Determination of characteristic strength values for Dutch larch round timber

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ABSTRACT

Round timber, as sawn timber needs to be strength graded before it can be used as a structural material.
A standard for round wood (prEN 14544, Structural timber with round cross-section-Requirements) is already drafted with regard to CE-marking.
In the face of these developments, home grown Larch from the Netherlands is tested and assessed in accordance with EN 14251:2003 and prEN 14544:2006.
This investigation deals with the determination of the modulus of elasticity and the bending strength in order to establish grading classes. Up to now in the Netherlands there is no grading system for round timber based on visual wood features with regard to strength properties.
The timber selected is larch with diameters between 100 mm and 140 mm, grown in The Netherlands. In total 205 specimens are investigated. The modulus of elasticity is determined by static and dynamic test methods. The data are included in multiple regression models in order to predict the bending strength.
Visual grading features are concerned as slope of grain, knottiness and rate of growth.
In order to increase the yield for high strength classes, additional predicting parameters for the bending strength are considered in the mathematical model such as density and vibration signals of the timber. Combining this with visual features the R^2-value becomes 0.73. In general the regression coefficient (R^2) between $f_{m,0}$ and visual features of timber is low (R^2=0.57).
The strength class for the larch grown in the Netherlands is C37 according to EN 338. The yield for C50 and C60 increases by using machine strength parameters.

INTRODUCTION

Small diameter round timber is obtained in large quantities from thinning. Presently the use of this material is not optimised in terms of commercial value, it is chipped for the panel industry, used as firewood or not even harvested from the forest site. In a European Research Project (Vries & Gard 1998) the available resource for the production of small-diameter (80 mm-150 mm) structural timber was studied in detail based on the first commercial thinning. It was shown that millions of cubic meters round timber of construction-quality per year are available just only in Finland.
The reason why round timber is not used in construction is summarised in the project as:

- Timber is not available via the commercial routes
- Shape of the timber requires special attention with the result that architects often are overtaxed
- Strength values also for connections are not available for engineers
- Lack of standards with regard to strength and test methods

This project triggered further activities in order to make these round timber resources available for structural purposes. In this line two European Standards were or will be published concerning structural timber with round cross-section (EN 14251 & prEN 14544). One deals with test methods and the other with the requirements on strength of round timber.
Actually the prEN 14544 is a Product Standard which leads to a CE-mark for round timber with regard to strength properties. At present there are no strength classes defined for round timber in comparison to swan timber in EN 338. Grading rules for round timber will be worked out on national (local) level which has to be linked to strength classes similar as for sawn timber in EN 1912. Following this methodology which is in line with sawn timber, round timber for structural use also has to be graded by strength. For sawn timber existing European Standards describe testing methods, procedures to calculate characteristic strength values (EN 384 2004), grading rules and strength classes (EN 338 2003).
Putting a first step in the development process of a round timber grading system for Dutch grown larch, the prEN 14544 is taken as a basis.
The principles to obtain strength classes are demonstrated in Fig. 1.

