Combined Visual and Machine Strength Grading

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Summary

The aim of this study was to show the possibility of the classification of structural timber (European spruce) into strength class C35 according to EN 338 by using combined visual and machine strength grading techniques. Three different visual - machine strength grading combinations are devised for allocating sawn timber into strength class C35. They are composed on the one hand of the visual grading according to DIN 4074-1 and on the other hand of machine strength grading of green or dry sawn timber by measuring the dynamic MOE or the apparent density of sawn timber. In order to allocate sawn timber into strength class C35 the machine settings for these combinations were estimated. The grading results show that combinations based on the dynamic MOE are suitable for strength grading of lamellae for glued laminated timber and joists. Combinations based on apparent density are also suitable for strength grading lamellae for glued laminated timber.

Keywords: visual grading, machine strength grading, strength class, dynamic MOE, apparent density

1. Introduction

The strength and stiffness properties of timber scatter in a wide range [1]. There are two main reasons for the large variability. On the one hand timber is a natural raw material causing a natural variation of physical and mechanical properties of timber products. On the other hand different sawing patterns cause different influences of knots and slope of grain on the strength and stiffness properties. The application of structural timber requires a suitable strength grading method ensuring characteristic strength values within different strength classes. EN 338 is the European standard for strength classes.

Sawn timber may be strength graded visually or mechanically. Visual grading is a simple method to grade structural timber. Each piece of timber is evaluated based on visual parameters. Because the density affecting the strength can hardly be determined by visual grading, the yield in the highest visual grade S13 according to DIN 4074-1 is limited. S13 corresponds to strength class C30 according to EN 338. Visual grading of European spruce timber into higher strength classes than C30 is not possible [2]. Grading machines, especially multiple sensing devices, allow the grading up to strength class C40. Multiple sensing grading machines, however, are quite expensive. Especially small glulam producers cannot economically exploit these grading machines.

If only the strength class C35 is envisaged, a combination of visual strength grading and a machine strength grading parameter, which can easily be determined, is sufficient. This combination would then allow to increase the value of timber with a limited expense for machine strength grading.

2. Material and methods

2.1 Testing material

To find a suitable selection of specimens, eighteen samples of spruce timber were taken in four saw mills located in Germany. Each mill delivered about a quarter of the test material. The lamellae and joists cover the application range of glulam lamellae and nail plate trusses. The length of the material was from 3,8 m to 5,2 m. Different cross-sectional dimensions were chosen to take into account the size effect on the bending or tensile strength.

Table 1 Cross-sectional dimensions [mm] and sample size

Lamellae				Joists			
depth width	20	36	48	height width	100	180	240
100	**60+89**		**57**	50	**53+60**		**52**
175		**50+60+56**	**60**	60		**53+88**	
220	**64**		**53+61**	80		**57**	**53+62**

2.2 Methods

A combination of visual strength grading and machine strength grading should be complementary. While visual grading is used to detect the weakest cross-section, the machine strength grading provides the overall timber quality as density or MOE. All the testing material was first graded visually according to DIN 4074-1. All the visual grading parameters listed in DIN 4074-1 were taken into account.

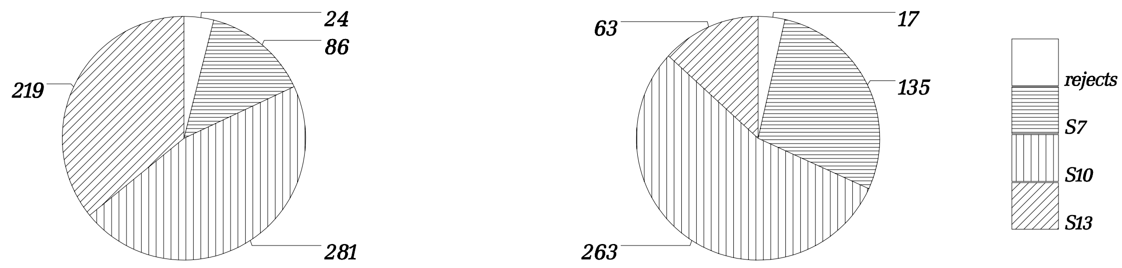
The following properties which may be used as machine grading parameters were subsequently measured: 1. depth or height, 2. width, 3. apparent density and hence 4. dynamic MOE, 5. apparent density of green sawn timber and hence 6. dynamic MOE of green sawn timber. [3] gives the basis of the applicability of machine strength grading based on dynamic MOE from longitudinal vibration.

