1	10700	361	28
INSTA	C30	396	28.5	13500	389	18
	C24	619	25.6	12500	366	27
	C18	928	20.0	10900	359	41
	C14	210	12.8	9700	360	9
NF	C30	52	28.1	14300	373	2
	C24	763	20.5	12400	371	31
	C18	897	21.1	11500	359	37

If the grading rules given in the British standard are followed, characteristic values above the requirements are reached. For the tested dataset this is not the case for any other standard. As the resulting properties values are clearly above the requirements, the assignments can be considered safe. The main reason for this is that C24 is the highest possible grade. If the rules are applied correctly, a reject rate of 20% is reached. Due to the sophisticated and rather complicated measuring method, it is questionable whether these high reject rates are actually reached in practice.

For the DIN rules for spruce tested in bending, the strength requirements are shortly missed, except for C18. The easy to use measuring principle given in the DIN standard leads to reject rates that are only half as high as those reached when BS is used. For the important commercial grades of C24 and better the yield is comparable (61% for BS, 62% for DIN). Also the characteristic values resulting from both grading rules would be very similar if the DIN standard did not distinguish between C30 and C24 but if the timber from these two grades was merged. The comparison of these two standards is of special interest as it is currently possible to use these rules for timber from the large source “CNE Europe” (EN1912: Central, North and Eastern Europe).

Spruce graded according to INSTA rules reaches the required values for C24 and C18, not for C30 and C14. Adding C14 at the bottom of available grades leads to the lowest total reject rates. However, the required strength for C14 is not reached and the share of timber graded into C24 or higher is low compared to BS and DIN. The timber graded into C14 is actually of low quality and should not be assigned to any strength class. As the used timber is mainly from Central and Eastern Europe the result for timber from the domestic area might reach the requirements. This might also be true for French timber. For the tested timber NF does not work properly. Besides, it may be doubted that the relation between knots and strength values for French timber is different compared to the rest of Europe. The yield in C30 is low, whereas yields in C24 and C18 are comparable. The application of absolute knot values as a grading criterion is unique among the analysed standards. This is also an important reason why the yields in C30 are low compared to the other standards. The effectiveness of this method cannot be demonstrated by the resulting characteristic values. The bending strength for C24 is 20.5 MPa, whereas 21.1 MPa is obtained for C18. Hence, this standard does not seem applicable for grading timber from Central Europe.

The coefficients of variation for the different grades are normally between 0.27 and 0.30. INSTA rules lead to slightly lower cov values. NF shows the highest cov values except for the highest strength class C30 (cov 0.24). Independent of the standard, none of the visual grades shows a cov smaller than 0.24.

3.1.2 Growth area

The influence of the growth area on the grading result is analysed for the visual method first. It is checked whether the assignments given in EN1912 [3] are correct for BS and DIN. These two examples represent the extreme as the assignment is valid for spruce originating from the growth area Central, North, and Eastern Europe. Table 3 shows the grading results analysed for Central and Eastern Europe. The required strength for C30 is reached neither for

Central nor for Eastern Europe. The results show that the prediction of strength works equally well for timber from these two regions. The lower quality of the ungraded timber sample is reflected after the grading process by lower yields for Eastern European timber. Similar characteristic strength values are reached for both sources. However, density and stiffness values for Eastern European timber are far below the values of timber from Central Europe. This is primarily a problem for density as the required characteristic values for C24 (350 kg/m³) and C30 (380 kg/m³) are not reached. Analysing timber from large regions is a rather rough approach to check the geographical influence. Differences are expected to be higher if the results are analysed on smaller areas e.g. countries.