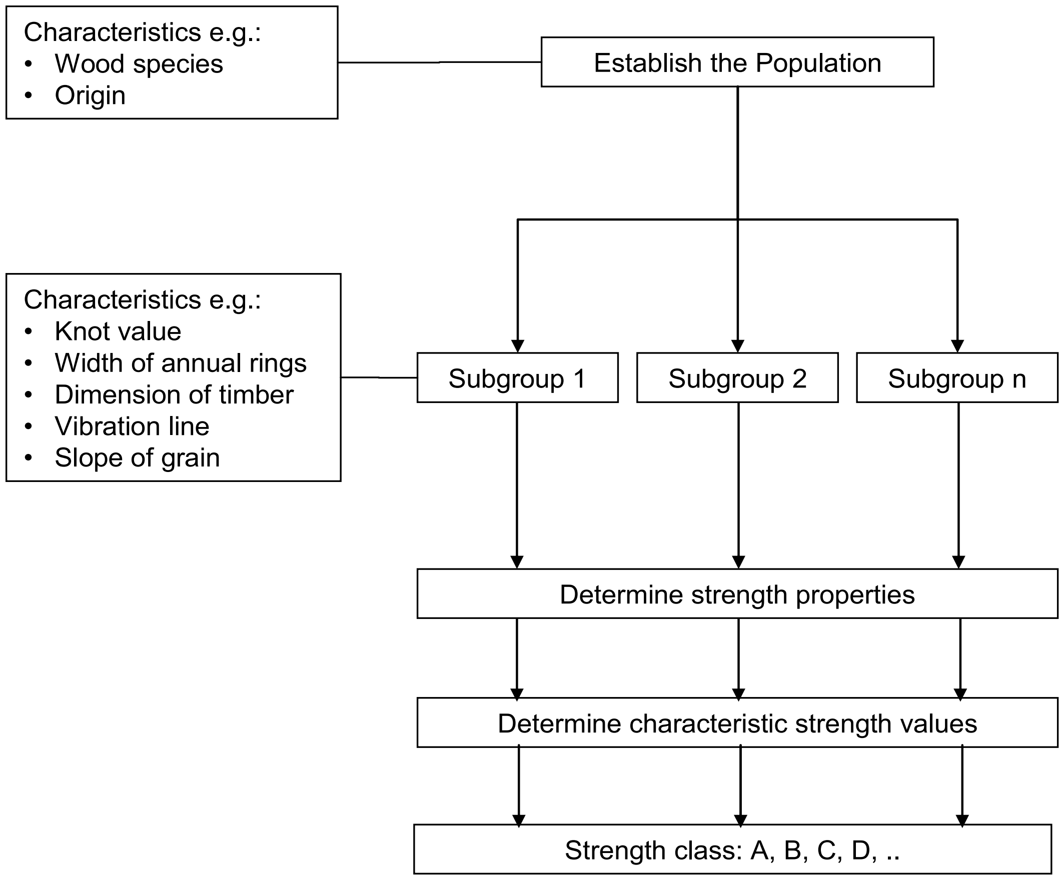

Figure 1: Principle to obtain a Strength Class for structural timber

This paper concentrates on determine the modulus of elasticity (E) and the prediction of the bending strength (f_m) with respect to strength class classification for Dutch grown round wood larch (*Larix kaempferi (LAMB.)* CARR.)

GRADING METHODS

For sawn timber both visual and machine strength grading systems are established in the wood industry. Reasonable relationships are found between the Modulus of Elasticity (*E*), some visual features (e.g. knots) and the bending strength (Modulus of Rupture, fm).
Currently round wood is not a high value building material, consequently grading procedures have to be simple and low cost level. But taking into the development on the use of renewable raw materials even small diameter round wood becomes more valuable. Actions to optimise the yield of that might be more sophisticated and be of value.

Visual strength grading

In principle every visible timber property or feature is suitable for strength grading, provided there exists a relation between this property and the strength and stiffness. Examples are slope of grain, growth ring width, knots or decay caused by micro-organisms.
Grading rules enable the prediction of the strength of a piece of timber, based on established relations between visible features and the member strength. Visual strength grading is therefore defined as classifying timber according to its strength, based on statistical relations between visible features and the load-carrying capacity.
Currently it is impossible to write a set of grading rules for round wood covering all the complexities and combinations of strength reducing features of a piece of timber.

Machine strength grading

Closer relations between strength and grading parameters produce a lower variation within a timber grade and consequently give better grade recoveries over visual grading. Most of the machines used for grading sawn timber are based on stiffness measurements, using the close relationship between the stiffness or modulus of elasticity of a piece of timber and its strength. The correlation between Modulus of Elasticity and Modulus of Rupture is about 0.7-0.8 (r-value) for sawn timber.
Most of the machine graded sawn timber today is graded using bending machines. These machines are not suitable for round wood because of the conic shape of the round wood.

Material

The specimens used for the investigation were larch (*Larix kaempferi* (LAMB.) CARR.) grown in the eastern area (3500 km^2) of the Netherlands. From larch 205 specimens were selected and tested (Tabel 1).

Table 1: Specimens involved

Diameter test piece [mm]	number	Length specimen [mm]	Length test piece [mm]	tree age [years]	taper [mm/m]
100	44	3500	2200	40 ± 6	
120	54	4000	2600	42 ± 5	
140	68	4500	3000	45 ± 4	
tapered 120-140	39	4500	3000	35 ± 6	5 ± 2

The moisture content (MC) at testing was about 15%. After drying most of the specimens were cracked along the grain. The width of the crack varies between 3 mm and 15 mm.

