Strategies for quality control of strength graded timber

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Abstract

The strength properties of timber are based on statistical principles. To determine settings for visual or machine grading a representative sample has to be tested. The settings for the non-destructive measurements in practice are not based on the distributions of the model, but on the non-parametric 5-percentile values of the test pieces. The purpose of the quality control of grading in practice is not clear defined in the relevant parts of EN 14081 (CEN 2005). For machine grading it is stated that for grades with a characteristic value above 30 N/mm^2 in every shift 2 beams have to be tested destructively. For visual grading it is stated that the process has to be controlled. It is not stated what has to be done when the control does not comply.

It is shown in this paper that the destructive testing for machine grading for grades with a characteristic value above 30 N/mm^2 does not give clarification whether the model or settings used are correct. The only use of control in the grading process is detecting of mistakes by machine or man, which can by controlled by periodic regrading of pieces. Verification of the model and the settings derived from the original sample could be done by regularly updating the test data from the growth area with new samples comprising the whole strength range. However, this seems to be more the responsibility of the strength grading machine manufacturer than the grading machine user, as written in the present standard.

Test samples from one location in a defined growth area for visual grading questions the applicability of the used model for this location. When samples from different locations in the growth area are both visual graded and machine graded, the applicability of the model for visual grading can be evaluated.

1 Introduction

The strength properties of timber are based on statistical principles. Strength properties are derived from representative samples. The rules for control in practice are different from those for deriving the initial settings. For machine grading beams assigned to strength classes with a characteristic bending strength higher than 30 N/mm^2 a small percentage should be destructively tested on a regularly basis. The characteristic bending strength for the last 100 consecutive destructively tested beams from the production line should meet

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the requirements for the strength class. It is not clearly stated what the purpose of this procedure is. There can be two reasons:

1. To verify if the derived settings are correct for the timber graded by the producer.
2. To check whether there has been an error in the data processing in the grading procedure and beams are assigned to the wrong strength class.

Ravenshorst and van de Kuilen (2008) have shown that to address reason 2 it is more effective to regrade beams and evaluate the p-values (a derivation of the model value) then to test them destructively.

Concerning the first reason for performing the quality control it is not stated in EN 14081-3 (CEN 2005) what has to be done when the requirements are not met. Settings are normally derived for a growth area consisting of a number of countries. It is a fact that the timber for some subsamples for some locations can be stronger and for some locations be weaker than predicted by the models. For producers located in the defined growth area but at a location where not was sampled the strength of the timber is assumed to be represented by the original samples. If the requirements are not met, should the manufacturer of the machine adjust the settings for the location of this producer or for the entire growth area? The question arises whether it is possible to verify the strength properties of samples in practice with enough accuracy to conclude the used settings are not correct.

For visual grading the only requirement according to EN 14081-1 (CEN 2005) is that during each shift the grading should be controlled. This means that for every shift the assignment to a visual grade is checked based on the visual characteristics for an undefined number of beams. The relation between strength class and visual grade is given in EN 1912 (CEN 2009). This correctness of this relation is not checked in the control procedure.

In this paper the effects of different control methods are investigated.

2 Material

For the analysis in this paper the following subsamples for spruce are used: 2 from Belgium, one from South-Germany and one from Germany/Czech Republic. The growth area is then defined as Belgium, Germany and Czech Republic. It is assumed that the settings are derived for a machine with already accepted settings; then a minimum of 450 test pieces is necessary. As a model parameter for the bending strength the dynamic Modulus of Elasticity is used. The dynamic Modulus of Elasticity is determined by the stress waves method. This is referred to as model 1, f_{mod1}. The r-squared value of the regression line is 0,50. All pieces were tested according to EN 408 (CEN 2003) and the characteristic values were determined according to EN 384 (CEN 2004), with the necessary adjustments for size and moisture content. In table 1 the values for the mean and standard deviation for the bending strength for grade are listed. Also the mean and standard deviations for the model values are given. In this paper we will focus on the bending strength, so values for MOE and density are not given.