Table 3: *Visual grading results for German (DIN) and British (BS) rules for spruce from Central and Eastern Europe. [6]*

Str. class	Visual standard	$f_{m,k}$ [MPa]	$E_{0,mean}$ [MPa]	ρ_k [kg/m³]	Yield [%]
Central Europe					
C30	DIN	28.0	13400	390	17
C24	BS	24.8	12500	374	63
C24	DIN	23.8	12100	367	50
C18	DIN	17.2	10300	358	25
C16	BS	18.9	10700	359	18
Eastern Europe					
C30	DIN	28.5	11500	336	9
C24	BS	23.6	11000	340	51
C24	DIN	23.2	10800	342	46
C18	DIN	18.0	9200	336	34
C16	BS	20.0	9600	336	24

We compared the visual and machine grading methods are on an equal using the same method [14] for the derivation of settings in both cases. Using the method intended for the derivation of grading machine settings, allows to grade timber visually up to strength class C30. However, conclusions on the level of countries are not possible as the low yield in that class leads to too few pieces for several countries.

The yield in C24 and better is high for visual grading. 79% yield is obtained for tKAR grading, 67% for DIN and 63% for BS, respectively. The 79% for tKAR is not surprising as the settings are optimized for the used dataset. While the setting guarantees that the strength requirement of 24.0 MPa is reached, this is not the case for the single countries. When analysed on country level, the 5th percentile MOR values range between 20.9 MPa and 27.7 MPa. Based on all sub-sample an average γ_M value, a factor considering the variation within a sample, of 2.33 is found.

3.1.3 Cross-section

The cross-section of the timber is an important factor for visual grading. Some standards have specific rules for certain cross-sections. The German standard offers completely different sets of grading rules depending on the cross-section and the intended use. Still, even when the different sets are considered an influence from the cross-section on the characteristic properties is expected.

Figure 5 shows the influence of the thickness for the most important grading parameters of DIN (DEK-value) and BS (tKAR-value).

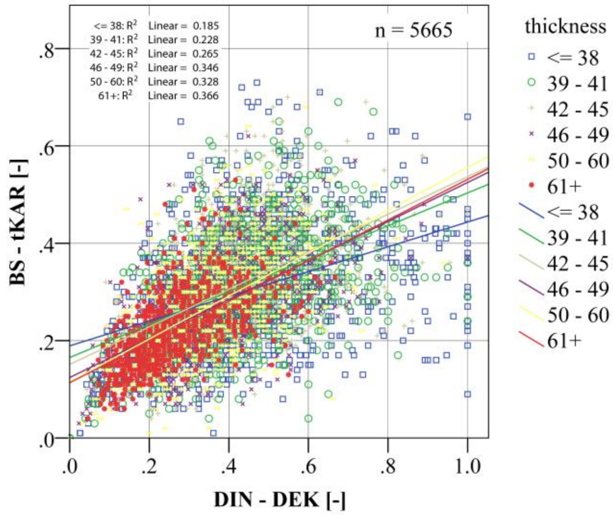

Figure 3: *The influence of the thickness on the crucial grading parameters tKAR (BS) and DEK (DIN). [6]*

The figure illustrates two facts:

1. The scatter of the different data clouds depends on the thickness. It becomes most obvious when the extremes are compared. While for smaller thicknesses high values for DEK and tKAR can be found, this is not the case for large thicknesses. At larger thicknesses large knots do not cause high tKAR and DEK values as the knot size is compensated by the larger thickness. The relative knot size is smaller for large thicknesses. Hence, only a few pieces are graded into a low grade or get rejected based on this grading parameter. As larger thicknesses have only a slightly higher average MOR value compared to smaller ones, the MOR values for high thicknesses are too low for C30. For C24 this problem does not exist as even the un-graded material reaches the required MOR value.

2. Based on the increasing R^2-values, it is obvious that with higher thicknesses the results from knot measurement rules slowly converge, even though the correlation remains low. This means that single pieces graded according to BS and DIN will be more likely assigned to the same strength class for high thicknesses rather than for small thicknesses.

