Forschungszentrum Karlsruhe

Technik und Umwelt

Wissenschaftliche Berichte

FZKA 6704

The Fractometer II - A Mobile Wood Testing Device

K. Götz, K. Bethge, C. Mattheck

Institut für Materialforschung

Programm Nachhaltigkeit, Energie- und Umwelttechnik

Forschungszentrum Karlsruhe GmbH, Karlsruhe
2002

Impressum der Print-Ausgabe:

Als Manuskript gedruckt

Forschungszentrum Karlsruhe GmbH
Postfach 3640, 76021 Karlsruhe

Mitglied der Hermann von Helmholtz-Gemeinschaft Deutscher Forschungszentren (HGF)

ISSN 0947-8620

The Fractometer II – A Mobile Wood Testing Device

Conventional determination of the strength characteristics of small, defect-free specimens is mostly accomplished in big universal testing machines. For specimen fabrication, the tree has to be felled and cut into pieces. The specimens to be investigated are characterized by a variable size and shape as well as by a varying humidity content. Furthermore, fixation of the specimen in the holding device, load direction, and data evaluation may vary depending on the method and standard applied.

Apart from conventional determination of the strength with large machines, strength may also be determined very effectively by means of the Fractometer II. The Fractometer II has been developed by the "Instrumenta Mechanik Labor GmbH" in cooperation with Forschungszentrum Karlsruhe. It is applied for measuring the bending and compressive strengths of green and dry wood. Felling of the tree is not required for specimen fabrication.

Das Fractometer II – Ein feldtaugliches Holzprüfgerät

Die konventionelle Ermittlung der Festigkeitskenngrößen von kleinen, fehlerfreien Proben erfolgt durchweg an größeren Prüfmaschinen. Zur Herstellung der Probe muss bei diesen Prüfverfahren der Baum gefällt und zersägt werden. Unterschiede in diesen Prüfverfahren bestehen in Größe und Form sowie Feuchtigkeitsgehalt der zu untersuchenden Probe. Die Einspannung des Prüflings in der Haltevorrichtung, die Belastungsrichtung und die Auswertung der erhaltenen Messwerte werden ebenfalls je nach angewandter Methode und Norm unterschiedlich durchgeführt.

Neben der konventionellen Ermittlung der Festigkeiten mit Großmaschinen bietet das Fractometer II eine sehr schnelle und dennoch genaue Möglichkeit der Festigkeits-bestimmung. Das Fractometer II ist eine vom „Instrumenta Mechanik Labor GmbH“ in Zusammenarbeit mit dem Forschungszentrum Karlsruhe entwickelte Messvorrichtung, mit der Biege- und Druckfestigkeitskennwerte von grünem Holz, aber auch von den meisten trockenen Hölzern ermittelt werden können. Zur Herstellung der Probe muss bei diesem Prüfverfahren der zu untersuchende Baum nicht gefällt werden.

Contents

1 Introduction

The three major functions of wood comprise load transport, water transport, and nutrient storage. Each tree is exposed to a variety of environmental impacts, including light, water or nutrient supply. Varying mechanical loads, such as wind, snow or crooked growth, require varying resistance forces.

The tree always tries to find a compromise between strength, biological and mechanical requirements. Depending on its location, the tree may somewhat neglect or promote a certain major function. Optimum relation between these tree functions determines the shape of the tree. Wood quality depends on the inner optimization of these functions.

For scientific wood research, it is necessary to derive relationships among the individual strength parameters and determine strength distributions inside the tree.

The complex anatomic, physical, and mechanical properties of wood aggravate an international standardization of strength determination. The following testing methods are distinguished:

- Testing of components of structural timber dimensions and
- Examination of small clear specimens.

Approaches to testing vary with each method [1].

Conventional determination of the strength characteristics of small, clear specimens is mostly accomplished in big universal testing machines. For specimen fabrication, the tree has to be felled and cut into pieces. The specimens to be investigated vary in size, shape, and humidity content. Furthermore, fixation of the specimen in the holding device, load direction, and data evaluation vary as a function of the method applied [2].

Apart from conventional determination of the strength with large machines, strength may also be determined by means of the Fractometer II. The Fractometer II has been developed by the "Instrumenta Mechanik Labor GmbH" in cooperation with Forschungszentrum Karlsruhe GmbH. It is applied for measuring the bending and compressive strengths of both green and dry wood. Felling of the tree is not required for specimen fabrication.

As outlined above, the Fractometer II can be used to determine strength characteristics of air-dry wood with the exception of extremely strong woods.

2 Strengths

Strength of a material is determined by measuring the stresses occurring at failure. If the stress prevailing exceeds the corresponding strength, the component fails. Depending on the type of load, e.g. bending strength σ_B, tensile strength σ_T, compressive strength σ_C, and shear strength τ are distinguished.

