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BRIEF ORIGINALS · KURZORIGINALIA

Relationship of toughness and modulus of elasticity in static bending of small clear spruce wood specimens

Stergios Adamopoulos · Costas Passialis

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Subject Unlike static bending, toughness is a mechanical property less commonly measured in clear wood. The paper presents results on the relationship of toughness and modulus of elasticity in static bending based on DIN standard tests on small, clear specimens of spruce, $2 \times 2\,\text{cm}^2$ in cross section.

Information on the relationship between toughness and modulus of elasticity of wood is not available. In this study, static bending and toughness tests on small wood specimens of spruce were conducted to find possible interrelations between the two strength properties which could be used for predicting toughness strength properties.

1 Introduction

Wooden members in timber structures in service are most commonly subjected to static as well as impact loads. For design of wooden constructions and maintenance an adequate level of safety, information on both static and impact bending properties is important.

Toughness is the reverse of brittleness or brashness and is termed as the ability of wood to resist the shock of a suddenly applied load that causes stresses beyond the proportional limit. Toughness is expressed as the energy required to rapidly cause complete failure in a centrally loaded bending specimen by a pendulum impact hammer. In the case of gradually applied load, the work done by the force is stored as strain energy in wood. When the load is removed, the stored energy is recovered, provided the stress is below the proportional limit of wood.

S. Adamopoulos (✉)
Department of Forestry and Management of Natural Environment, Technological Educational Institute of Larissa, Terma Mavromihali,
431 00 Karditsa, Greece
e-mail: adamopoulos@teilar.gr

C. Passialis
School of Forestry and Natural Environment, Laboratory of Forest Utilisation, Aristotle University,
541 24 Thessaloniki, Greece

2 Materials and methods

The study material comprised 80 small, clear and straight-grained specimens of spruce (*Picea abies* (L.) Karsten) mature wood with approximate dimensions of $2 \times 2 \times 34\,\text{cm}^3$. An attempt was made to select 40 specimens with narrow growth rings and 40 specimens with wide growth rings as judged by their cross-sections. The specimens with narrow growth rings contained 9–19 rings and had a mean ring width of 1.6 mm. The specimens with wide growth rings had 4–8 rings with 3.6 mm mean ring width.

The length, width, height, and mass of each specimen were recorded for determining the air-dry density. All specimens were conditioned at 20 °C and 65% relative humidity before testing. The static bending test was performed using a Shimadzu testing machine by centerpoint loading over a 30-cm span. Half of the specimens with narrow or wide growth rings were loaded in the radial direction while the other half in the tangential direction. The load applied was about half of the estimated proportional limit load for each specimen and was based on previous tests. The crosshead speed was according to DIN 52186. From the load-deflection curve, the modulus of elasticity (MOE) in radial and tangential plane was obtained as follows:

$$\text{MOE} = PL^3/4bd^3y \quad (1)$$

where

MOE modulus of elasticity, N/mm^2
P load in the region of proportionality, N
L length between specimen supports, mm
b width of specimen, mm
d height of specimen, mm
y mid span deflection of specimen at load P, mm.

Toughness tests were conducted on an Amsler Universal wood testing machine at 24-cm span with center loading. For each specimen, the impact by the falling pendulum occurred in the respective plane (radial or tangential) of static bending test. The work produced from fracturing the specimen was noted and toughness strength was calculated according to DIN 52189 as follows:

$$W = 1000w/bd \qquad (2)$$

where

W toughness, kJ/m^2
w work to total fracture, J
b width of specimen, mm
d height of specimen, mm

3 Results

The data were grouped according to rate of growth (narrow and wide rings) and mode of loading (radial and tangential plane) and were examined by analysis of variance (Table 1) and linear regression (Fig. 1).

According to Table 1, rate of growth and mode of loading showed highly significant differences for both MOE and toughness. Further analysis of the data by Duncan's Multiple Range Test revealed some of the specific areas of variance. There was no significant difference between MOE and toughness means in the case of specimens with wide rings loaded in radial and tangential planes. For specimens with narrow rings, mean MOE and toughness values of radial plane loading were greater than those of tangential plane loading but the difference was only significant (5% level) for toughness. A comparable difference in toughness between the two loading directions was also found in white ash (Baker 1970) as well as Douglas-fir, southern pine and ponderosa pine (Keith 1964, Chow 1973). No significant difference between the radial and tangential MOE was reported for southern yellow pine, fir and black locust (Biblis 1971, Passialis 1985, Adamopoulos 2002). In both radial and tangential plane loading, greater average MOE and toughness values were obtained from specimens with narrow rings. However, significant differences at the 5% level between specimens with narrow and wide growth rings only existed in radial plane loading. Rate of growth has been shown to affect the toughness of white ash (Baker 1970). It should be noted that specimens with narrow rings had a significantly higher air-dry density than those with wide rings. Toughness on tangential plane gave less variability in results than toughness on radial plane (see standard deviation values in Table 1) and this finding was in agreement with a previous investigation by Keith (1964).