In order to show the reliability of combined visual and machine strength grading, not only the characteristic bending strength but also the characteristic tensile strength was determined. Thus one half of each sample was tested in bending and the other half in tension. The bending strength of lamellae was determined flatwise and of joists edgewise. The tests were carried out according to EN 408 with the weakest cross-section from visual grading in the area of the maximum moment.

3. Visual grading and machine strength grading

3.1 Visual grading – strength relation

Fig. 1 shows the result of visual grading according to DIN 4074-1 of lamellae and joists, respectively. Fig. 2 reveals the relation between bending strength and knot ratio. For the lamellae the knot cluster according to DIN 4074 was used and for joists the single knot. Symbols representing rejects or grade S7 occur in an area indicating a higher visual grade, if a different grading parameter was grade determining. As an example the occurrence of pith downgrades S13 to S10.



a b

Fig. 1 Grading results according to DIN 4074-1. Lamellae for glulam (a) and joists (b)

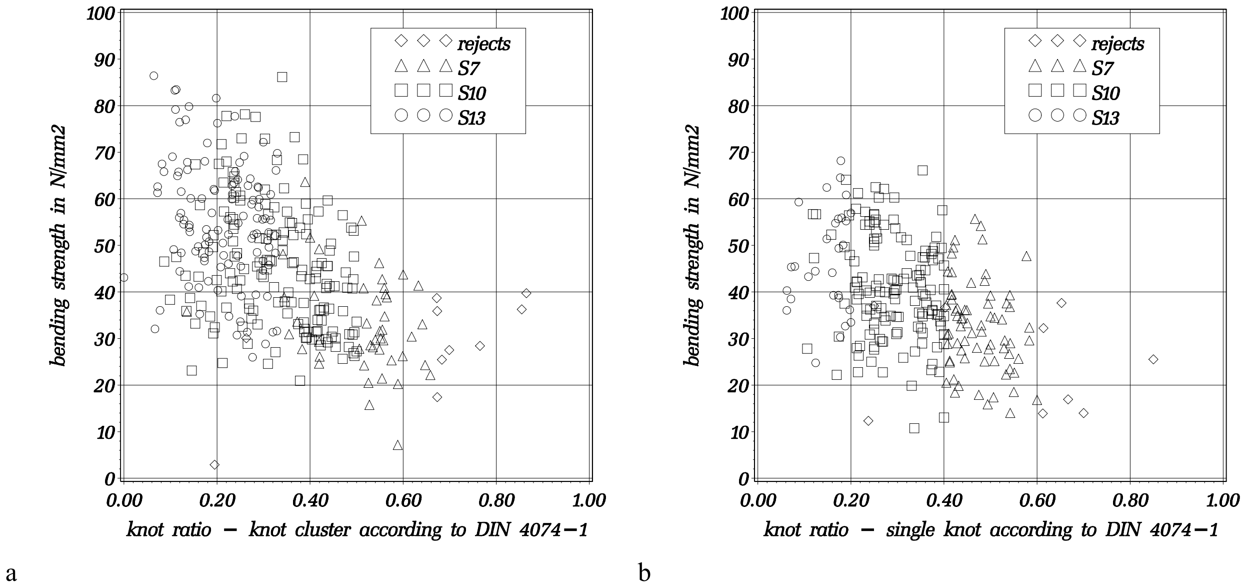


Fig. 2 Bending strength of lamellae depending on the knot ratio – knot cluster (a) and of joists depending on the knot ratio – single knot (b)

3.2 Mechanically determined parameter – strength relation

There is a close correlation between the MOE of dry and green sawn timber. The correlation coefficient is 0,98. The moisture content of green timber after sawing generally is above 30% and after kiln-drying about 10% in case of lamellae and 12,3% in case of joists. The close correlation between the different MOE allows to determine the machine strength grading parameter immediately after sawing. This is advantageous since rejects may be taken out of the production line. The scatter plots (see Fig. 3) illustrate the bending strength – MOE and bending strength – apparent density relation. The 95% confidence limits show the better prediction of bending strength by the dynamic MOE. For a given value of MOE (apparent density) 95% of the values of bending strength lie within a range of 40 N/mm² (51 N/mm²).

