Ultrasound measurements of glulam beams to assess bending stiffness and strength

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Abstract

The objective of this study was to determine the possibilities to assess the bending properties of 44x200x3800 mm, 44x300x5700 mm, 70x200x3800 mm, and 70x300x5700 mm dimensioned glulam beams made of Norway spruce and Scots pine with ultrasonic measurements of ready-made beams. The beams consisted of 8–13 finger jointed lamellae. Lamellae on the tensile and compressive faces of the beams were machine strength graded to represent grade C24, at minimum, whereas the inner lamellae represented poorer strength grades. Altogether 163 Norway spruce and 91 Scots pine beams were measured both using non-destructive ultrasonic measurements with portable Pundit testing device (CNS Farnell Ltd., London, UK) and destructive static bending tests according to EN 408. The ultrasonic measurements were done separately for compressive and tensile faces, and the lamella in the middle of the beam. Due to the cross-sectional dimensions of the beams, extra supports were needed during the destructive bending tests to avoid buckling. The average ultrasound velocities for spruce and pine beams were 5,302 and 4,987 m/s, respectively. The results showed that the correlation between ultrasound velocity and bending properties was higher for the spruce beams than for the pine beams. Ultrasound velocity of the lamella on tensile face appeared to somewhat correlate with beam's modulus of elasticity. The beam dimensions did not differ from each other concerning the correlation between the ultrasound velocity and bending properties. The current material does not yet provide enough accuracy for reliable prediction models or generalisation of the results.

1 Introduction

Glulam is an engineered structural material that optimises the technical properties of timber. Glulam components consist of individual laminates of structural timber. The laminates are not only strength graded but also finger jointed to give greater mechanical performance and higher lengths, and are then glued together to produce the desired size. As a result of the production method, very large structural components can be manufactured. Also smaller glulam beams typically have higher characteristic strength and stiffness than the solid structural timber with corresponding dimensions(*e.g.*, Heikkilä & Heräjärvi 2008). In comparison with its self-weight, glulam is stronger than steel. This means that glulam beams can span large distances with a minimal need of

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intermediate supports (Nordic… 2001). In Finland, most common tree species for glulam manufacture is Norway spruce (*Picea abies* Karst.). However, use of Scots pine (*Pinus sylvestris* L.) has become more common lately. Simultaneously, the log supply has shifted into smaller dimensions, and nowadays approximately 10% of Scots pine and 5% of Norway spruce logs sawn in Finland are so called small-sized logs (top diameter from 80 to 150 mm). Lumber from small-sized logs is also further processed into glued products, such as glulam boards and beams.

Ultrasound measurements can be used for wood quality assessment in two different ways. In most cases, the analysis relies on the wave velocity measurements, while the other methods account for the wave characteristics, such as amplitude, attenuation, and frequency (van Dyk & Rice 2005). In wood sciences, ultrasound has been used for variety of purposes, and with varying success (*e.g.*, Tucker 2001, Beall 2002, van Dyk & Rice 2005, Lin *et al.* 2007). Reasonable correlations have also been found between the log and lumber modulus of elasticity when stress wave transmission and transverse vibration techniques have been used (see: Ross *et al.* 1997). The objective of this study was to assess the possibilities to predict Modulus of elasticity (MOE) and Modulus of rupture (MOR) of ready-made glulam beams using ultrasound.

2 Materials and methods

The material originated from two different sources. Firstly, the lumber for the inner lamellae of the glulam beams originated from six stands, of which five were at the second commercial thinning stage and one was at final felling stage. All stands were located in south-eastern Finland and harvested in January 2009. Logs from these stands were divided into two top diameter classes, 130–150 mm (on bark) for the small-sized log materials, and 150–240 mm for the normal saw logs. Logs were sawn for dimension lumber using either 2 ex log or 4 ex log patterns. Boards were thereafter conventionally dried down to 12% nominal MC. Secondly, the lumber used for the surface lamellae was bought from saw mills in eastern Finland. It consisted of unsorted centre boards that were dried down to 12–16 % MC.