An in depth analysis of the effect of the cross-section was carried for the German grading rules in DIN 4074-1 [7]. The DIN rule was chosen as it is applied not only in Germany, but is adopted in other national standards. It is used for the major part of graded timber in Germany, Austria, Italy, Czech Republic, Slovakia and Switzerland. More important than the countries is the fact that DIN 4074-1 gives different grading rules depending on both the cross-section and the intended use. Both available sets of grading rules have been analysed with regard to the cross-section. For the joists rules the smaller dimension is more important while for the board rules the larger dimension is governing.

Figure 6 shows the trend for the bending strength values for different width categories. Results are given for all three grades and the ungraded timber. Dotted lines stand for the mean value, while all other elements in the figure are used for the 5th percentile values. The dashed lines are drawn at the height of 5th percentile strength requirements given in EN338. Thus, they represent the 5th percentile strength values resulting from the analysis for all widths.

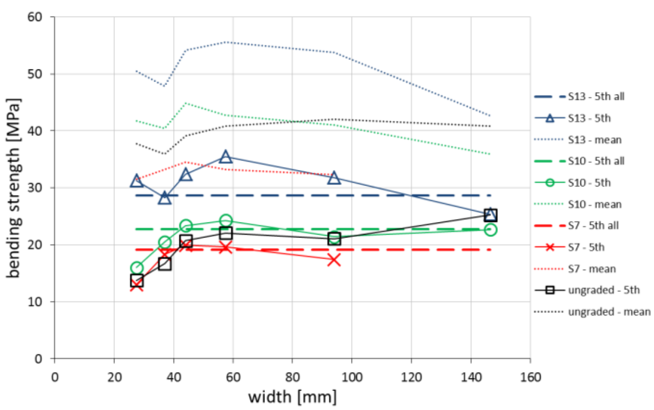

Figure 4: *Bending strength for joists over width classes for different visual grades. [7]*

The highest and the lowest width class clearly show a different behaviour compared to the classes in between. Especially critical are the 5th percentile bending strength values for C24 (S10) of 15.3 MPa for the smallest widths and the low strength for C30 (S13) of 25.4 MPa for the highest class. Obviously, the grading rules do not match the challenge of very small or very large cross-sections. The reason for the low bending strength for S10 may be found in the low frequency of the appearance of knots on the edge of the joist. The reason for the low strength of large sized S13 joists can be found in the combination of maximum knot diameter and minimum cross-section of the joist together with the disregard of the pith.

Values for S7 are in the range of values of ungraded timber. Values for S10 are usually clearly above. The difference between the strength values of S7 and S10 is usually far less than 6 MPa as one would expect from the assigned corresponding strength classes C18 and C24. On the other hand, the difference between S13 (C30) and S10 (C24) is larger than expected. Not considering the values for the largest width class, the difference is between 7.8 and 15.3 MPa.

The share of S7 and reject is decreasing with increasing width. This causes high shares of S10 and S13 for the larger widths. For the largest widths, a high yield in S13 is found.

For the DIN board grading rules similar effects can be found.

3.2 MACHINE GRADING

Machine grading of timber is regulated in European standards. Hence, influences on the grading result caused by national standards can be ruled out. Depending on the parameters that are measured by a grading machine, it is possible to find effects, comparable to those caused by the cross-section, for machine graded and for visual graded timber. However, the most frequently used parameter eigenfrequency is expected to lead to stable grading results with less influence of timber size. Furthermore, in contrast to visual grading, the envisaged cross-section has to be tested during approval tests for grading machines. For these reasons, the emphasis is on the source and regulations within the European standard that are assumed to influence grading results.

3.2.1 Source

Machine grading results for a machine measuring the tKAR value and the dynamic MOE as variables for the prediction of the bending strength have been analysed [8]. The good prediction of the bending strength allows that grades up to C40 can be analysed. Comparisons between the results on country level are limited to C24 and C30 because a substantial amount of data for each country is needed. For both grades settings have been derived with and without the k_v-factor that reduces the required characteristic strength value for machine graded timber.