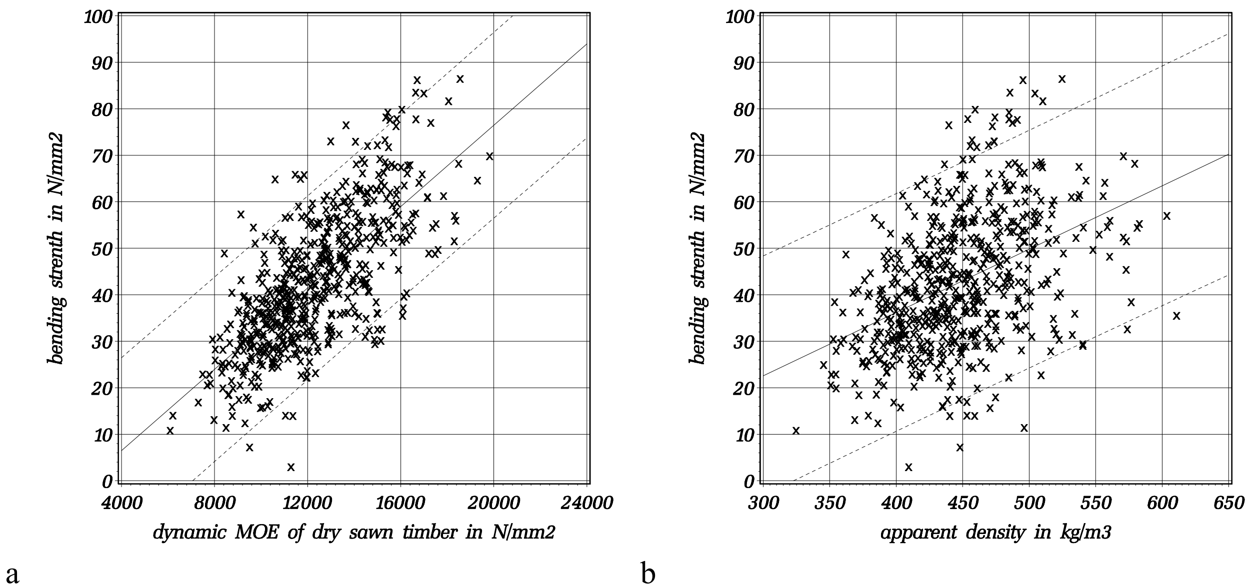


Fig. 3 Bending strength depending on dynamic MOE of dry sawn timber (a) and on apparent density (b)

4. Combining visual and machine grading

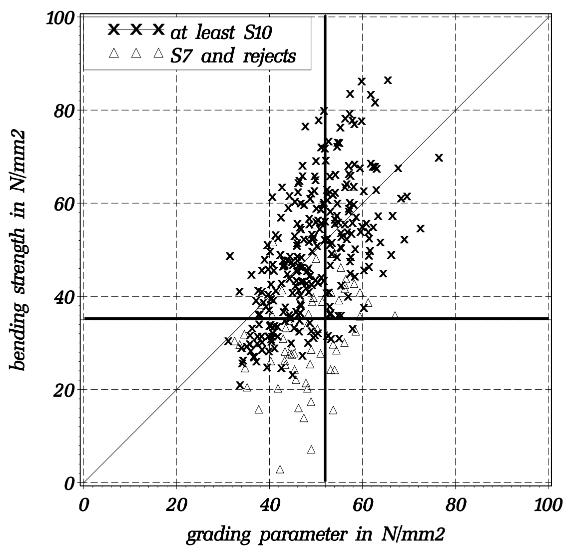
4.1 Regression equations for machine strength grading

The machine strength grading parameter predicts the minimum value of the bending strength of each piece of structural timber. A multiple linear regression analysis was performed to determine the machine strength grading parameter. The bending strength was taken as governing variable. The cross-sections, the apparent density and the MOE were taken as explanatory variables. Only those observations meeting the criteria for S10 and S13 were used for the regression analysis. Table 2 displays the most important regression equations relevant for a practical application. More details can be found in [4]. In a stepwise method the threshold value (see Table 3) was raised to find out a suitable value to grade C35 with a characteristic bending strength of 35 N/mm². The regression equations and the threshold values were verified by grading structural timber and predicting the tensile strength. For this purpose a characteristic tensile strength of 21 N/mm² is required.