METHODS

Visual grading parameters

To predict the strength of the specimens the following visual features of the test specimens were determined: knottiness, ring width, slope of grain and density. For the specimens from larch the features were determined as followed:

- The density was calculated by measurement of the test piece dimensions, mass, crack width and moisture content.
- Slope of grain was determined with the aid of cracks on the surface of the timber caused by drying. The cracks follow the grain.

- Knottiness was expressed in different ways:
  - as maximum knot diameter at the 6D area (KM)
  - as a quotient of the test piece maximum knot diameter (at 6D area) and the diameter of the specimen (KD)
  - as a quotient of the test piece maximum knot diameter (at 6D area) and the cross-section area (KA)
  - as reduction factor of the moment of inertia in loading direction:

  It was expected that the position of the knots relative to the loading direction influences significantly the impact of the knots on the bending strength. Both knot size and position were recorded.

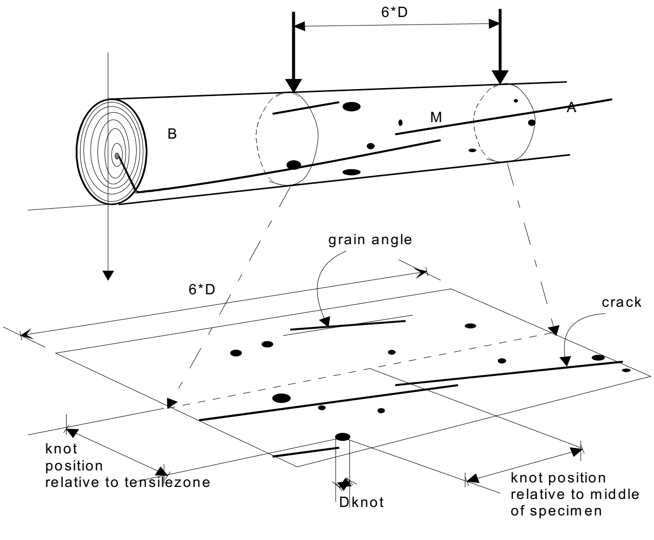

Figure 2: Projection of the knots, slope of grain and fissures on the transparent paper

When the specimen was placed on the test rig and the loading direction was determined, all knots (diameter >7 mm) and fissures at the 6D area were projected on a piece of transparent paper (Fig. 2). After the specimen was tested the failure location was marked on the transparent paper. The paper image of the specimen was used to gain the exact knot data, grain angle and failure location.

The position relative to the tensile zone as well as the position relative to the middle of the specimen was recorded.

For statistical analysis the knot data were transformed to usable knot parameters. Reduction of the moment of resistance of a knot. Using a model in which the pith position corresponds with the center of the section and the knot is modeled as a cone with the pith as apex, the theoretical influence of the knot can be expressed on various ways;

KIR_{actual}: the value of the knot parameter based on the position of the knot relative to the actual loading direction.
KIR_{max}: the theoretical maximum influence of a knot (loading direction = knot direction).
Both KIR values were calculated for all the knots on the registration paper. Then, using the knot position relative to the specimen middle section, for each of 12 zones of width $R_{specimen}$ the sum of the KIR_{actual} values (ΣKIR_{actual}) was calculated. The maximum of the 12 values for ΣKIR_{actual} (KIR_{AM}, weakest section), the maximum value of KIR_{max} (KIR_{MM}, maximum knot diameter) as well as the average value of ΣKIR_{actual} over all zones (KIR_{AA}) were used as knot descriptors for the specimen.