Strength values for machine graded timber for single countries can become as low as 23.3 N/mm² for C30 and 18.9 N/mm² for C24 if the k_v-factor is used (Table 4). If k_v is not applied, the 5th-percentile strength values obviously increase. The minimum for C30 in that case is 25.8 MPa. The remaining nine countries reach at least 90% of the required strength values.

Table 4: *5th percentile bending strength values for different countries. [8]*

Grade		C30	C30	C24	C24	C24
Mehod		Machine	Machine	Machine	Machine	Visual
k_v		No	Yes	No	Yes	No
	Country					
$f_{m,k}$	A	29.4	26.0	24.5	22.6	25.1
[MPa]	B	31.2	27.8	24.0	21.8	25.0
	C	28.5	26.5	22.3	18.9	22.0
	D	25.8	23.3	22.6	19.3	21.6
	E	31.9	27.8	27.5	24.9	27.7
	F	32.6	28.0	26.6	23.0	27.4
	G	31.6	27.8	23.9	21.2	23.9
	H	34.4	24.5	23.4	21.2	22.8
	I	27.7	25.3	22.2	21.7	21.9
	J	30.5	26.2	23.9	19.5	20.9
	All	30.0	27.0	24.0	21.4	24.0

In current standards, characteristic values are only checked on combination of different sources for which machine settings are being derived [15]. What happens to the yield when the requirements have to be reached on regional or country level, is presented graphically in Figure 5. The yield is always given for two different methods of determination for characteristic properties, the non-parametric method according to EN 384 and the proposed log-normal distribution (labelled prEN 14358 [22]). The influence of the method will be discussed below (3.2.2).

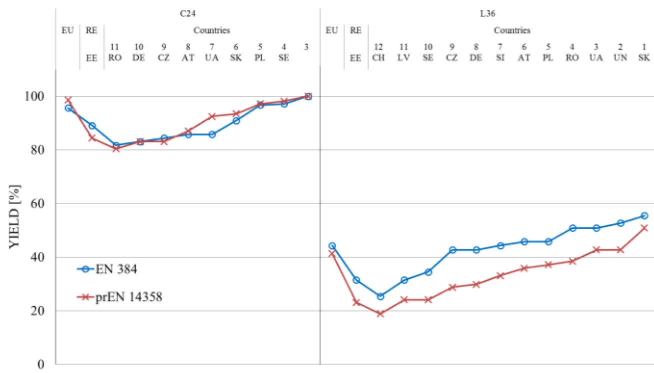

Figure 5: *Yield for different strength classes depending on the source for that timber properties are guaranteed. Analysed for C24 and L36. [15]*

In a first step results according to EN 384 are discussed. The figure includes two examples, C24 and L36. The curve for each strength class starts with the yield that results from settings that guarantee that the complete datasets reaches the requirements ("EU"). Moving right, the yield is connected to settings that work for different regions ("RE"). The region EE (Eastern Europe) leads to the required more conservative setting. Yields for settings that lead to safe timber properties on country level are given on third rank including the country which is crucial for the reduction. Above the country code the number of countries for which the corresponding setting is valid can be found.

For C24 the difference between European and regional level is large. The required settings for EE lead to a decrease in yield of 6.5%. Density requirements lead to higher settings for EE. However, this could be easily avoided. Introducing an additional IP for the density would solve that problem. Without that extra IP the minimum yield, for which characteristic values could be guaranteed for all 11 countries would result in a yield for the European dataset of 81.7%. Checking the setting on the European dataset leads to a yield of 95.6% instead. This EU setting would lead to too low characteristics for timber from RO, DE, CZ, AT, UA and SK. Due to the high quality of the ungraded timber from BE, FR and SI no settings at all are required for C24. For these samples, all characteristic values can be reached without grading.

In L36 the yield calculated for the European dataset is only lower if the settings are based on timber from CH, LV, SE or CZ or DE. For all other countries higher yields are reached. The maximum difference in yield between proof on European and on country level is 18.9%.