After planing the lamellae, beams representing two different heights, 200 and 300 mm, were manufactured. The webs, *i.e.*, inner parts of the beams, consisted of 6 and 11 lamellae in cases of 200 and 300 mm-height beams, respectively. Both centre and side boards were used in the webs. Standard EN 408 (2003) sets the requirements for beam length if the heights are known. In this case, 3.8 and 5.7 metre-long beams were finger jointed from the 200 and 300 mm-height beams, respectively. Finally, the nominal beam dimensions in the bending tests were 44x200x3800 mm, 44x300x5700 mm, 70x200x3800 mm, and 70x300x5700 mm. Table 1 presents the numbers of the beams in different strata. The specimens in which the time in the bending test was clearly over or under the nominal time of 300±120 seconds, were rejected from the study material. Furthermore, some specimens were rejected due to buckling, malfunctioning of the test device, too high MC, *etc*. Finally, 254 specimens were accepted in the analyses.

Table 1: Numbers of beams in different strata.

Species	*Beam nominal dimensions (mm)*				
	44x200x3800	44x300x5700	70x200x3800	70x300x5700	*All*
			N of beams		
Pine	28	12	29	22	*91*
Spruce	76	22	45	20	*163*
All	*104*	*34*	*74*	*42*	*254*

The dimensions as well as the moisture content (MC) were measured from the beams prior to the bending test. The MC was measured from 3–4 points near to the ends of the beam using an electric moisture meter. The air-dry density was not measured from 131 specimens out of 254 specimens. In those cases, the average density of the measured ones was used (460 kg/m^3 for Norway spruce and 499 kg/m^3 for Scots pine (Table 2)) in the calculations.

The ultrasound velocity was measured from three different locations (two surface lamellas and one measurement from the web) using a portable ultrasonic non-destructive digital indicating testing (Pundit) device. The modulus of elasticity (MOE) and modulus of rupture (MOR) in four-point static bending was measured from all beams according to EN 408 (2003) (Fig. 1). Based on a visual inspection, the weaker surface (usually larger knots or greater number of knots) was selected to be the lower, *i.e.*, the tensile face in the bending test.

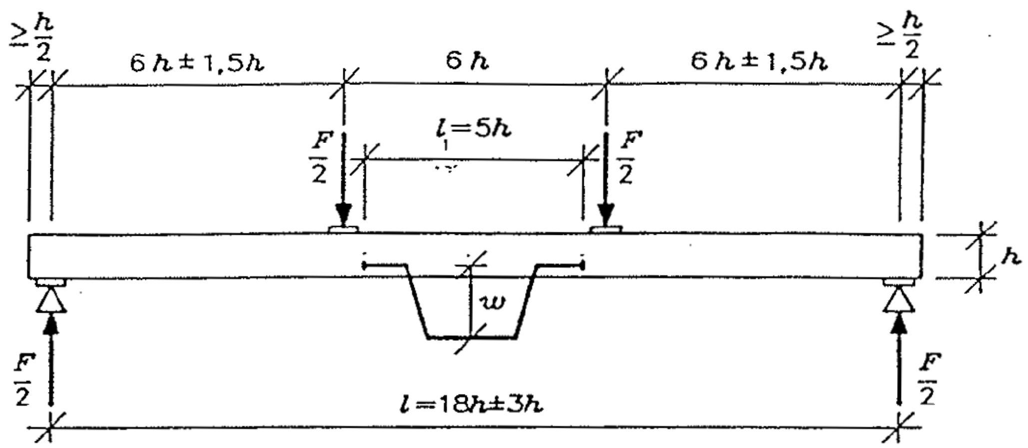

Fig. 1: Experimental setup in static four-point bending test according to EN 408 (2003).

The global MOE ($E_{m,g}$, N/mm^2=MPa) was calculated according to Equation 1:

$$E_{m,g} = \frac{l^3(F_2 - F_1)}{bh^3(w_2 - w_1)}\left[(\frac{3a}{4l}) - (\frac{a}{l})^3\right], \quad \text{Equation 1}$$

where l = distance between the lower supports (mm), b = specimen width (mm), h = specimen height (mm), a = distance between the load point and the closest support point (mm), $F_2 = 0.4F_{max}$ (N), $F_1 = 0.1F_{max}$, w_2 = displacement at the point F_2 (mm), w_1 = displacement at the point F_1 (mm).

In case of MOE, the MC’s of the beams were adjusted to correspond to 12% using Equation 2 (Boström 1994):

$$E_{12} = \frac{E_\omega}{1 + 0.0143(12 - \omega)}, \quad \text{Equation 2}$$

where E_{12} = MOE in 12% MC (MPa), ω = MC at the time of test (%), E_ω = MOE at the MC of ω % (MPa).