The results on the relationships between toughness and MOE for all combinations of growth rate and mode of loading are shown in Fig. 1. Simple linear regression analyses revealed significant correlations in all cases except for specimens with wide growth rings loaded in tangential plane. Concluded from the correlation coefficients, the toughness and MOE relationships were stronger for specimens with narrow rings irrespective of the direction of load ($r = 0.923$ and $r = 0.884$ for radial and tangential plane loading, respectively). The higher strength variation observed in the case of specimens with narrow rings could be explained by the higher variation in the number of annual rings (9–19 rings/2 cm) in comparison to the specimens with wide rings (4–8 rings/2 cm). In conifers, ring width is related to wood density and strength properties. When all specimens (narrow + wide rings) were grouped according to mode of loading, MOE was a good predictor of toughness in both radial ($r = 0.855$) and tangential planes ($r = 0.744$). The overall results indicate that the toughness performance of small spruce specimens, $2 \times 2\,cm^2$ in cross section,

Table 1 Modulus of elasticity (MOE) and toughness of small spruce wood specimens[1]
Tabelle 1 Elastizitätsmodul (MOE) und Zähigkeit von kleinen Fichtenproben

Growth rings/ load application	Air-dry density, g/cm^3 Mean	s±	MOE, N/mm^2 Mean	s±	Toughness, kJ/m^2 Mean	s±
Narrow/radial[2]	0.404a	0.015	8929a	1838	34.51a	22.36
Narrow/tangential[3]	0.400a	0.015	8420ab	1766	21.70b	8.17
Wide/radial[2]	0.377b	0.023	7816b	661	23.76b	9.30
Wide/tangential[3]	0.375b	0.013	7949b	628	16.40b	5.02
F	16.318*		2.786*		6.824*	

[1] values followed by a different letter within a column are statistically different at $P = 5\%$ (ANOVA and Duncan test)
[2] specimen loaded on tangential side
[3] specimen loaded on radial side
* differences statistically significant at $P = 5\%$

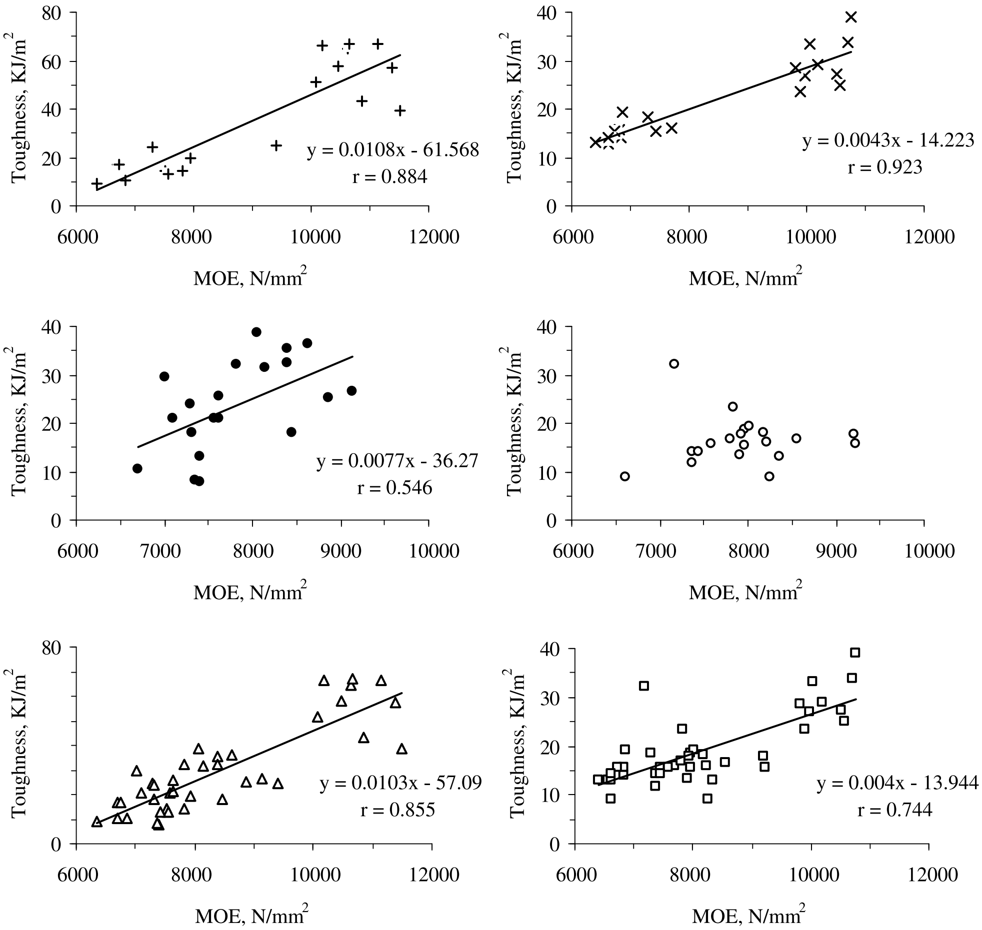

Fig. 1 Relationship between toughness and modulus of elasticity (MOE) of small spruce wood specimens. Narrow rings/radial plane (+), Narrow rings/tangential plane (×), Wide rings/radial plane (•), Wide rings/tangential plane (◯), Radial plane/narrow + wide rings (△), Tangential plane/narrow + wide rings (□)
Abb. 1 Beziehung zwischen Zähigkeit und Elastizitätsmodul (MOE) von kleinen Fichtenproben. Schmale Jahrringe/radiale Ebene (+), Schmale Jahrringe/tangentiale Ebene (×), Breite Jahrringe/radiale Ebene (•), Breite Jahrringe/tangentiale Ebene (◯), Radiale Ebene/schmale und breite Jahrringe (△), Tangentiale Ebene/schmale und breite Jahrringe (□)

could be well correlated with modulus of elasticity in static bending.

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