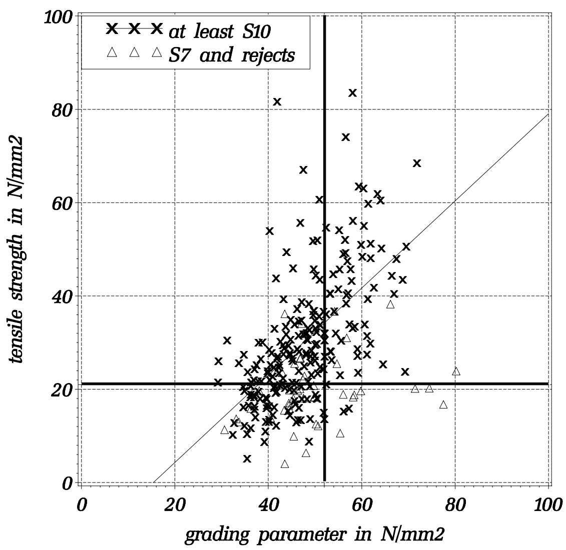
Table 2 Regression equations

equation	grading parameter [N/mm²]	intercepts and coefficients of regression equations						coefficient of correlation
		intercept [-]	width [mm]	depth height [mm]	apparent density [kg/m³]	MOE dry wood [N/mm²]	MOE green wood [N/mm²]	
1	$f_{m,p}$ =	-44,8	-0,01710	+0,1160	+0,2080			0,592
2	$f_{m,p}$ =	+13,4	-0,01320	-0,0449	-0,0414	+0,00454		0,729
3	$f_{m,p}$ =	+4,98	-0,00474	-0,0492			+0,00422	0,713

Fig. 4 displays the relation between bending strength and tensile strength and the machine strength grading parameter according to equations 1 and 2. The thick lines indicate the threshold values (vertical) and the characteristic strength values (horizontal). Fig. 4 explains why only the specimens fulfilling the requirements of S10 and S13 were used to derive the regression equations. Although observations of the visual grade S7 and of rejects can be found in the total range of the grading parameter values – 30 N/mm² to 80 N/mm² – according to equation 1 (see Fig. 4a and 4b), they mostly show bending strength values below 35 N/mm² (see Fig. 2). Hence it is reasonable to use only grades S10 and better within a combined method.

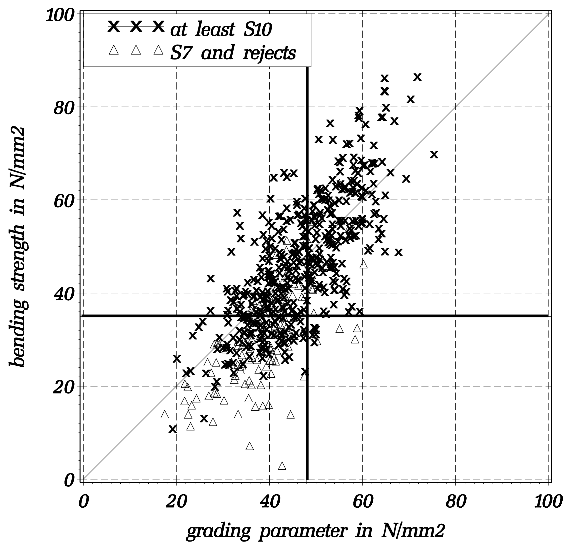


a

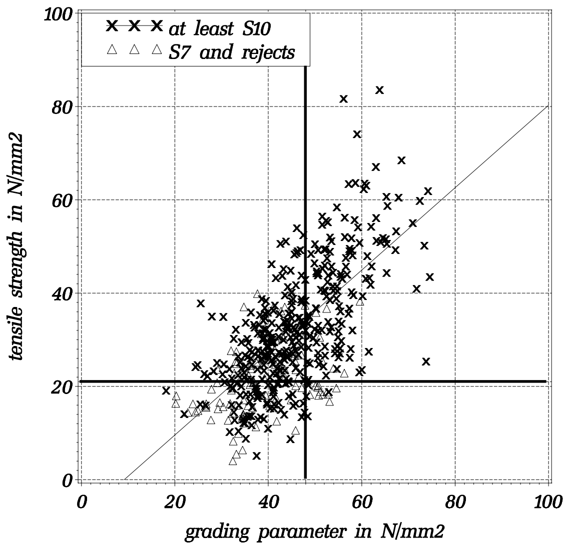


b

Fig. 4 Bending strength (a) and tensile strength (b) depending on grading parameter according to equation 1



c



d

Fig. 4 (continuation) Bending strength (c) and tensile strength (d) depending on grading parameter according to equation 2