Table 1: Basic data

Sub-sample	n	Source	Bending strength (N/mm^2)		f_{mod1} (N/mm^2)	
			Mean	Standard deviation	Mean	Standard deviation
1	180	Germany	40,8	14,2	41,1	9,2
2	193	Germany/Czech Rep.	39,1	12,9	39,4	9,3
3	148	Belgium	35,6	10,3	36,6	7,4
4	140	Belgium	36,4	10,3	35,5	7,6

3 Machine graded timber

3.1 Characteristic bending strength values of the test data

The characteristic bending strengths for graded timber with model 1of the whole dataset are presented in table 2. The settings are derived according to the procedure of EN 14081-2 (CEN 2005); the predicting parameter is the dynamic MOE. It shows that the parametric and non-parametric (ranking) values are almost the same for the grades with a high number of data. For grade C24, with less than 100 data points, the 2 values differ more.

Table 2: Characteristic values for the whole dataset for model 1

Assigned strength class	n	Non-parametric 5-percentille bending strength value (N/mm^2)	Parametric 5-percentille bending strength value (N/mm^2)	Required 5-percentile value (including k_v-factor) (N/mm^2)
C30	302	27.1	27.6	26.8
C24	96	22.8	24.2	21.4
C18	241	17.3	17.1	16.1
reject	22			

3.2 Expected characteristic values

In table 2 the characteristic values for the whole dataset are presented. The question is what will happen if a producer wants to control his grading procedure for his local area. We assume hereby that there are 4 producers, producing from the 4 sub sample locations. To judge this, we make use of a so called p-value, which was introduced in (1). This value is a simple reformulation of the model value, but then calculated for every strength class. It gives for every model value the chance that when this beam is tested destructively, the test result will fall below the characteristic value of a certain strength class. This value therefore depends on the strength class. In figure 1 this p-value is shown for the 3 strength classes C30, C24 and C18, for characteristic values including the k_v-factor. In figure 1 also the tested bending strength is plotted against the modelled bending strength, and the 5% lower bound regression line between these two properties is drawn.

When the p-value is 0.05, then the model value coincides with model value on the 5% lower bound regression line for that grade. In figure 2 the p-values for all beams of the whole dataset are shown for the different strength classes, together with the distribution of f_{mod1}. What can be seen is that the p-value for a strength class has an interval around the value of 0,05. The characteristic p-value for this interval can be calculated out of the distribution of f_{mod1} by using the following formula:

$$p_{char} = \frac{\int_{i=f\,\mathrm{mod}\,l}^{i=f\,\mathrm{mod}\,h} \left(p(i) * prob(f\,\mathrm{mod}(i)) \right)}{\sum_{i=f\,\mathrm{mod}\,l}^{i=f\,\mathrm{mod}\,h} prob(f\,\mathrm{mod}(i))} \qquad \text{Equation 1}$$

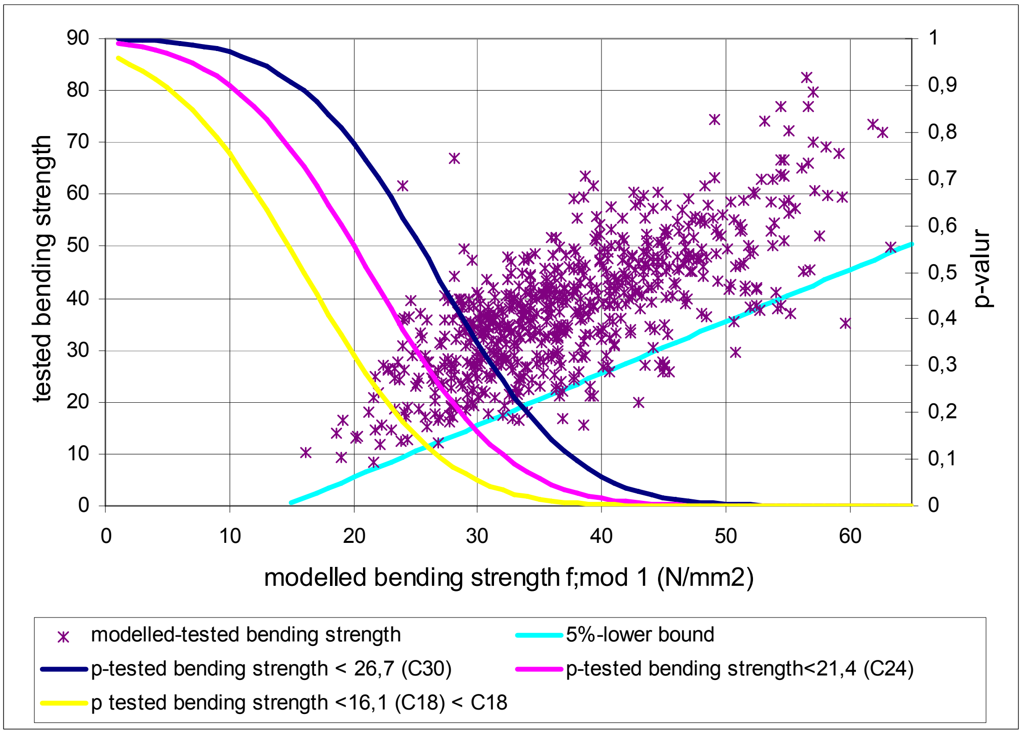

Figure 1: p-values and scatter plot for model 1.

