Bending strength and stiffness of aspen sawn timber

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ABSTRACT

In order to investigate the possibility of using sawn timber of European aspen (Populus tremula L.) as a structural material, 150 pieces of the dimension 45 x 120 mm^2 were selected from a sawmill in the south of Sweden. The material was visually strength graded using the Nordic standard INSTA 142 and the British standard BS 4978-1996, respectively. The timber pieces were also subjected to flat-wise bending in a Cook-Bolinder® strength grading machine. Finally all specimens were tested in edge-wise bending according to the European testing standard EN 408. Global and local moduli of elasticity as well as bending strength were determined.

The results indicate that the visual grading rules, intended for use on Norway spruce and Scots pine, seem to work fairly well on European aspen. However, grading in a flat-wise bending machine like the Cook-Bolinder seems to give a lower correlation between stiffness and strength for aspen timber than generally found for coniferous. Further, the correlation between density and bending strength was found to be very low for the aspen timber tested. It was also noticed that the aspen timber has a slightly higher bending strength and modulus of elasticity than is the case for normal qualities of Norway spruce.

The study indicates that sawn timber of European aspen grown in southern Sweden can be visually graded and used as structural material.

INTRODUCTON

Background

European aspen (Populus tremula L.) is one of the most widely spread species in the world, with a natural range stretching from the Arctic Circle in Scandinavia to north Africa, and from Britain across most of Europe and north Asia to China and Japan. In Sweden aspen is the second most common hardwood species forming 2 % of the total wood supply. Only very little of the Swedish aspen supply goes to the sawmill industry for processing and since there are no Swedish grading rules and design values for aspen timber nothing of the timber is used for structural purposes.

Purpose

The purpose of this study was to investigate if sawn aspen timber originating from Sweden is proper to use as a future structural material, to find out the possibilities of using visual and machine grading and to determine some of the mechanical properties of the material in bending.

MATERIAL AND METHOD

Selection of boards

The material for the study, consisting of European aspen boards of the length 3000 mm, was selected from the Werner Träförädling sawmill in Vimmerby situated in the south of Sweden. After the sawing, the boards were kiln-dried to a moisture content (MC) of 7 %. A selection, in principle at random, of 150 boards was carried out after this stage. The boards were finally planed to the nominal cross sectional dimension 45 x 120 mm^2.

Visual grading

After the material had been delivered to the laboratory the boards were visually graded according to the Nordic standard INSTA 142 and the British standard BS 4978-1996. In the Nordic standard the timber is graded into four classes T0, T1, T2 and T3. These classes are placed in the European strength classes C14, C18, C24 and C30 respectively. At the visual grading of the boards no consideration with respect to distortions were taken. In this paper only the results of the grading according to the Nordic T-rules will be presented.

Machine grading

Prior to testing, all boards were passed through a Cook-Bolinder strength-grading machine for recording of the flat-wise modulus of elasticity (MOE) distribution along each board. In order to reduce the effects of vibrations in the machine, the boards were passed through the machine at the low speed of 40 m/min.

Testing of boards in bending

The test arrangement used, see Figure 1, was in agreement with European testing standard EN 408 with two point loads acting in the third points. The distance between the supports was 18h where h is the board depth. According to testing standard EN 384 the worst defect possible to test was placed in the centre between the point loads and located randomly with regard to the compression and tension side of the board. The position of the worst defect was determined based on visual inspection of the boards.

In the testing standard it is stipulated that the MOE, here referred to as E_{local}, shall be determined from the curvature of the centre of the test piece over a gauge length of 5h. In this case the vertical displacement was measured at the centre of the tension flange (point D relative to C and E). In addition, the global MOE (E_{global}) was determined by measuring the mid-span vertical displacement (point F) relative to the supports A and B.

After the MOE-values had been determined, the boards were tested in bending to failure. For determination of moisture content ω and density ρ small specimens were cut out close to the cross sections where failure occurred in the boards. In this paper we will only report the dry density $\rho_{0,\omega}$ of the wood material.

In the testing standard EN 408 it is stated that the test pieces shall be conditioned at 20 °C and 65 % relative humidity. For softwoods this corresponds to a MC of 12 %. It should be noted that the timber in the present investigation had a MC of about 7 % at testing.