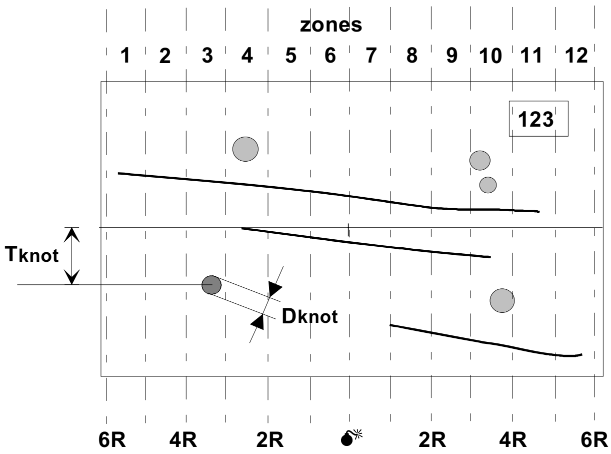

Figure 3: Projection of all knots at the 6D area subdivided in 12 areas

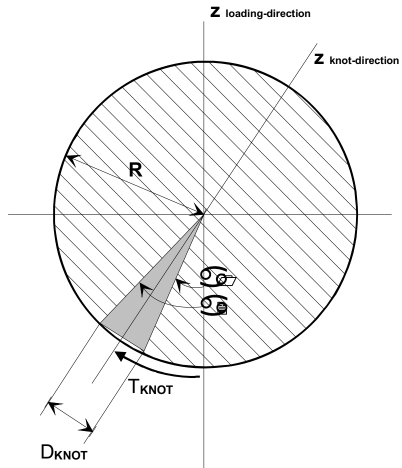

Figure 4: Knot position projected at the cross-section area

- The <u>rate of growth</u> was expected to be an important parameter in the quality characterisation for round wood. The composition, width and number of the growth rings give information on the share of juvenile wood and the age of the specimens.

The following aspects were recorded (Fig. 5):

- the maximum number of complete growth rings and the accompanying width in mm (N_{max}, R_{max})
- the number of rings in the first 20 mm from the pith (N_{20})

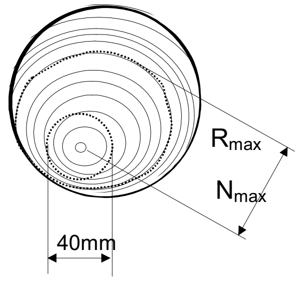

Figure 5: Growth ring determination

Using these data the following growth ring characteristic was calculated:
$RWA_{average} = (R_{max}-20) / (N_{max} - N_{20})$ [mm/year].

Dynamic Modulus of Elasticity ($E_{m,dyn}$)

A relatively cheap and quick way of measuring the stiffness of timber is based on the relationship between the eigen frequency for free-free condition of a specimen and its elasticity. This method is based on the Euler beam theory for free flexural vibrations of prismatic beams. The own frequency of a material is the basis vibration of the whole specimen at normal mode. Due to the geometry and mass of the samples and test arrangement considered, the longitudinal vibration method was applied. Longitudinal vibrations of beams with small cross-sections with respect to length are not significantly influenced by shear and torsional deformations.

The fundamental relationship is given by the differential equation (1)

$$\rho \frac{\partial^2 u}{\partial t^2} = E \frac{\partial^2 u}{\partial x^2} \qquad (1)$$

u Longitudinal displacement
x Distance along the beam
ρ Density
E Modulus of elasticity

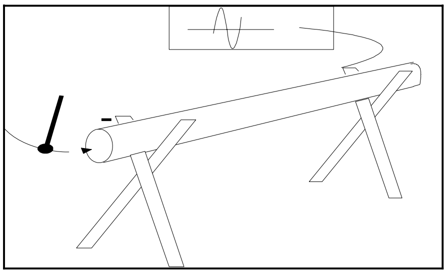

Figure 6: E_{dyn} test arrangement

From equation (1) the Modulus of Elasticity can be derived.

$$E_{m\,dyn} = 4l^2 f^2 \rho \qquad (2)$$

$E_{m\,dyn}$ Modulus of Elasticity dynamic
l Length of the specimen
f Freuquency
ρ Specific gravity

Figure 7: Timber Grader MTG

High correlation between $E_{m,dyn}$ and $E_{m,stat}$ are established for sawn timber (r=0.93) on laboratory scale (Görlacher 1984). When applying the vibration method under industrial conditions the correlation coefficient obtained is lower (Blass & Gard 1994, Görlacher 1984).
The vibration was initiated by a longitudinal impact (Fig. 6). The acceleration was measured by a Piezo-electrical transducer. The applied device is called GrindoSonic MK5 'industrial'.
In addition the E_{dyn} were measured by an industrial handheld instrument called Timber Grader MTG (Fig. 7).