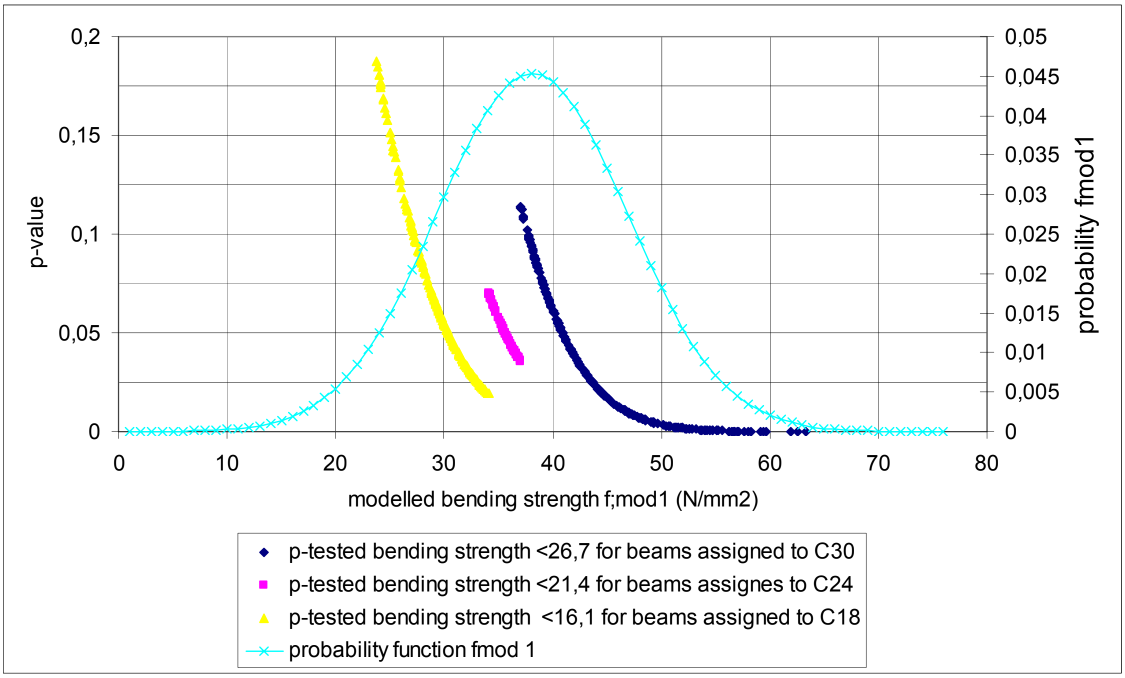

Figure 2: p-values of graded pieces and distribution of model 1.

In table 3 the p-chars are listed for the whole dataset according to the EN 14081-2 (CEN 2005) settings and also the p-boundaries are calculated to achieve a p-char of 0.05. Based on the p-chars the derived setting for C18 seems to have to be more conservative.

Table 3: p-char values for the whole dataset

Assigned strength class	n	p-char value (f mod 1 value)	Lower bound p-value for p-char to be 0,05 (f mod 1 value)	Higher bound p-value for p-char to be 0,05 (f mod 1 value)
C30	302	0.041(37.1)	0.0 (∞)	0.15 (35.5)
C24	96	0.058(34.1)	0.04(36.5)	0.065(34)
C18	241	0.071(23.7)	0.02(34)	0.11 (26.5)
reject	22			

3.3 Comparison of characteristic values

Because the distributions of fmod1 are known for every individual sub sample the p-chars can be calculated for every subsample. The results are presented in table 4. The parametric and non-parametric characteristic values for every grade are given.