MOR (f_m, N/mm^2=MPa) was calculated according to Equation 3:

$$f_m = \frac{aF_{max}}{2W}, \quad \text{Equation 3}$$

where a = distance between the load point and the lowest support point (mm), F_{max} = maximum force (N), and W = section modulus (mm^3).

In case of MOR, the MC’s of the beams were adjusted to correspond to 12% using Equation 4 (Boström 1994):

$$f_{m,12} = \frac{f_\omega}{1+0.0295(12-\omega)}, \quad \text{Equation 4}$$

where $f_{m,12}$ = MOR in 12% MC (MPa), ω = MC at the time of test (%), f_ω = MOR at the MC of ω % (MPa).

Dynamic MOE, based on the ultrasound velocity, was calculated using Equation 5:

$$E_d = v^2\rho_{12}, \quad \text{Equation 5}$$

where E_d = dynamic MOE (GPa), v = ultrasound velocity (m/s) ja ρ_{12} = air-dry density (kg/m^3). Both air-dry density and ultrasound velocity values are measured from specimens with 14% MC, on average.

3 Results and discussion

The average ultrasound velocity in tensile face lamellae of Scots pine and Norway spruce specimens were 4,987 and 5,302 m/s, respectively. Figure 2 presents the dependence of static MOE on the dynamic MOE. Dynamic MOE was calculated based on the ultrasound velocity of the tensile face lamella that had the highest correlation with the global static MOE value (Pearson correlation: 0.350). Divos & Tanaka (2005) reported that according to many previous studies the correlation between dynamic and static MOE is very high (r^2: 0.90-0.96). However, in case of glulam beams it appears that other factors than dynamic MOE calculated based on the ultrasound velocity have greater influence on the static MOE. The same is even more obvious in the case of MOR (Fig. 3). Divos & Tanaka (2005) also stated that the dynamic MOE value is typically approximately 10% higher than the static one. This is very close to the mean difference in our material, where the dynamic value was, on average, 8.6% higher (Table 2).

4 Conclusions

The purpose of this study was to assess the possibilities to predict the static bending stiffness and strength of Scots pine or Norway spruce glulam beams using ultrasound velocity. Dynamic MOE, which is known to highly correlate with the static MOE of solid wood, was computed based on the ultrasound velocity and wood density information. The results indicated that in case of high-profile glulam beams, the dynamic MOE somehow correlates with the static MOE, but cannot be used in prediction of MOR. Apparently, other factors than the dynamic MOE, such as knots, grain angle and glue performance have greater effect on glulam beams ultimate strength.

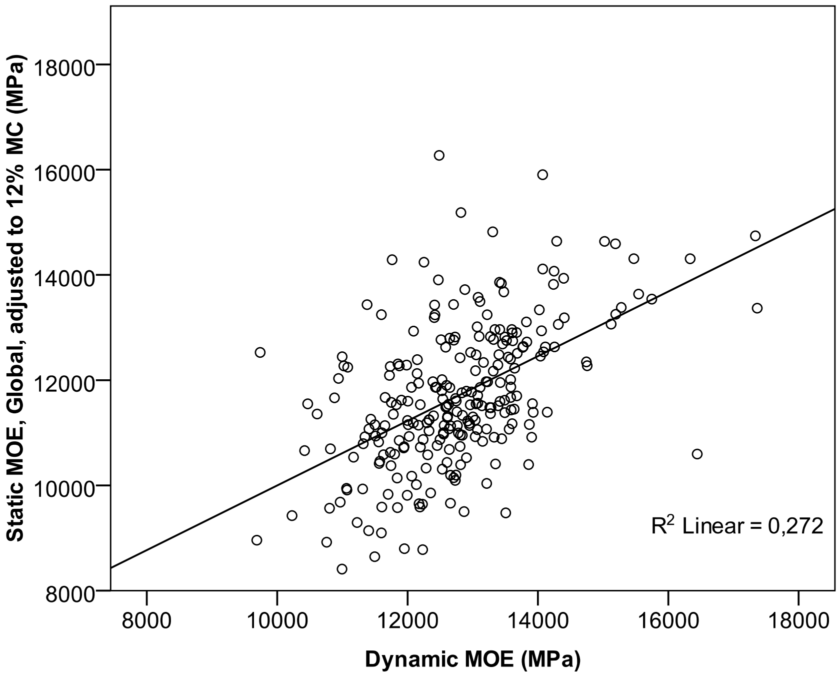

Fig. 2: A scatter plot and a linear regression line showing the relationship between the ultrasound velocity-based dynamic MOE and static bending MOE of glulam beams made of Scots pine or Norway spruce.