Reference test methods for Modulus of Elasticity ($E_{m,stat}$)

A key element in a strength grading system is a reference testing method to determine f_m en E_m. For the design of the test arrangement, the standard EN 14251 was used. Round poles differ in many ways from sawn timber, practical problems raised:

- Round wood poles normally have some initial curvature. The curvature may force special positioning of a pole in the test arrangement. This means it is not possible to measure the relevant cross section dimensions for the calculation of the moment of inertia until after the pole is placed in the test bench.
- When using external devices to measure displacements special attention should be paid to rotations of the test piece during loading.

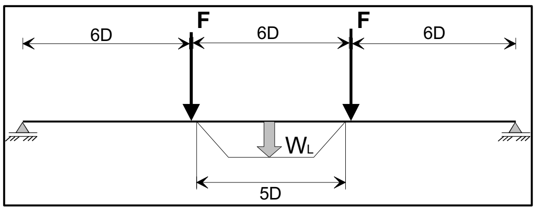

Figure 8: $E_{m\,local}$ deflection measurement

At the laboratory a test arrangement was built, according to the EN 14251 *(*Fig. 8*)*. The design of the loading heads enabled both rotation of the loaded sections and translation of the test piece surface during testing. To carry out the measurements of the displacements, three reference points were attached to a specimen.

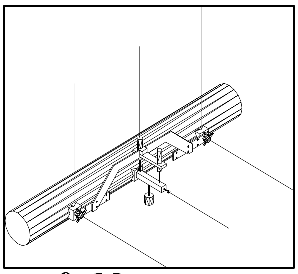

Figure 9: Measurement of deflection

On the two outer reference points a frame with the Linear Variable Displacement Transducers LVDT was mounted (Fig. 9).
The maximal force applied during the Modulus of Elasticity experiment was 40% of the expected failure load (F_{MAX}) of the specimen. After the Modulus of Elasticity test, the poles were relieved and again loaded to failure to determine the bending strength.

RESULTS

Characteristic strength values

In general timber strength classes are defined for structural use. It gives characteristic strength and stiffness properties and density values for each class and the rules for the allocation of timber populations. These classes are described in the standard EN 338.
The whole population is regarded as one sample. Previous research showed that sub-samples characterised by the diameter of the log, didn't lead to significant differences of strength characteristics. Since no significant difference was found with regard to strength properties for diameters between 100mm and 140mm, the height correction factor given in EN 384 could be considered as unnecessary. The corrected value for the bending strength ($f_{m,k}$) is given in *Tab 2*.

The key characteristic values (Tabel 2*)* are calculated from the test results according to the EN 338. The larch, grown in the Netherlands, has a characteristic bending strength of 37 Nmm^{-2}. Visual characteristics are tabulated in Tabel 3.

Table 2: Characteristic values for larch round timber based on EN 338

	Sample
n	205
$f_{m,k}$ [N/mm^2]	37
$E_{0,mean}$ [N/mm^2]	15400
$E_{0,05}$ [N/mm^2]	10100
ρ_k [kg/m^3]	450
ρ_{mean} [kg/m^3]	590

Table 3: Visual characteristics for larch grown in the Netherlands

Visual characteristics	
Knot	KD<0.35
Rate of growth	RWA<4 mm
Slope of grain	SoG<1:8

The knot characteristic KD is chosen among the other knot parameters because of the highest r-value (0.64) as predicting knot parameter for the bending strength. From the investigation it is apparent that none of the KIR characteristics, which were expected to have a high correlation with the bending strength, have succeeded.
Restricting the maximum knot diameter KD to 0.2 at equal rate of growth and slope of grain obtains strength class C50 for the larch population in the Netherlands.

Model predicting characteristic values

Particular key characteristic values of a strength class can be predicted by mathematical models. Primarily the modulus of elasticity and the modulus of rupture have to predict by easy to determine features of the timber. In Tabel 4 correlation values of selected features are given. From Tabel 4 it is obvious that the MOE ($E_{0,dyn}$) is the most suitable predicting parameter for bending strength.