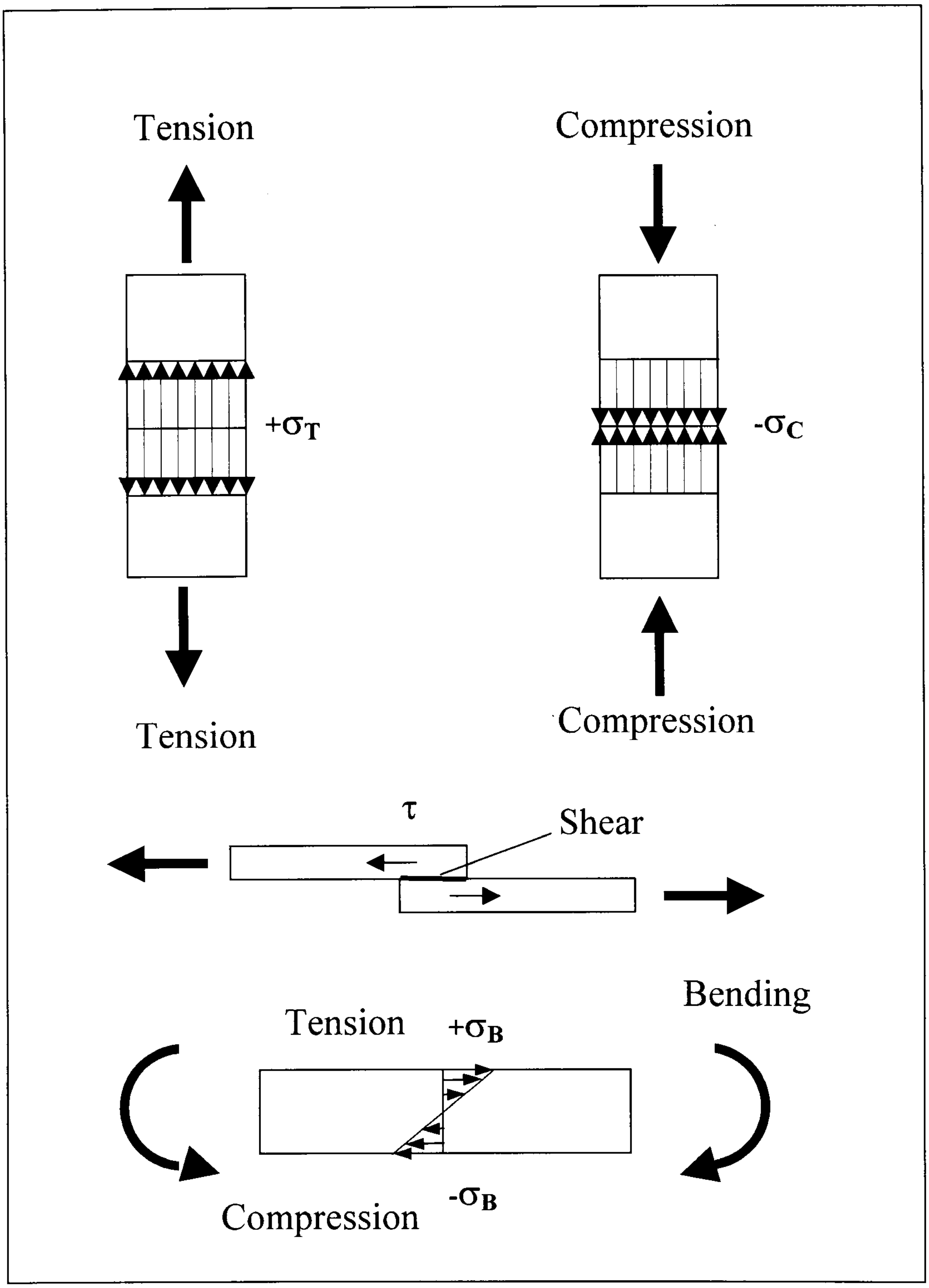


Figure 1: Simplified classification of internal stresses caused by external loads acting on a component into tensile, compressive, and shear stresses

2.1 Compressive Strength

By the bending of the trunk, the latter is exposed to compressive stress in axial direction. Axial compressive strength $\sigma_{C,l}$ means the resistance of the tree against failure due to axial compression (Fig. 2).

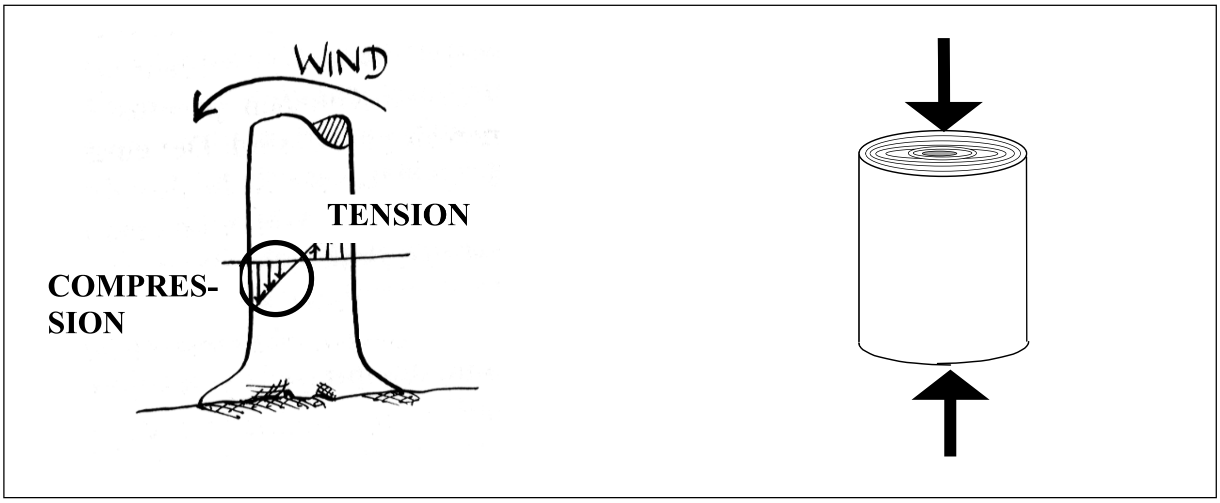


Figure 2: Loads acting on the tree, resulting compressive stresses, and schematic representation of load direction in a trunk

2.2 Lateral Tensile Strengths

The bending of the trunk causes a tensile stress to act on the trunk in axial direction. In this case, tangential or radial tensile stresses are generated in the root onsets as well as in crooked trunks. Radial tensile strength $\sigma_{T,r}$ denotes the resistance of the trunk against failure due to radial tensile stress (Fig. 3). This strength counteracts the formation of hazard beams [3], [4].