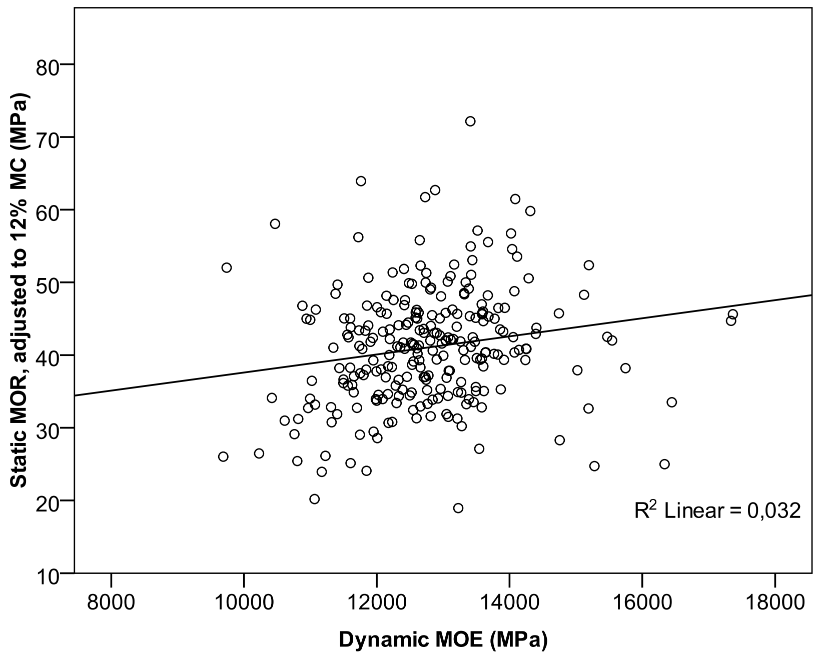

Fig. 3: Scatter plot and linear regression line showing the weak relationship between the ultrasound velocity-based dynamic MOE and static bending strength of glulam beams made of Scots pine or Norway spruce.

Table 2: Dimensions, average air-dry densities, dynamic and static MOEs and static MORs in Scots pine and Norway spruce beams. Standard deviations are presented in parentheses.

Beam dimension, mm	Air-dry density, kg/m^3	Dynamic MOE, GPa	Static MOE, global, adjusted to 12% MC, GPa	Static MOR, adjusted to 12% MC, MPa
		Scots pine		
44x200x3800	501 (17)	12.09 (1.02)	12.06 (1.33)	42.7 (6.1)
44x300x5700	495 (14)	12.36 (0.79)	11.82 (1.01)	42.6 (4.4)
70x200x3800	497 (20)	12.20 (1.21)	11.59 (1.45)	46.2 (13.1)
70x300x5700	500 (1)	13.19 (0.46)	11.98 (0.71)	46.6 (5.6)
All	*499 (16)*	*12.43 (1.04)*	*11.86 (1.21)*	*44.7 (8.8)*
		Norway spruce		
44x200x3800	464 (11)	13.44 (1.35)	12.23 (1.45)	41.4 (5.9)
44x300x5700	454 (12)	12.40 (0.79)	11.26 (1.00)	35.6 (5.7)
70x200x3800	459 (10)	12.55 (0.85)	11.22 (1.36)	38.0 (7.9)
70x300x5700	458 (10)	12.75 (0.80)	10.57 (0.97)	36.0 (4.7)
All	*460 (12)*	*12.97 (1.19)*	*11.62 (1.44)*	*39.0 (6.7)*
		All		
44x200x3800	474 (21)	13.07 (1.40)	12.18 (1.41)	41.7 (6.0)
44x300x5700	468 (24)	12.39 (0.78)	11.46 (1.03)	38.1 (6.2)
70x200x3800	474 (24)	12.41 (1.01)	11.37 (1.40)	41.2 (10.9)
70x300x5700	480 (23)	12.98 (0.67)	11.31 (1.10)	41.5 (7.4)
All	*474 (23)*	*12.77 (1.16)*	*11.70 (1.37)*	*41.1 (8.0)*

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