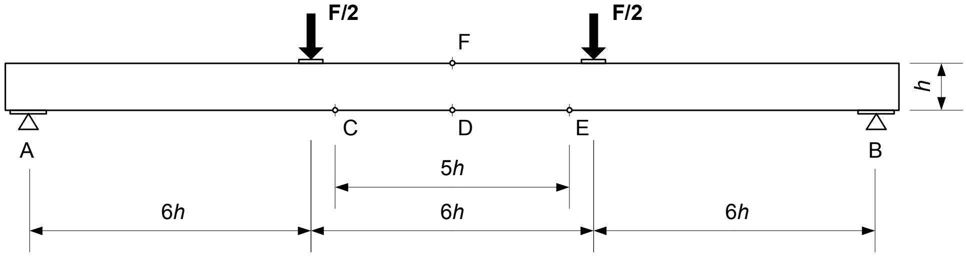

Figure 1. Test arrangement for determination of MOE and bending strength.

RESULTS AND DISCUSSION

Basic statistics of measured parameters

Basic statistics of measured parameters, presented in Table 1, include minimum and maximum values, arithmetic means, standard deviation (SD) and coefficient of variation (COV). In Table 2 the correlation matrix with respect to some of the parameters is given.

Table 1. Measured parameters. The values of the last column have no units.

	Units	Min.	Max.	Mean	SD	COV
Moisture content ω	%	6.2	9.0	7.0	0.005	0.068
Dry density $\rho_{0,7}$	kg/m^3	325	538	434	42	0.097
E_{local}	MPa	7080	19540	13770	1990	0.145
E_{global}	MPa	7400	16160	11930	1590	0.134
E_{cook}	MPa	5110	14320	10500	1670	0.159
Bending strength f_m	MPa	16.0	94.3	55.1	13.8	0.25

Table 2. Correlation matrix of measured parameters.

r	$\rho_{0,7}$	E_{local}	E_{global}	E_{cook}	f_m
$\rho_{0,7}$	1	0.41	0.46	0.40	0.18
E_{local}	0.41	1	0.84	0.61	0.50
E_{global}	0.46	0.84	1	0.73	0.49
E_{cook}	0.40	0.61	0.73	1	0.55
f_m	0.18	0.50	0.49	0.55	1

Bending strength of ungraded boards

In Figure 2 the cumulative frequency of all bending strength data is shown together with a fitted normal distribution function. The MC of the boards was, as already mentioned, about 7 % at the time of testing. This low MC has probably caused that the compression strength of the wood material has become somewhat higher than normal. The influence of the low MC on the tension strength is probably fairly small. From this it can be concluded that the test specimens with dominating compression failure, i.e. specimens with high bending strength, probably have obtained somewhat too high values while test specimens with dominating tension failure, i.e. specimens with low bending strength, are almost unaffected by the low MC.

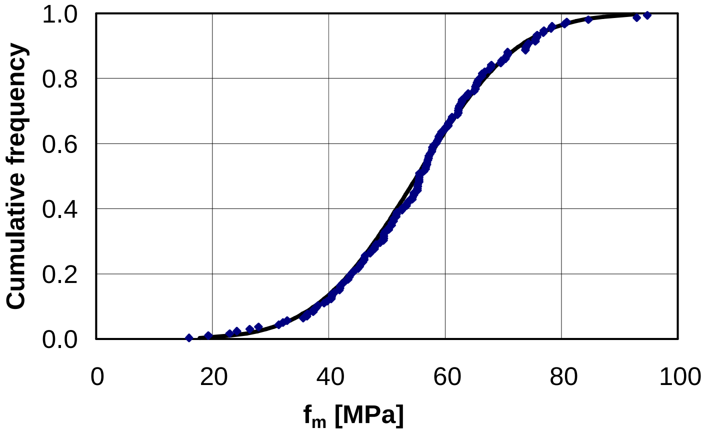

Figure 2. Empirical and fitted distribution functions of bending strength data.

The measured bending strength and density values are in Table 3 compared with results from a Norwegian investigation of aspen timber (Fjærtoft et al 1998) and a Swedish investigation of Norway spruce (Picea abies L.) timber (Johansson et al 1992). The dimension of the aspen timber was for most boards 48 x 148 mm^2 while the dimension of the Swedish spruce timber was 58 x 120 mm. The results presented in Table 3 show that the bending strength of Swedish grown aspen is in good agreement with the one of Norwegian grown aspen. It can also be seen that the bending strength of the aspen timber in both investigations is higher than normally found for Swedish grown spruce. The density values of the aspen timber in Table 3 have been adjusted to $\rho_{0,12}$ values (mass determined at 0 % MC and volume at 12 % MC) assuming a linear volumetric shrinkage of 13.5 % for the wood material between 28 % MC and 0 % MC.