Table 4: p-char values for the whole dataset

Sub-sample	n	Assigned strength class	p-char value	Non-parametric 5-percentille bending strength value (N/mm^2)	Parametric 5-percentille bending strength value (N/mm^2)
1	100	C30	0,034	26,0	24,1
2	113	C30	0,037	28,4	28,8
3	47	C30	0,051	29,5	31,8
4	42	C30	0,054	26,4	30,2
1	33	C24	0,058	20,3	22,0
2	22	C24	0,058	22,6	22,6
3	20	C24	0,058	21,1	27,0
4	21	C24	0,059	25,6	29,8
1	43	C18	0,061	16,5	13,6
2	50	C18	0,065	17,3	16,9
3	78	C18	0,063	17,8	18,2
4	70	C18	0,065	16,8	19,4

The table shows no consistency in the expected 5%-values and the 5%-values based on test results. What can be seen is that the 5%-values for the parametric and non-parametric distribution differ much more from each other than when the whole dataset is judged. The reason for this is probably due to the fact that the number of pieces in the grades for the subsamples is low.

4 Visual graded timber

Subsamples from Belgium were also visually graded according to DIN 4074-1 (2008). For the evaluation in this section they are regarded as one subsample. The settings can therefore be taken from DIN 4074-1 (2008). In this case the beams were graded according to the most governing criteria, namely the maximum value of the smallest diameter of a knot on the edge size dived by the thickness, and the same on the flat side. The maximum value of the two, called the A-value, has to be evaluated: lower than 0,2 complies with C30, lower than 0,4 with C24 and lower than 0,2 with C18. The correlation of this parameter for the entire growth area is not known. For the combined growth area of these 2 subsamples a model can be made based on a regression with the A-values. The model is shown in figure 3. In figure 3 also the 5-percentile line of the model line is shown and also the 5-percentile line, based on the criteria according to DIN 4071-1 (2008)

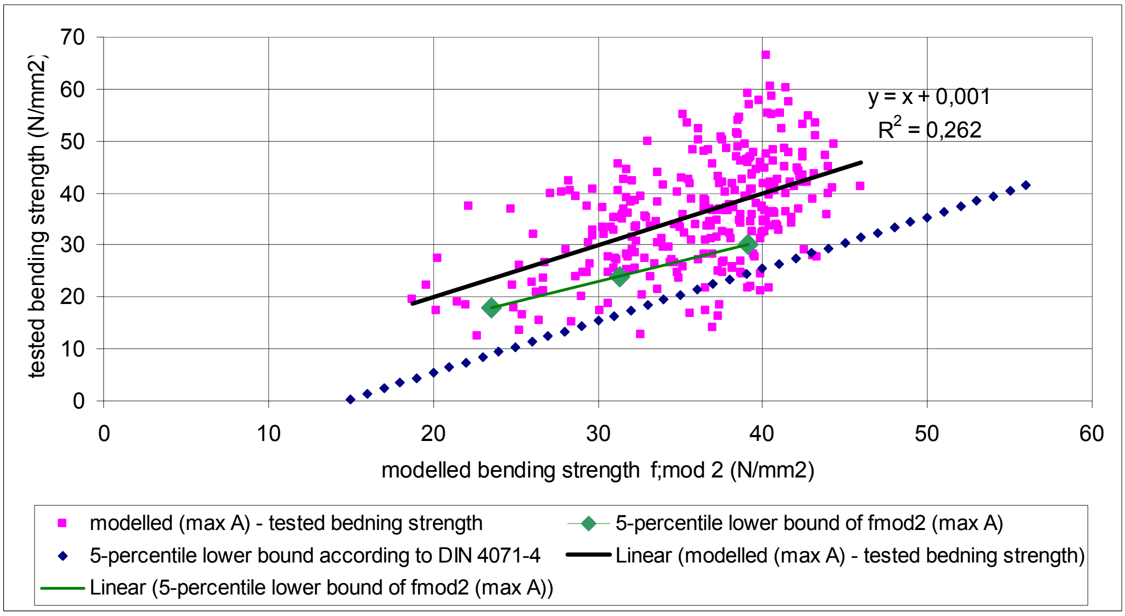

Figure 3: p-values of graded pieces and distribution of model 1.

For visual grading the required characteristic bending strengths for beams graded in strengths classes until C30 are higher than for machine grading. This is due to the k_v – factor of 1,12 that may be used in machine grading to reduce the required settings. This factor brings into account the difference in accuracy of the grading procedure in practice. In table 5 the 5%-values are listed according to the grading by DIN 4074-1(2008).