3.2.2 Standard

In Figure 5 not only the influence of countries is illustrated but also the influence caused by the calculation method of characteristic values. As mentioned before, it is suggested to calculate strength values no longer by using a non-parametric method, but by using a parametric approach assuming a log-normal distribution of the MOR values instead. For the two examples there is clearly a difference between C24 and L36 depending on the method. While differences between the two calculation methods for C24 are small, immense differences can be found for L36. Assuming the proposed log-normal distribution, resulting tension MOR values are low compared to the values from the calculation used today. The reason for this is that values for the coefficient of variation for tension data in the graded samples are higher. The relatively higher variation leads to lower characteristic strength when a distribution is assumed for the calculation of characteristic values instead of using only the extreme values that are used for the ranking approach.

For the two remaining grade determining properties - for that a change in the calculation method is also drafted - no differences between C- and L-classes is found. While differences between the methods are small for the MOE, the characteristic density determined in accordance with prEN14358 results in lower characteristic density values. Assuming a normal distribution for density values of in-grade timber leads to lower 5th percentile values in all cases. Although, differences for the particular settings are usually not above 10 kg/m³ this might be grade determining in single cases, especially for the density values listed in EN 338.

EN 384 specifies the k_v-factor which has to be used for the determination of the bending strength value of machine graded timber. It is applied to class C30 and classes below. That this factor directly results in a lower bending strength for graded timber is obvious and not further surprising. However, the lower requirement on the strength has a second effect. The variation of timber in-grade properties is increasing due to the increased yield. Depending on whether a strength class is graded on its own, e.g. C24-reject, or in combination, e.g. C35-C24-rej, the variance of properties differs. If extremes for the grade C24 shall be compared the combination C24-rej using k_v and the combination C35-C24-rej not using k_v are good examples. Figure 11 and Figure 12 show how differently the lower tails of batches of C24 timber could be composed. For C24 from C35-C24-rej not using k_v a total of 2377 pieces are assigned to that grade, while there are 4611 pieces in C24 if C24 is graded on its own (C24-rej using k_v).

3.3 COMPARISON OF THE GRADING METHODS

Deviations from declared values for graded timber occur for both, visual and machine grading. Based on timber properties and the yield a comparison between the two grading methods is possible.

Differences for strength values on country level can be big for both grading methods. Due to the lower prediction quality for visual graded timber the difference between the highest and the lowest value found for the different countries is higher. However, one can find lower absolute values for machine graded timber if the k_v-factor is used. The given reason for the existence of the k_v -value - to allow for the lower variability of f_{05} values between samples for machine grades in comparison with visual grades – cannot be confirmed. Neither is the coefficient of variation of the graded material within a sample influenced in a positive manner. As a consequence, the k_v-factor as currently applied cannot be justified.

Yield figures were analysed the different grading methods using different standards and grading parameters. Although, the datasets are not perfectly equivalent (compare Table 1) comparable yield values can be found. A direct comparison of yield values is given in Table 5.

Obviously, not all listed strength classes would practically be graded in the given combinations (e.g. C40-rej, C30-rej, L30-rej). For bending, C24-rej is the most frequently used grade combination. For currently accepted grading rules, DIN 4074 shows the best performance here. Only 38% of the timber does not reach strength class C24. This yield could be increased if the theoretical visual grading procedure was used (using only tKAR; settings derived according to the machine grading standard). 79% of the timber could be graded to C24. For real machine grading the yields are higher. Depending on whether the tKAR is used in addition to the dynamic MOE or not, the yield for in-grade timber lies between 96% and 98%. Strength classes above C35 can only be reached if machine grading is used.

Reject grades for tension grades for machine and visual grading are close together. For the popular combination L36-L25-L17-reject for machine graded timber are “only” 5% lower. The distribution of in-grade timber shows larger deviations for the two grading methods. For L36 machine grading allows a yield of 44% while visual grading does not even reach half of this value.