Table 4: Correlation coefficients (r) between significant parameters for larch

	f_m	ρ_{timber}	E_{dyn}	KD	RWA	SoG
f_m	1.00					
ρ	**0.65**	1.00				
$E_{0,dyn}$	**0.77**	0.69	1.00			
KD	-0.64	-0.38	-0.61	1.00		
RWA	**-0.68**	-0.30	-0.58	0.59	1.00	
SoG	-0.37	-0.05	-0.30	0.31	0.31	1.00

ρ_{timber} = density of the specimen; E_{dyn} = E vibration measurement; KD = knot value; RWA= growth rate; SoG=Slope of grain

<ins>*Modulus of elasticity (E)*</ins>

The regression coefficient between the vibration measurements (E_{dyn}) and the E determined under bending load according to EN 14251 is R^2=0.75 (Fig. 10*)*.

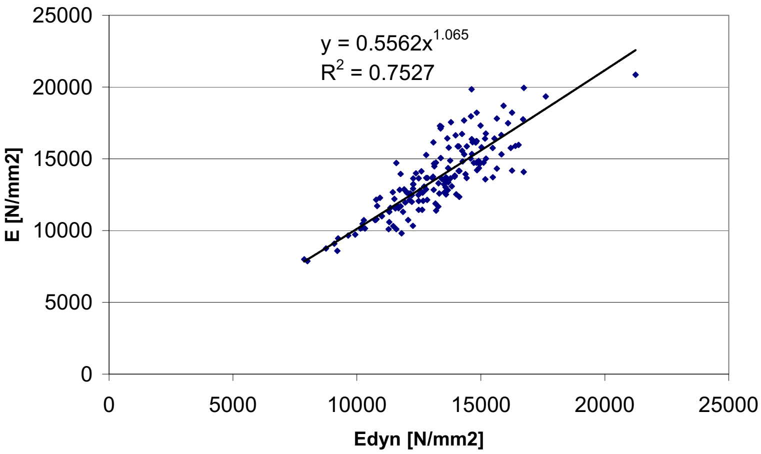

Figure 10: Regression line of E and E_{dyn}

<ins>*Modulus of Rupture (f_m)*</ins>

The strongest single correlation between f_m and the material properties that were taken into account is obtained by E_{dyn}. This regression value can be improved by applying multiple regression analyses. The results are shown in Tabel 5.

Table 5: Regression coefficients (R^2) between fm and parameters involved in the model for the population

model	Regression coefficient (R^2)	model parameters				
		E_{dyn}	KD	SoG	ρ_{timber}	RWA
1	0.73	x	x	x	x	x
2	0.73	x	x	x		x
3	0.71	x	x			x
4	0.69	x				x
5	0.68	x	x	x		
6	0.65	x	x			
7	0.63	x		x		
8	0.59	x			x	
9	0.59	x				
10	0.57		x	x		x

ρ_{timber} = density of the specimen; E_{dyn} = E vibration measurement; KD = knot value; RWA= growth rate; SoG=Slope of grain

The best result in order to predict f_m is obtained by model 1 and 2 (Tabel 5*)*. A slightly lower R^2 results from model 3 where the rate of growth and the knot value are involved. The rate of growth has a clear added value for the property to be predicted. In spite of this positive effect, in practice it is difficult to determine the growth rate easily.

In order to validate the model, it is based on 2/3 of the test data. The other 1/3 is predicted by the model. The R^2-value is 0.726 (Fig.11).