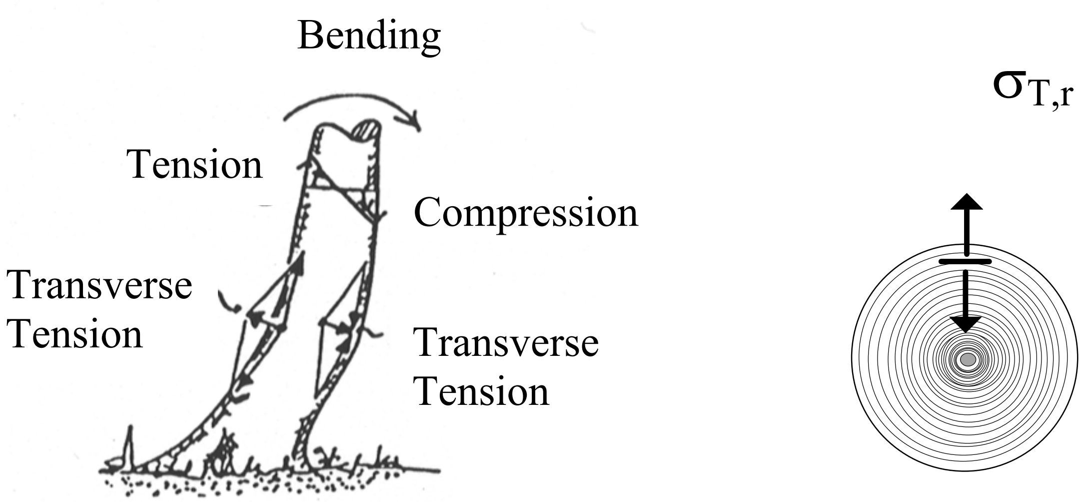


Figure 3: Loads acting on the tree, resulting radial tensile stresses, and schematic representation of load direction in a trunk

Bending of a hollow trunk causes a compressive stress to act on the trunk in radial direction. In this case, flattening of the trunk may occur. On the inner and outer surface of the hollow trunk, tensile stresses are generated in tangential direction (Fig. 4). Tangential tensile strength $\sigma_{T,t}$ is the resistance of the tree against failure due to tangential tension.

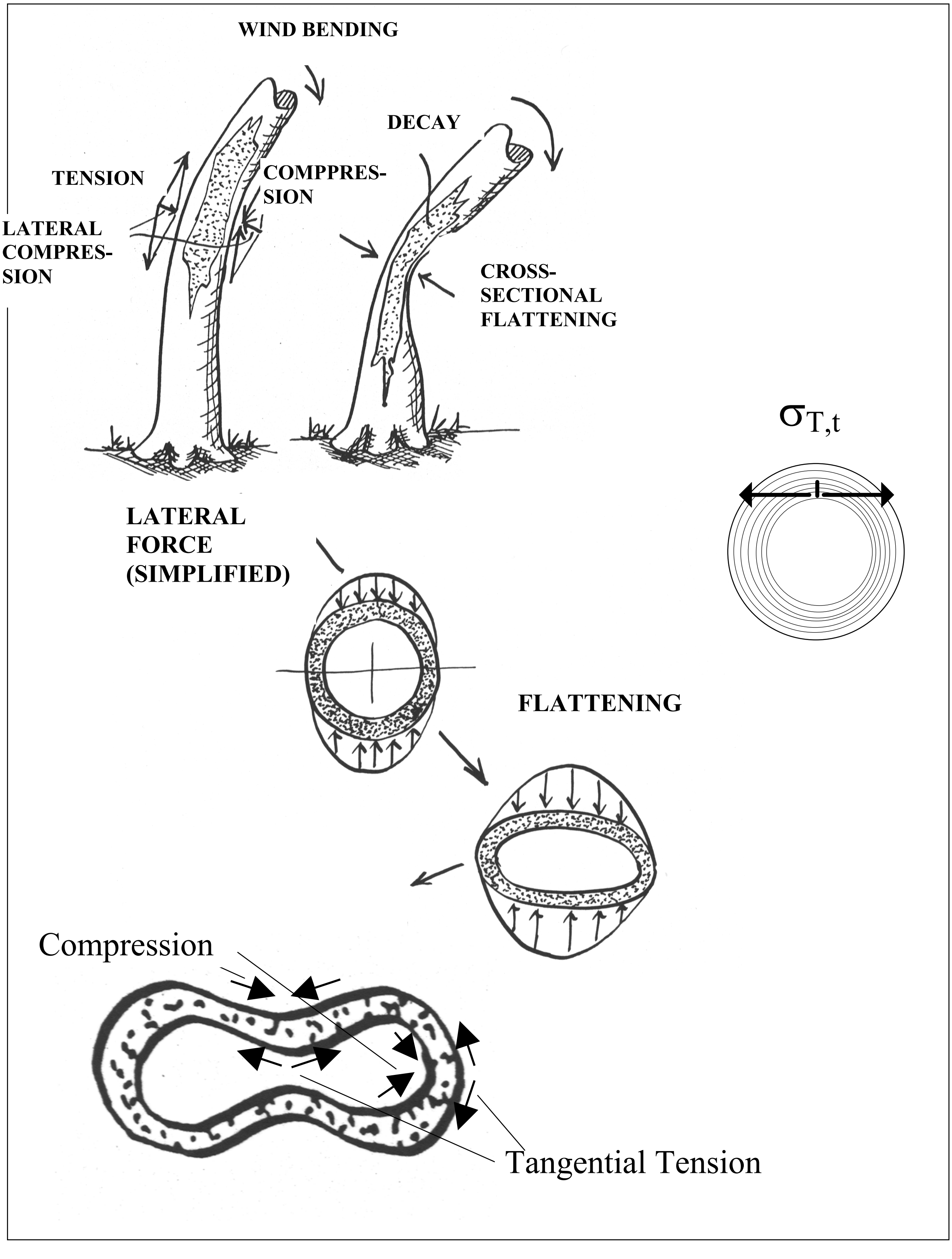


Figure 4: Loads acting on the tree, resulting tangential tensile stresses, and schematic representation of load direction in a trunk [5]

3 The Fractometer II

The Fractometer II is a device for measuring the bending and compressive strengths of green wood and not extremely hard, dry wood. For this purpose, an increment core of 5 mm in diameter is used. The increment core is withdrawn from the tree in radial or tangential direction by means of an increment borer (Fig. 5).