As mentioned earlier, the parameters used for the grading procedure were all recorded in laboratory. For machine grading this means that the differences to grading in practice are small. For visual grading the results in practice are expected to be different. Two major effects have to be expected. Due to an increased accuracy during the grading procedure wrong assignments become more likely. Unlike in the laboratory - where only the centre part of the board is of interest (Figure 1 & Figure 2) - the complete length of the board has to be considered for grading. This would further increase the share of timber that is graded into low grades or gets rejected. As the dynamic measurement of

Table 5: *Overview of yield figures.*

Testing	Method	Standard or used parameter	Yield [%]						
Bending			C14	C18	C24	C30	C35	C40	reject
	Visual	BS 4978	-	19	61	-	-	-	20
		DIN 4074-1	-	28	50	12	-	-	10
		INSTA 142	9	41	27	18	-	-	5
		NF B 52-001-1	-	37	31	2	-	-	30
		tKAR	-	-	79	-	-	-	21
	Machine	dyn MOE	-	-	76	-	16	-	8
			-	-	-	57	-	-	43
			-	-	96	-	-	-	4
			-	100	-	-	-	-	0
		dyn MOE& tKAR	-	-	-	-	-	10	90
			-	-	49	-	28	-	23
			-	-	-	74	-	-	26
			-	-	98	-	-	-	2
Tension				L17	L25	L30	L36		reject
	Visual	DIN 4074-1 lamellas		16	56	-	21		8
	Machine	dyn MOE		27	26	-	44		3
				-	-	71	-		29
				-	93	-	-		7
				100	-	-	-		0

the MOE considers the whole length in the laboratory and in practice, no differences have to be expected here. This would put machine grading in an even better position in terms of yield. The existing large differences in yield figures between the methods give rise to the question, why visual grading is still preferred in Central Europe. It is recommended to adjust the normative framework as well as to regulate both grading procedures similarly.

4 CONCLUSIONS

The properties of graded timber are influenced by the cross-section, the origin of the timber and the applied grading standard. The four major European grading rules DIN, BS, INSTA and NF cannot be compared grade by grade, as the number of possible grades in the single standards ranges between two (BS) and four (INSTA). The application of DIN, BS and INSTA on spruce reveals that they can be used to grade the material safely except for large cross-sections above C24. An in-depth analysis of the DIN standard DIN4074-1 with special focus on the influence on cross-sections was carried out. It was shown that the graded timber properties are influenced by the timber size.

Comparing the standards, yield differences for spruce graded in C24 and better can be found. The DIN rule gives the highest yields. Due to the possibility of assigning material to strength class C14 the lowest share of rejected timber is found for the INSTA standard.

The calculation method for characteristic values is also of interest when settings for grading machines are derived. In grading, it is usually the strength that determines the settings not MOE or density. In the process, the assumed distribution directly influences the yield within a strength grade. If large datasets are available, log-normal distributions result in the highest declared bending strength values and therefor the yields are also high. However, this is not true for tension strength classes as within single grades the coefficients of variation are high compared to C-classes (bending). Differences between the assumed distributions tend to increase with decreasing sample size. In addition to strength, density may also be a decisive factor for spruce assignments. Any of the applied parametric calculation methods leads to wrong estimations of the actual distribution as modern grading techniques usually allow exact property prediction and therefor lead to truncated distributions.

Independent of the applied calculation method, settings are strongly influenced by local variations in timber properties. This factor becomes more important when large grading areas need to be assessed. Countries should not be combined to grading areas without checking conformity.

Comparing the two grading methods – visual and machine – it is obvious that there is a clear effect on the strength, stiffness and density values of the timber samples of equal strength classes. Due to the current method used for the derivation of settings for grading machines, it cannot be guaranteed that machine graded timber shows a better performance than visual grading. However, this is only happening in a limited number of cases.

Based on limited test data visual grading methods are applied on a larger area, on more cross-sections and a variety of species. As the principles of the two methods are similar, efforts need to be undertaken to treat visual and machine grading equally.

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