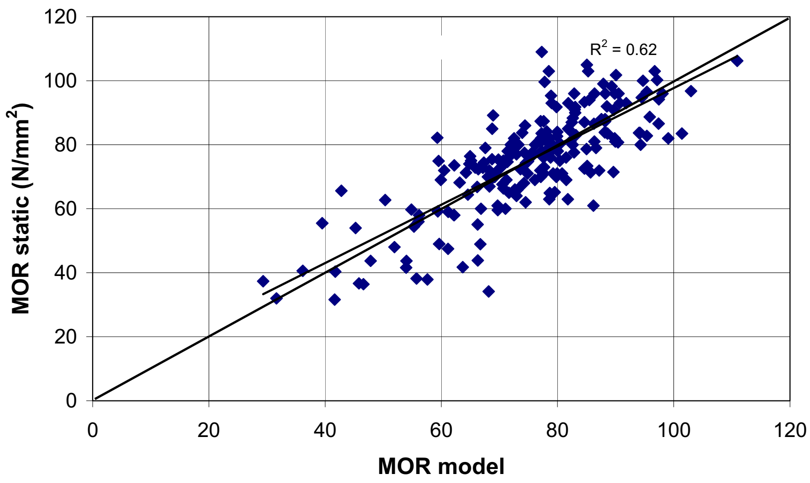

Figure 11: Regression between the model parameter and the MOR_{static}.

Model 2 and 3 have the capability to increase the yield of higher strength classes than C40 based on EN 338. By applying the regression model, it is possible to establish strength classes up to C59 *(*Tabel 6), which can not be achieved by visual grading characteristics.

Table 6: Yield for larch grown in the Netherlands with regard to strength classes

Strength class based on EN 338	Yield (%) visual	model incl. MOE_{dyn}
C27	20	0
C30	0	20
C50	80	47
59 Nmm^{-2} x)	0	33

x) strength classes for softwood are not defined above C50

CONCLUSION

From the results obtained, the following conclusions can be drawn with regard to the
<u>Strength class for larch:</u>

- The characteristic bending strength value for larch round timber grown in The Netherlands is 37 Nmm^{-2}. According to prEN 14544 the procedure, used in EN 384, has to be applied in order to determine compression strength. Based on the EN 338, Dutch larch round timber can be assigned to strength class C35.
- It is ascertained that the characteristic value of the modulus of elasticity is higher as such of the assigned strength class to the sample according to EN 338.
- The height correction factor given in EN 384 could be considered as unnecessary

Mathematical models to predict f_m:

- In general the regression coefficient (R^2) between f_m and visual features of round timber is too low in order to use them for strength prediction. If vibration measurements (E_{dyn}) are involved in the model, then even knot parameters and rate of growth contribute to the R^2.
- Machine strength grading parameters applied, increase the yield of higher grades for larch up to characteristic bending strength of 59 Nmm^{-2}.

SYMBOLS

$f_{m,k}$	characteristic value of bending strength
$E_{0,mean}$	mean characteristic value for elasticity
$E_{0,05}$	5-percentile characteristic value
ρ_k	characteristic value of density
ρ_{mean}	mean value of density

REFERENCES

Blass H.J., Gard W.F. 1994. *Machine strength grading Proceedings:PTEC 1994 Brisbane/Australia, Vol.2, pp.589-603*. Proceedings:PTEC 1994 Brisbane/Australia, Vol.2, pp.589-603.

EN 14251. 2003-12. *Structural round timber - Test methods*. European Committee for Standardisation, Brussels/Belgium.

EN 338. 2003. *Structural Timber - Strength classes*. European Committee for Standardisation, Brussels/Belgium.

EN 384. 2004. *Structural Timber - Determination of characteristic values of mechanical properties and density*. European Committee for Standardisation, Brussels/Belgium.

Gard W.F.. 1996. *Saving Drying Costs by Presorting Green Timber with Regard to Strength*. 5th International IUFRO Wood Drying Conference in Quebec City/Canada, Proceedings pp.555..

Glos P.. 1995. *Strength Grading*. In: Timber Engineering STEP1, Centrum Hout Almere/Netherlands, p. A6/1-8.

Görlacher R.. 1984. *Ein neues Messverfahren zur Bestimmung des Elastizitätsmoduls von Holz*. Holz als Roh- und Werkstoff No.42, pp. 219-222.

prEN 14544. 2006-8. *Timber Structure - Structural timber with round cross-section - Requirements*. CEN/TC 124, European Committee for Standardisation, Brussels/Belgium.

Ranta-Maunus A.. 1999. *Round small-diameter timber for construction*. Final report of project FAIR CT 95-0091;VTT Publication 383, Espoo, Finland.

Vries de P., Gard W.F.. 1998. *Strength Grading for Small Diameter Roundwood*. Heron, Vol.43, No.4, pp.183-197