Table 3. Comparison of f_m, $\rho_{0,12}$ and E_{local} found in different studies.

Timber species	Bending strength f_m			Dry density $\rho_{0,12}$			Modulus of elasticity E_{local}		
	Mean [MPa]	SD [MPa]	COV	Mean [kg/m^3]	SD [kg/m^3]	COV	Mean [MPa]	SD [MPa]	COV
Aspen (Sweden) *	55.1	13.8	0.25	423	41	0.10	13770	1990	0.15
Aspen (Norway) *	53.0	12.5	0.24	440	37	0.08	12800	1800	0.14
Spruce (Sweden) **	45.9	12.0	0.26	416	-	0.10	12790		0.21

* Measured dry density values have been adjusted to $\rho_{0,12}$.

** Grade determining defect located on tension side of board.

Bending strength of visually graded boards

The results of the visual grading of the aspen timber can be seen in Figure 3 where the empirical distribution functions of bending strength are shown for the material belonging to the different Nordic T-classes.

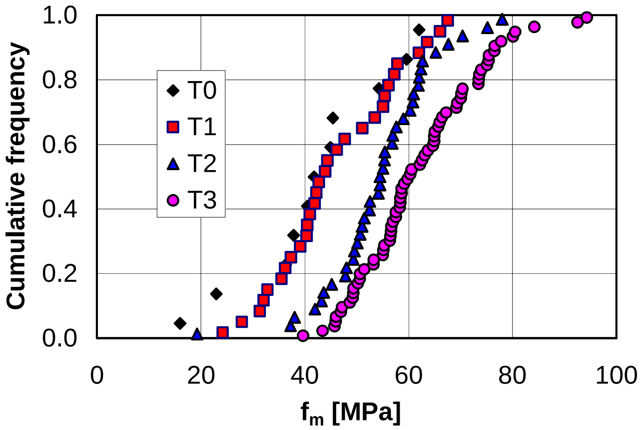

Figure 3. Empirical distribution functions of bending strength for timber graded into the Nordic T-classes.

The yield of the visual grading of the aspen timber into different classes and the bending strength of these classes are given in Table 4. To the right in the same table some results are presented from an investigation of Swedish grown spruce timber (Johansson et al 1992). The mean bending strength of the different classes is higher for the aspen timber than for the spruce timber. For the two lower classes T0 and T1 the coefficients of variation for the aspen timber seem to be slightly higher than for the spruce timber.

Table 4. Yield and bending strength of visually graded aspen boards. Bending strength of visually graded spruce.

	Swedish aspen						Swedish spruce	
Class	n	Min. [MPa]	Max. [Mpa]	Mean [Mpa]	SD [Mpa]	COV	Mean [MPa]	COV
T3	68	39.7	94.3	62.1	12.3	0.20	55.4	0.19
T2	39	19.3	78.0	54.3	10.8	0.20	47.0	0.23
T1	30	24.2	67.6	45.8	11.6	0.25	40.3	0.20
T0	11	16.0	62.0	42.0	14.1	0.34	34.0	0.29
Reject	2	26.4	55.4	40.9	-	-		

Of the 150 aspen boards tested only one board (see class T2 in Table 4) had a bending strength value lower than the characteristic value of the class in question. In Table 5 the characteristic bending strength $f_{m,k}$ of the different visual T-classes (for Nordic grown spruce and pine) are given in the second column. In the last column the calculated characteristic bending strength of the tested aspen boards $f_{m,k,aspen}$ are given. These later values represent 5-percentiles calculated at a confidence level of 50 % assuming that the bending strength values within each T-class are of normal distribution. The relatively high characteristic values found for the aspen timber indicate that visual grading of aspen timber would be proper to use.

Table 5. Characteristic bending strength $f_{m,k}$ of T-graded Nordic spruce and pine timber. Estimated characteristic bending strength $f_{m,k,aspen}$ of aspen timber tested.