Table 5: Characteristic values for the whole dataset for model 2

Assigned strength class	n	Non-parametric 5-percentille bending strength value (N/mm^2)	Parametric 5-percentille bending strength value (N/mm^2)	Required 5-percentile value (no k_v-factor)
C30	71	27,8	28	30
C24	163	21,2	20,2	24
C18	46	15,1	15,3	18
reject	8			

The required 5% values are not met. Figure 4 gives the p-values for model 2 for the graded beams. The required p-values to reach a value for p-char for every grade are represented by the dotted horizontal lines. Interesting is then that the upper boundary for C30 is only met by 12 beams. Looking at the distribution of f_{mod2} it is in practice not possible to grade beams in C30 based on this model, although it is allowed according to the defined growth area in EN 1912 (2009) for grading from DIN 4074-1 (2008). Because the values differ that much from the DIN settings, it is questionable if these are representative for the Belgium dataset. Grading the beams with the machine grading model f_{mod1} leads to p-values up to 0,7.

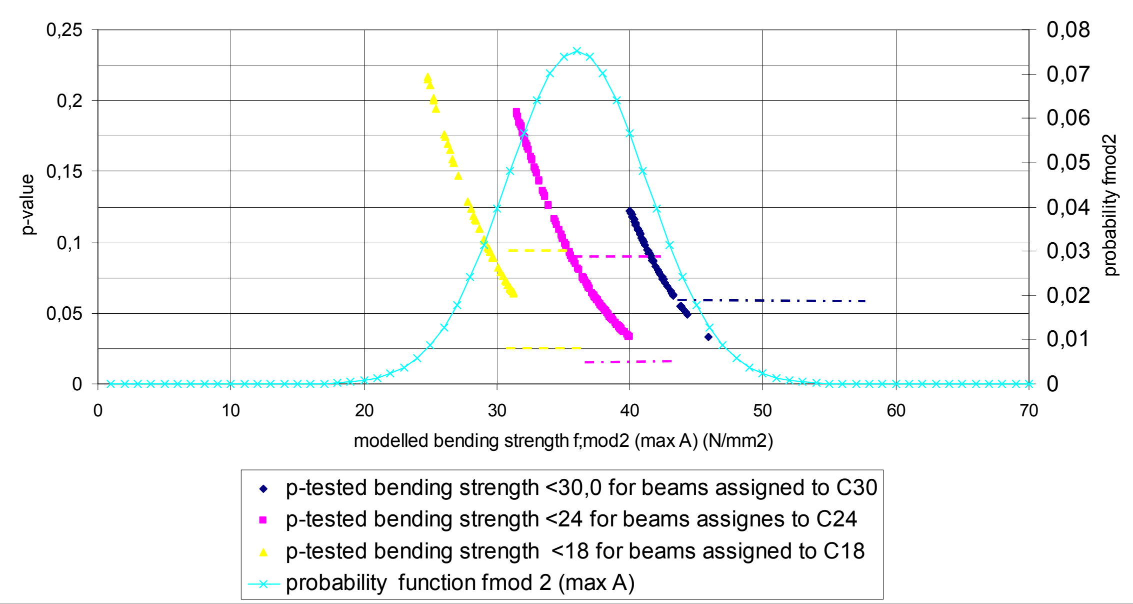

Figure 4: p-values of graded pieces and distribution of model 1.

5 Conclusions

For the control of strength grading the following conclusions can be drawn:

- The settings derived according to the procedure from EN 14081-2 (2005) differ from the procedure based on the model distributions.

- The parametric and non-parametric 5-percentile values of the grades for individual sub samples are not consistent with expected values based on model distributions. The original settings can not be verified by destructive tests on pieces taken from the high grades.

- The verification of derived settings for strength grading machine can only be verified by updating the original data set with sub samples from locations of the growth area covering the whole dataset. This seems to be more the responsibility of the strength grading machine manufacturer than the users of the machines.

- Visual graded Belgian spruce according to DIN 4074-1(2008) does not meet the strength requirements, although Belgium is part of the growth area according to EN 1912 (2009) for these grades.

- To get more insight in the defined growth areas for visual grading, subsamples from a number of locations within this growth area could be both visual as machine graded. Assuming that the machine grading model is more correct, the correctness of the visual grading models can be evaluated.

- To verify the correctness of the grading process in a company regrading by a controller can be an effective method.

References

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