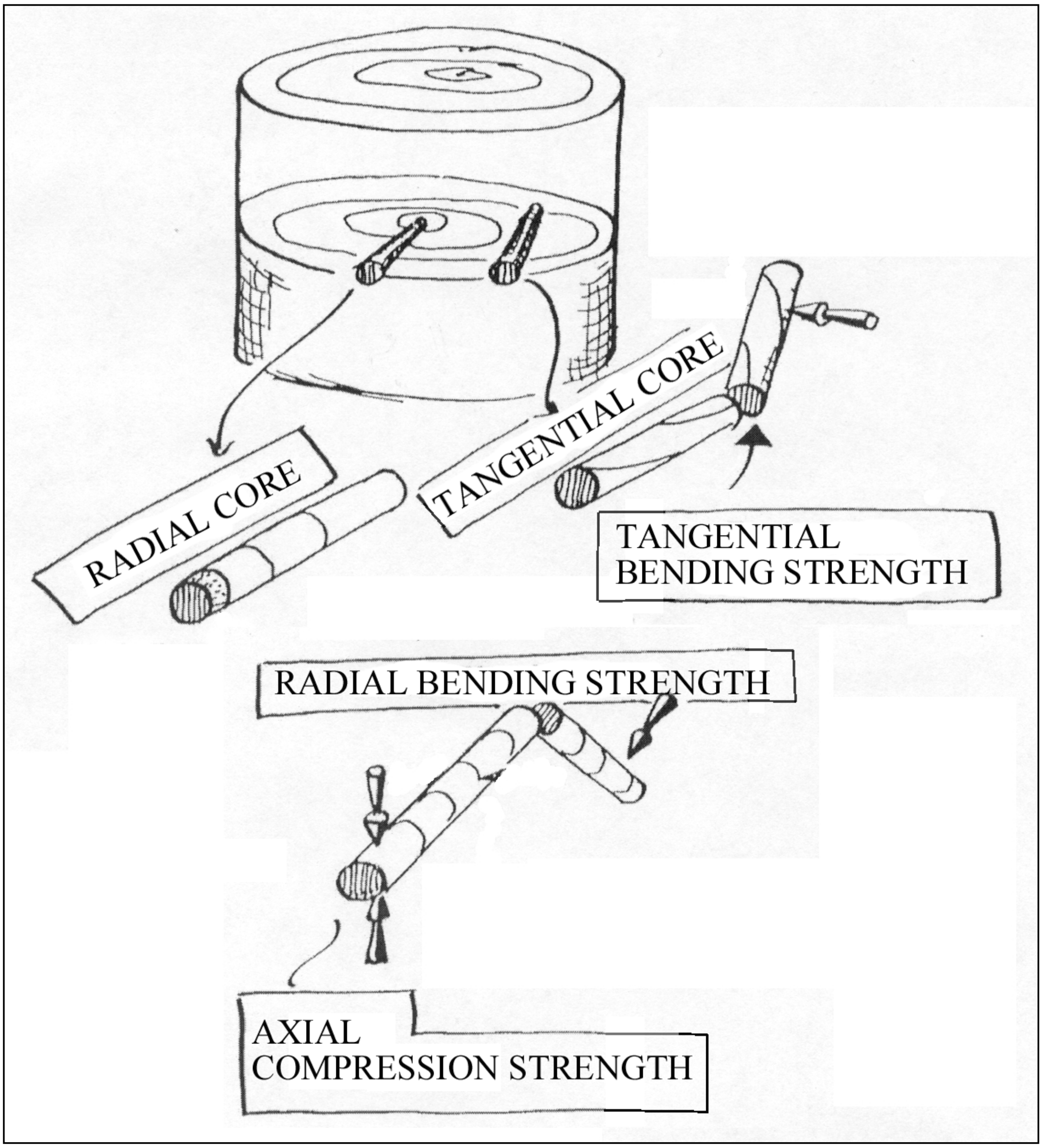


Figure 5: Strength characteristics that can be determined by breaking a radial or tangential increment core using the Fractometer II [6]

3.1 Setup of the Fractometer II

The Fractometer II consists of the following five major components (Fig. 6):

- Lever for force introduction (A);
- Load meter with maximum pointer (B);
- Bending lever arm (C);
- Fixing units for the increment core or increment core segments (D);
- Displacement transducer for determining the bending angle (E).

Figure 6: The Fractometer II with its five components

3.2 Functioning Principle of the Fractometer II

To determine a strength value, the increment core or a specimen segment is inserted into the respective fixing unit and oriented in accordance with fiber direction. By slow, continuous moving of the outer lever, a force is transmitted to the fixing unit and, hence, to the specimen. This force is increased until failure of the specimen. The maximum force applied until failure of the specimen is measured. This force or the corresponding strength is indicated by the drag pointer of the load meter. The bending angle covered until failure of the specimen is measured by means of the displacement transducer.

3.2.1 Fractometer II Measurements Using Radial Increment Cores

Radial bending strength is determined by the bending lever arm of the fixing unit (Fig. 7). Thereby the increment core is broken into 10 mm long specimen pieces at least, and the maximum force or radial bending strength is determined (Fig. 8). For subsequent compressive strength measurements, a length of the broken pieces of 20 mm is recommended.