Class	$f_{m,k}$	$f_{m,k,aspen}$
T3	30	41.9
T2	24	36.6
T1	18	26.7
T0	14	18.9

Prediction of bending strength

In order to study which parameters that can be used for prediction of the bending strength a multiple linear regression analysis was carried out. The parameters used in the analysis were the dry density $\rho_{0,\omega}$, the global modulus of elasticity E_{global}, the local modulus of elasticity E_{local} and the modulus of elasticity E_{cook} obtained by the Cook-Bolinder grading machine. The results of the analysis are, for the aspen timber tested, shown in Table 6 in form of coefficient of determination (R^2) and standard error of estimate (SEE). As a comparison the corresponding values obtained in the investigation of Swedish grown spruce (Johansson et al 1992) are given in the right part of the table. The R^2-values in Table 6, stating how large fraction of the variation in the bending strength (y-variable) that can be explained by the different parameters (x-variables), are much lower for the aspen timber than for the Swedish grown spruce timber. Note that the R^2-value for the Cook-Bolinder grading machine is 0.55 for the spruce timber while it is only 0.30 for the aspen timber. None of the grading machines used on the European market today will give such a low R^2-value when predicting strength. It is also notable that edge-wise bending (E_{global} and E_{local}) gives lower R^2-values than flat-wise bending (E_{cook}) for the aspen timber which is in contrary to what is the case for spruce timber.

Table 6. Results of regression analysis for prediction of bending strength.

	Swedish aspen		Swedish spruce	
Parameters	**R^2**	**SEE [MPa]**	**R^2**	**SEE [MPa]**
$\rho_{0,\omega}$	0.04	13.50	0.20	10.3
E_{global}	0.24	11.92	-	-
E_{local}	0.25	11.86	0.72	6.1
E_{cook}	0.30	11.54	0.55	7.8
E_{cook} and E_{local}	0.34	11.15	-	-

As an example on the weak relations between the measured parameters and the bending strength a plot of the relation between E_{local} and f_m is shown in Figure 4.

In the investigation of Norwegian aspen timber (Fjærtoft et al 1998) R^2-values are given in the range between 0.15 and 0.25 for the parameter E_{local}. This is even somewhat lower than the R^{2-}value given for E_{local} in Table 6.

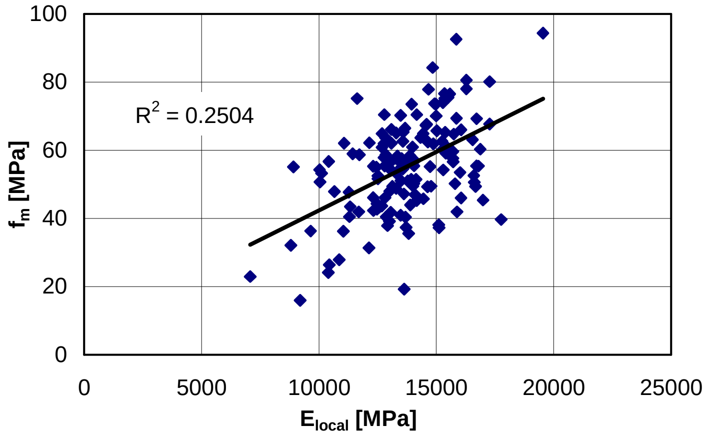

Figure 4. Bending strength f_m as function of E_{local}.

CONCLUSIONS

The aspen timber tested has somewhat higher bending strength and MOE than is the case for normal qualities of Norway spruce. The measured mechanical properties of the aspen timber are in fairly good agreement with the ones obtained in a Norwegian study of aspen timber.

The Nordic visual grading rules, intended for use on Norway spruce and Scots pine, seems to work fairly well on European aspen.

Machine grading in flat-wise bending using a Cook-Bolinder machine gives a lower correlation between MOE and bending strength for the aspen timber tested than generally found for Norway spruce and Scots pine timber. It is doubtful whether machine grading based on measurement of MOE can be applied on aspen timber.

The correlation between density and bending strength was very low for the aspen timber tested. In contrary to what is known for Norway spruce and Scots pine, the flat-wise MOE seems to be a better parameter for prediction of bending strength of aspen than the edge-wise MOE.

The study indicates that sawn timber of European aspen grown in southern Sweden can be visually graded and used as structural material.

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