Fig. 4c and 4d differ from Fig. 4a and 4b, respectively, regarding the distribution of grade S7 and rejects. In Fig. 4c and 4d, the predicted bending strength is mainly situated below the value of 48 N/mm². This indicates that the density, being the main parameter in equation (1), is not correlated with the knot ratio while the dynamic MOE is obviously affected by the knot ratio.

Apart from that, Fig. 4a and 4c display, that observations of the visual grade S7 and of rejects do not fit in the linear relationship between bending strength and grading parameter. The observations are situated below the regression line fitting the observations of S10 and S13 being the bisection line in both scatter plots. Therefore, the observations of S7 and rejects were disregarded in the multiple linear regression analysis.

4.2 Discussion of the regression equations and the grading results

Grading structural timber with a method according to equation 1 is simple particularly with regard to the mechanical component – only the apparent density has to be determined. Just two conditions have to be fulfilled to grade lamellae in strength class C35: the material corresponds to S10 or better and the grading parameter exceeds 52 N/mm². This method is not appropriate to grade joists because of the mediocre correlation of only 0,49 between bending strength and apparent density in case of joists. The missing influence of knots on the grading parameter according to equation 1 makes visual grading critical in this combined method (see Fig. 4a).
Taking the dynamic MOE of dry sawn timber into account, it is possible to increase the yield significantly. This leads to equation 2. Determining the dynamic MOE for one thing requires more mechanical expense but has some advantages. This method is suitable to grade lamellae and joists. The evident influence of knots on the grading parameter (see Fig. 4c) according to equation 2 makes this method more insensitive with regard to the inaccuracy of the visual grading.
The close correlation between the dynamic MOE of dry and green sawn timber produces the same threshold values of 48 N/mm² and basically the same yield for determining the MOE of dry or green sawn timber. Table 3 gives an overview of threshold values, characteristic bending strengths and tensile strengths and the yield for each of the three methods. Strength class C35 according to EN 338 requires a mean MOE of 13000 N/mm² and a characteristic density of 400 kg/m³. The structural timber graded into strength class C35 has a mean dynamic MOE of at least 14300 N/mm² and a characteristic density of at least 400 kg/m³.

Table 3 Characteristic bending and tensile strength and yield based on combined visual and machine strength grading

equation	collective	threshold [N/mm²]	yield of C35	$f_{m,k}$ [N/mm²]	number	$f_{t,k}$ [N/mm²]	number
1	lamellae	52	27%	35,9	102	21,4	64
2	lamellae	48	41%	38,4	147*	21,1	104
	joists		18%	31,3	44	35,4	41
	lamellae + joists		31%	36,1	191	22,5	145
3	lamellae	48	40%	39,0	109*	20,6	110
	joists		18%	31,4	45	29,6	43
	lamellae + joists		30%	36,3	154	21,4	153

*the dynamic MOE of 60 lamellae was not determined hence the number of 109 deviates from the number of 147

5. Conclusions

Three different combined visual and machine grading methods are suitable to grade structural timber into strength class C35. They consist of a machine strength grading and a simplified visual grading according to DIN 4074-1. Machine strength grading requires the dynamic MOE of dry or green sawn timber on the basis of e.g. longitudinal vibration and/or the apparent density. The grading parameter is calculated using these properties. The grading parameter has to be greater than the corresponding threshold value. Additionally a visual grading is necessary. Structural timber has to fulfil at least the criteria of S10. Here, only knots and slope of grain have to be taken into account additionally to the criteria in table 5 of DIN 4074-1. These criteria lay down the rules for the visual part within machine strength grading procedures.

Combined methods based on the dynamic MOE are suitable to grade lamellae and joists. It is also possible to determine the dynamic MOE of green sawn timber to grade structural timber immediately after sawing. The combined method based on the apparent density is only suitable to grade lamellae.

This study proves the possibility to combine visual and machine strength grading. Both visual grading and machine strength grading are well known methods. This eases the introduction of a combined method in practice.

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