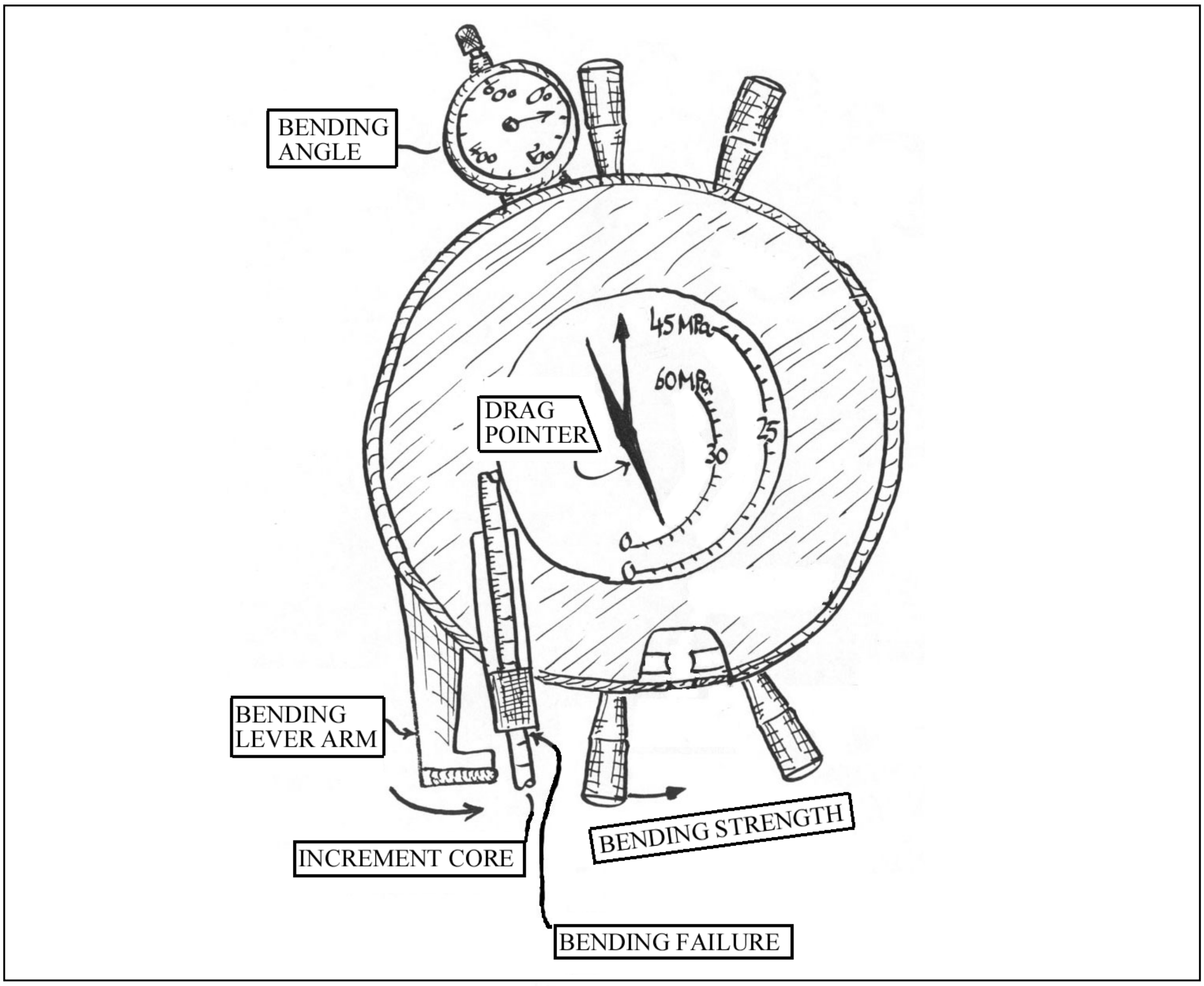


Figure 7: Schematic representation of bending failure of a radial increment core for determining radial bending strength

In case of radial bending failure, the specimen first fails on the tension side. Therefore, radial bending strength can be used as a measure of radial tensile strength (lateral tensile strength).

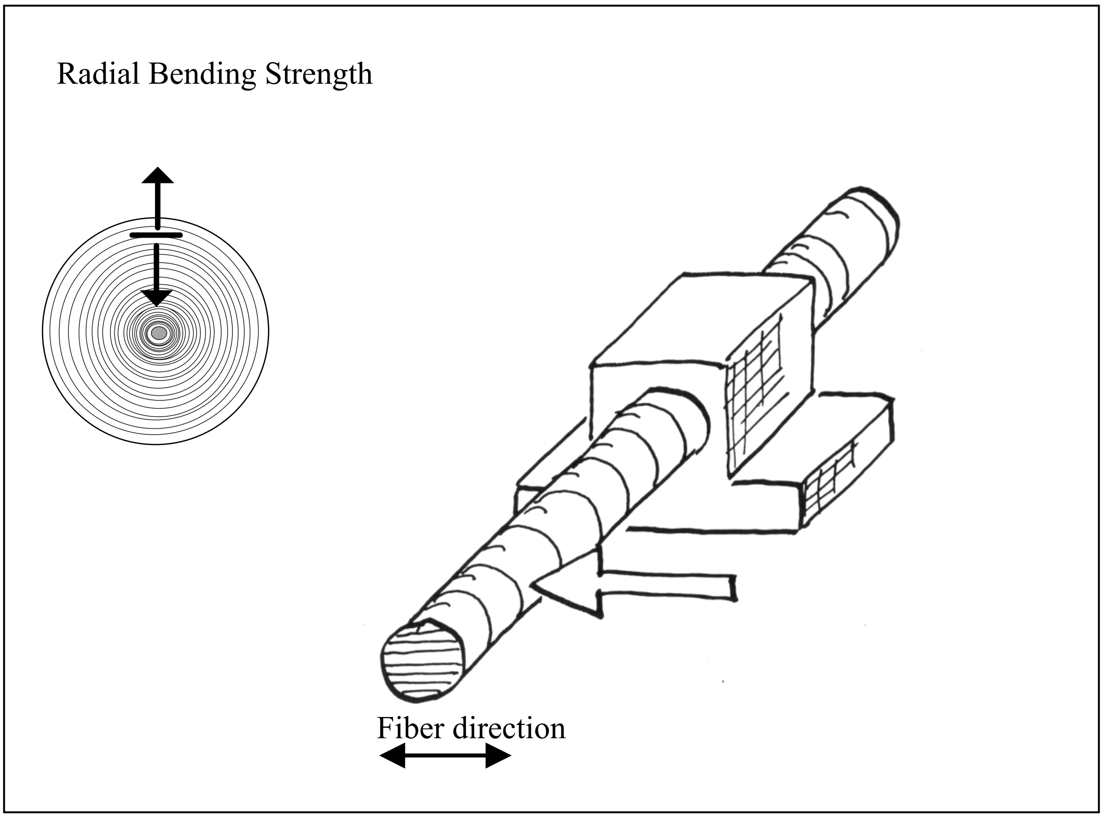


Figure 8: Schematic representation of loading and orientation of the specimen to be investigated when determining radial bending strength

After this, a disk of about 2 mm thickness is cut from each specimen piece using a razor blade. This is done to remove the wood fibers and rays that have been delaminated by the bending strength test. Then, the 20 mm long specimen piece is cut into three segments of 5 mm length each (Fig. 9).

