Stiffness of spruce wood – Influence of moisture conditions

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In this paper stiffness measurements on 968 specimens, $11 \times 11 \times 200$ mm$^3$, from Norway Spruce are presented. The measurements were carried out using a dynamic test method at equilibrium moisture content in 30% and 90% relative humidity. The test material, from two stands, was well defined with respect to growth conditions, material properties as knots and compression wood and position in the tree. Large variations in dynamic modulus of elasticity between the two moisture levels were found. For specimens from some trees, these variations were extremely large. The variations were not systematic within each tree as many other wood parameters. A part of the variations was explained by occurrence of compression wood and knots. A strong individual variation in stiffness between different trees was found. To achieve a more fundamental understanding of the relationships between stiffness and moisture content it appeared that also microscopic characteristics need to be taken into account.

1 Introduction

1.1 Background

In many practical cases, the stiffness is of importance for the use of wood. This study is focused on how different moisture conditions influence the elastic properties of Norway spruce wood. This is of importance, for example, when developing models for creep deformations of wood under varying humidity. The dynamic test method offers a fast and reliable way of determining the modulus of elasticity (E). It is therefore a suitable tool for establishing the relationship between moisture content (MC) and E. The tests were conducted on material with well-defined properties which gives new input into the understanding of the relationship between MC and E.

1.2 Literature

Kollmann and Krech (1960) reported measurements of E-modulus with vibration technique at different moisture contents. For E-modulus of spruce parallel to grain, the results showed a decrease in E of 1.4% per percent increase in MC. This value was lower than the 2% change in E per percent MC that Wilson (1932) reported and the 2.1% that Kollmann (1951) reported. Thunell (1941) reported E-values of pine at different moisture contents. Between 9% and 20% MC these values showed a change in E of 1.5% per percent MC. The results referred to above came from small specimens. Hoffmeyer (1979) presented E-values of spruce specimens of structural size. Between 14% and 24% MC, these values showed a change in E of 1.1% per percent MC. In the European standard (EN 384:1995) an adjustment factor for E with 2% per percent MC is recommended for tests of E, not conducted at reference conditions.

The influence of wood characteristics as density and knot area ratio (KAR) on E-modulus is reported many times in the literature. Usually the scatter in results is very large. It is also difficult to determine the influence of isolated characteristics when the E-modulus of a large piece of wood is measured.

Compression wood usually has smaller E-value and larger density compared to normal wood, see for example Bodig and Jayne (1982) and Seeling (1998). However, these relations are not clear, mainly due to the difficulty in defining compression wood. Also, the dependency of knots on E-values is difficult to quantify. Some knots induce

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large fiber disturbances (specially green knots) but other
(mainly black knots) have a very local influence on the
properties of the wood.

Studies on Radiata pine (Booker et al. 1996) indicated a
large variation between individual specimens for the in-
fluence of MC on E measured with a dynamic test method
parallel to grain. Their results showed decrease in E with
increasing MC of 86–222 MPa per percent MC between
oven dry and fibre saturation point for specimens made of
Radiata pine sapwood. Variations of similar magnitude
were found also for Norway spruce in this study.

1.3 Objectives
One objective of the study presented in this paper is to
clarify the relationship between dynamic E parallel to grain
and MC for Norway spruce and to try to identify possible
causes for individual variation. Another objective is to
study the variation in E with respect to different raw
material parameters. Both the variation from pith to bark
within trees and the variation between trees from different
growth sites will be evaluated. In this study, knots and
compression wood were studied specially. The study is
limited to specimens from Norway spruce wood.

2 Test Material
The raw material, Norway spruce (Picea abies), for the test
specimens came from two well-documented stands, one
slow-grown and one fast-grown, from the southern part of
Sweden. The specimens were well-defined with respect to
position in the tree and with respect to physical material
properties. A more complete description of the test ma-
terial is given in Kliger et al. (1994) and Perstorper et al.
(1995). Results from specimens from twelve trees are in-
cluded in this paper, six trees from the slow-grown stand
and six trees from the fast-grown stand.

The centre parts of the butt logs were cut into six bat-
tens, outer, intermediate and core. The small specimens,
$11 \times 11 \times 200 \text{ mm}^3$, were then sawn from a nearly knot-
free piece of each batten, see Fig. 1. All specimens from
one tree were cut from the same vertical level in the tree
and all specimens came from the butt logs. The sawing
pattern of the specimens made it possible to study the
variation in E over whole cross sections from pith to bark.
When cutting the specimens in this way, it was not pos-
sible to study the variation in E of “clear wood specimens”
as some specimens contained compression wood and
knots. It was not possible to measure the slope of grain
of each of the specimens, as all of them did not have a clear
tangential plane. A visual assessment of the specimens
showed that none of them had an extremely large slope of
grain.

Each 15 specimens from one batten were classified in
juvenile, intermediate and mature wood. This classifica-
tion was made under the assumption that the 0–15 first
annual rings consisted of juvenile wood and the wood
nearest to the bark was assumed to be mature wood. With
a few exceptions, the 30 specimens cut closest to the pith
were assumed to contain juvenile wood and the 30 speci-
mens cut closest to the bark were assumed to contain
mature wood.

To determine the influence of compression wood on
the dynamic E-modulus, the specimens were examined
visually. The specimens were grouped into three
groups:

- CW-0: No visible compression wood
- CW-1: Widened latewood band in one or several growth
  rings
- CW-2: Dominating latewood band in one or several
  growth rings.

This type of visual examination of compression wood was
also used by Perstorper et al. (1999). Problems with this
classification occurred when there was a gradual change in
the width of the latewood bands of the annual rings be-
tween specimens cut just beside each other.

Knot Area Ratio (KAR) was used as a parameter de-
scribing the size of the knots. KAR means the percentage
of the cross section that is covered by a projection of the
knot(s). The groups were:

- KAR-0: KAR = 0% (clear specimens)
- KAR-1: 0 < KAR ≤ 33%
- KAR-2: KAR > 33%

This parameter was also used by Perstorper et al. (1999).

The dynamic E at equilibrium MC at 30% and 90%
relative humidity (RH) was measured on a total amount of
968 specimens, 484 specimens from 6 trees from the fast-
grown stand and 484 specimens from 6 trees from the
slow-grown stand. For five of the trees from each stand a
whole cross-section, as in Fig. 1, was studied. For one of
the trees from each stand only half a cross-section was
included. All E-values presented in this paper are dynamic
E-values.

The influence of oven drying until zero percent MC on
the dynamic E was studied on 60 specimens from four
trees, two slow-grown and two fast-grown. After the
oven drying, the specimens were rehumidified to equi-
librium MC at 30% RH and the dynamic E was measured
again.

![Fig. 1. Cutting of specimens from the batters. The centre part of
each butt log was cut into six battens, outer, intermediate and
core. From each batten 15 small specimens for measurement of
dynamic modulus of elasticity parallel to grain were sawn](image-url)