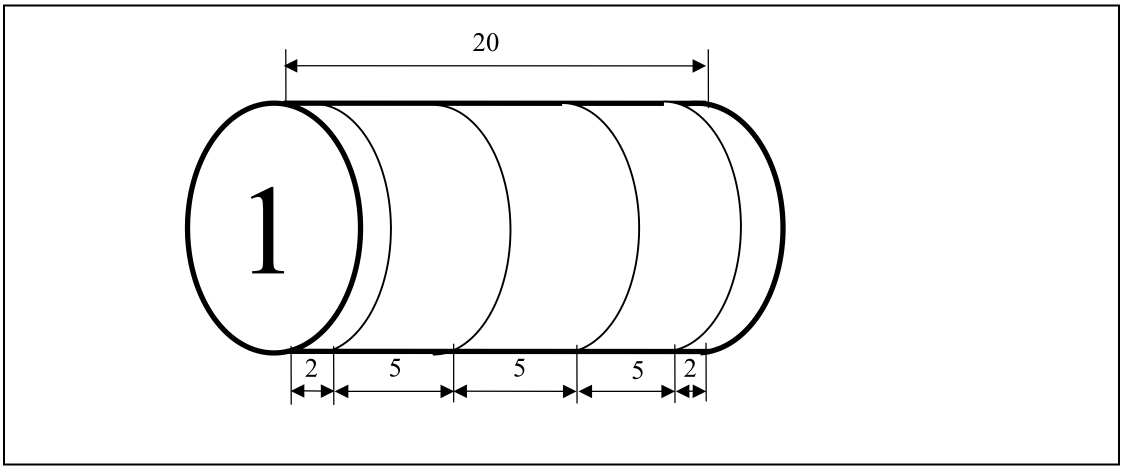


Figure 9: Cutting of the about 20 mm long increment core segment obtained after bending failure for subsequent compressive strength measurements

Axial compressive strength is determined in the fixing unit of Fractometer II represented below (Fig. 10). As specimens, the three 5 mm long increment core segments are used.

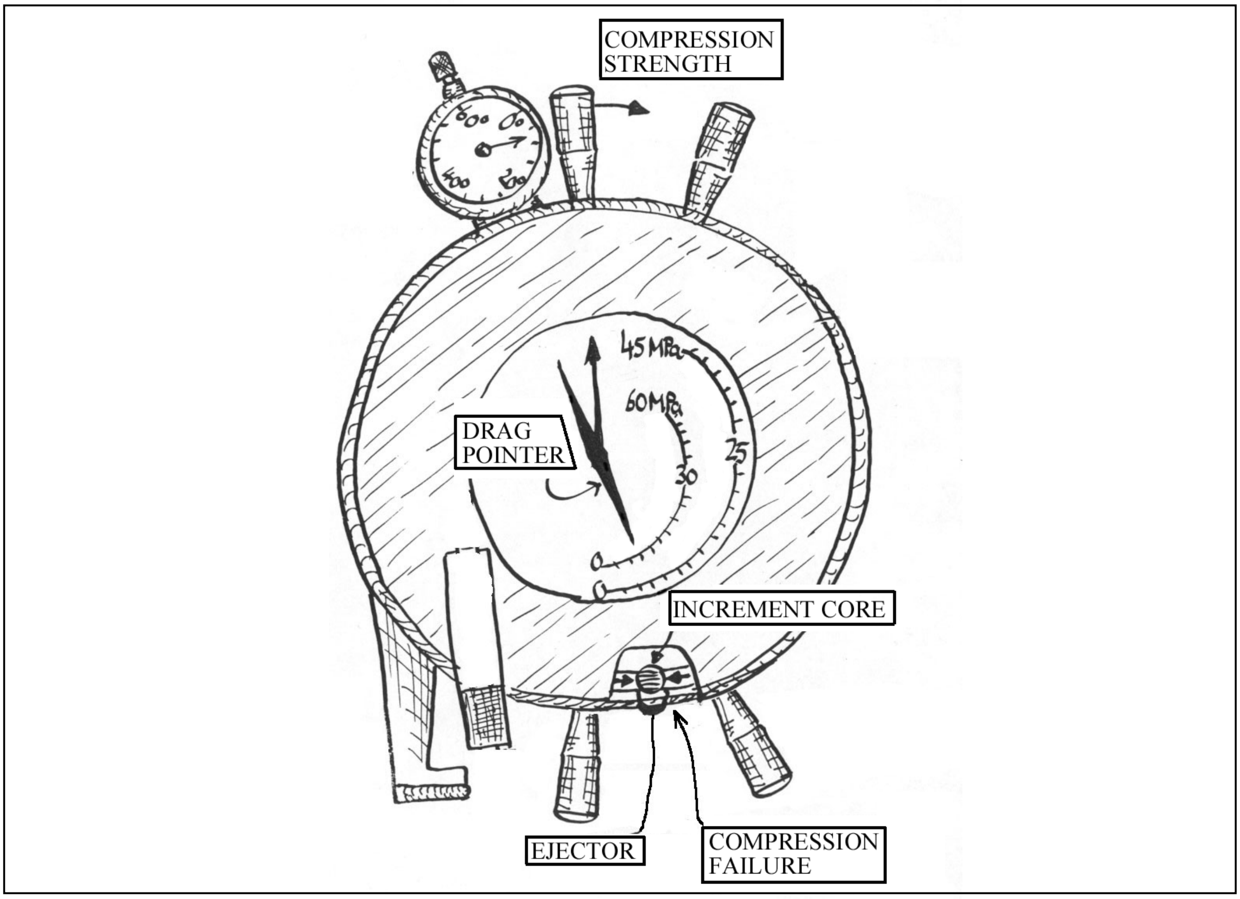


Figure 10: Schematic representation of the test performed using a radial increment core to determine axial compressive strength [8]

The specimens are subjected to loading until failure in direction parallel to fiber (<u>first</u> load drop!!!), and maximum compressive load or axial compressive strength is determined (Fig. 11).

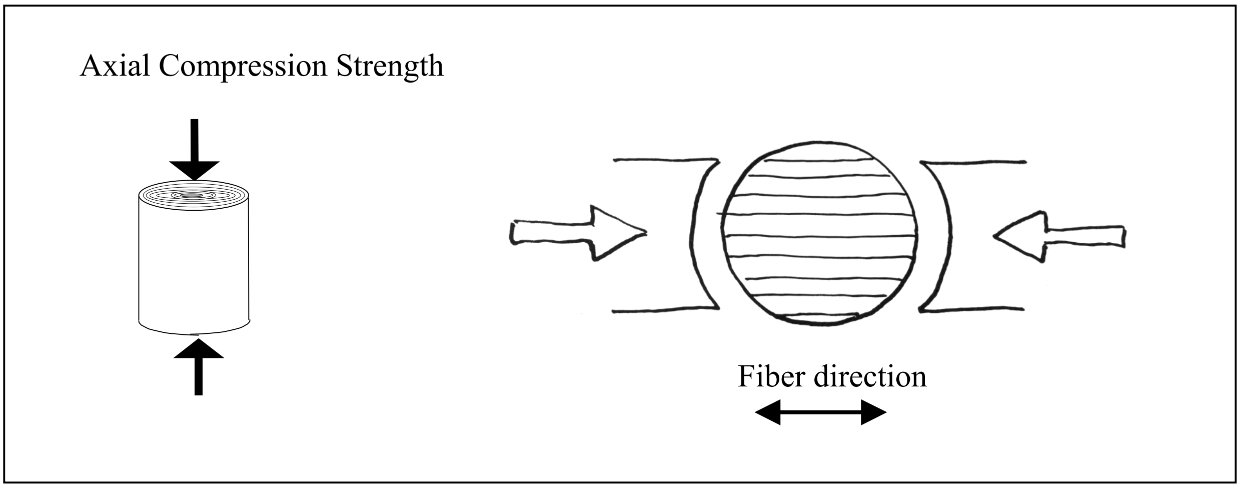


Figure 11: Schematic representation of loading and orientation of the specimen to be investigated when determining axial compressive strength

3.2.2 Fractometer II Measurements Using Tangential Increment Cores

Tangential bending strength is determined by the bending lever arm in the fixing unit (Fig. 7). Only those areas of the increment core, where the annual rings are parallel or the wood rays are vertical to the longitudinal axis of the increment core, may be applied for determining tangential bending strength [6]. In this case, the increment core is subjected to tangential loading, and the maximum load until fracture is determined (Fig. 12). Thus, only one measurement point per increment core is obtained for determining tangential bending strength using a tangential core.

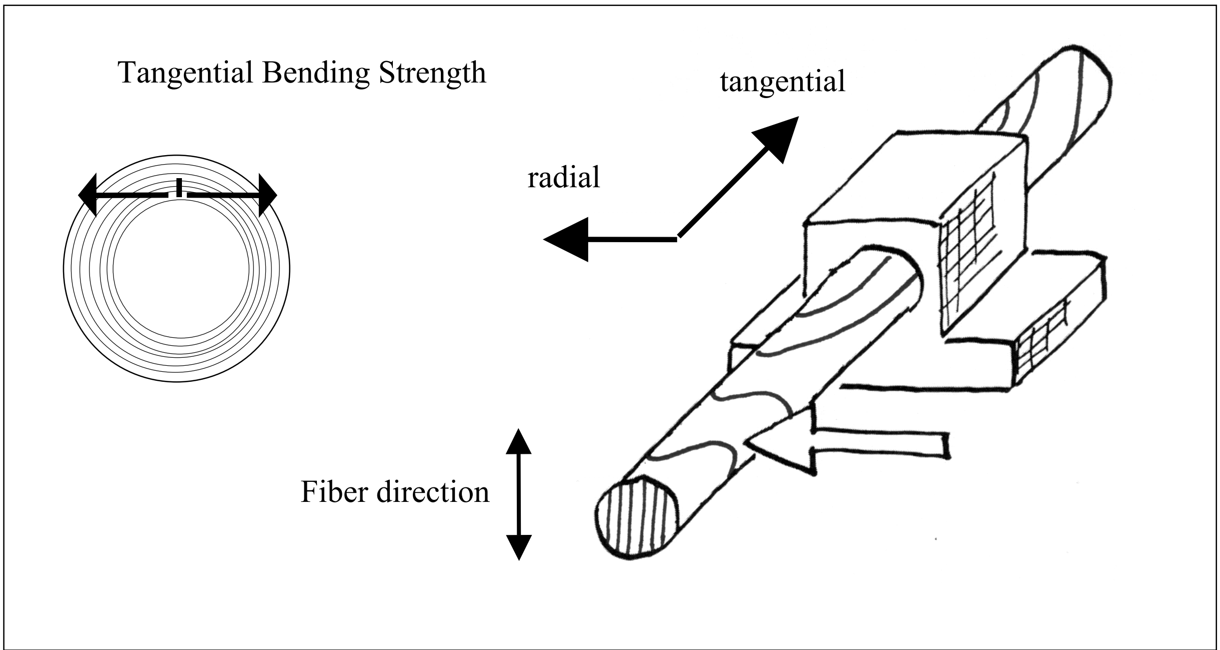


Figure 12: Schematic representation of loading and orientation of the increment core to be investigated when determining tangential bending strength

4 Influence of Loading Velocity and Specimen Length on Compressive Strength, demonstrated by the Example of Beech

In the present section, possible impacts of loading velocity and specimen length on the axial compressive strength values determined shall be discussed.

In a field study involving nine beeches (*fagus sylvatica L.*), the compressive strengths obtained at a loading velocity of one or two seconds until specimen failure were compared. In additional experiments, specimen length of the increment core segments used in the compressive test was varied. Compressive strengths of specimens having a length of five millimeters were compared with the compressive strengths of specimens having a length of 10 mm only in order to illustrate the influence of lateral support of the uncompressed area.

The figures below illustrate the influence of loading velocity and specimen length on the compressive strengths (Figs. 13 and 14).

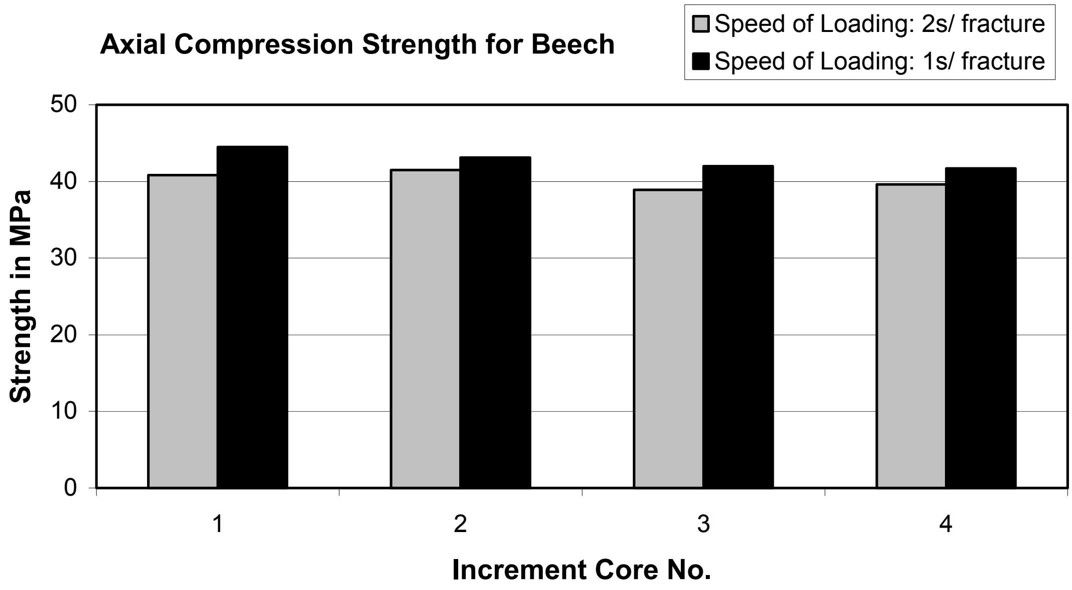


Figure 13: Influence of loading velocity on the axial compressive strength of beech

According to Fig. 13, loading velocity has a small influence on compressive strength only. If the specimen is loaded relatively quickly (about 1 second until rupture), higher strength values are obtained. This average increase amounts to 6.5%. As described in Section 3.2, the wood specimen should be loaded by continuous motion of the levers. Loading velocity should amount to about 2 seconds.

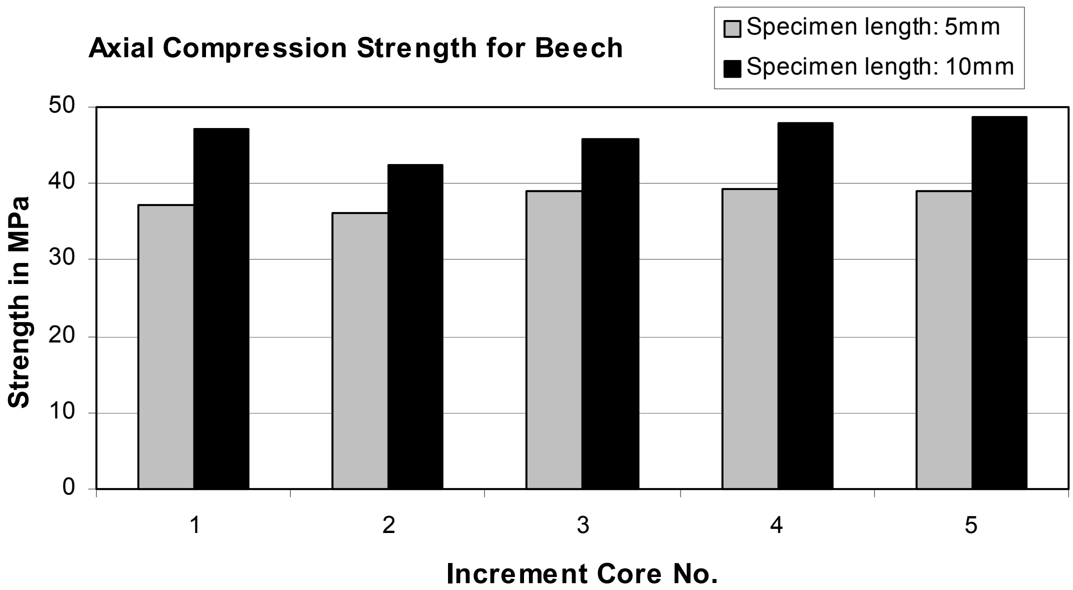


Figure 14: Influence of specimen length on the axial compressive strength of beech

According to Fig. 14, specimen length has a considerable influence on compressive strength. Use of wood specimens of 10 mm length leads to higher compressive strengths than use of 5 mm long wood specimens.

The lateral support effect of the protruding, unloaded wood specimen area on the loaded specimen body leads to an increased compressive strength. Mean increase amounts to 21.7%.

Due to this significant difference between 5 mm and 10 mm long wood specimens, it is urgently recommended to use specimens of 5 mm length only.

5 Compressive and Bending Strengths of Green Trees

Within the framework of a field study, axial compressive strengths ($\sigma_{C,l}$), radial bending strengths ($\sigma_{B,r}$), and tangential bending strengths ($\sigma_{B,t}$) of domestic deciduous and coniferous trees were investigated [7].
Only straight grown, defect-free trees were used for the study. The following types of trees were investigated:

- Douglas fir
- Ash
- Pine
- Birch
- Larch
- Plane
- False Acacia
- Beech
- Spruce
- Poplar
- Willow
- Sycamore
- Oak
- Fir

The increment core was taken from the tree at a height of about 1.3 m. Examination took place directly after having taken the increment core or not more than one hour later in the laboratory. For protecting the increment core from drying out, it was stored in a plastic tubelet until measurement with the Fractometer.

Varying loads of the tree cause differing strengths. Light conditions as well as the water or nutrient supply influence the structure of the wood and, hence, its strength. The figures below illustrate the varying strengths of the individual types of trees (Fig. 15). These measurement results do not have an absolute character. They only represent the strength of a trunk at a height of 1.3 m of randomly selected trees. **Other locations with different wind loads may cause other values to be measured.**

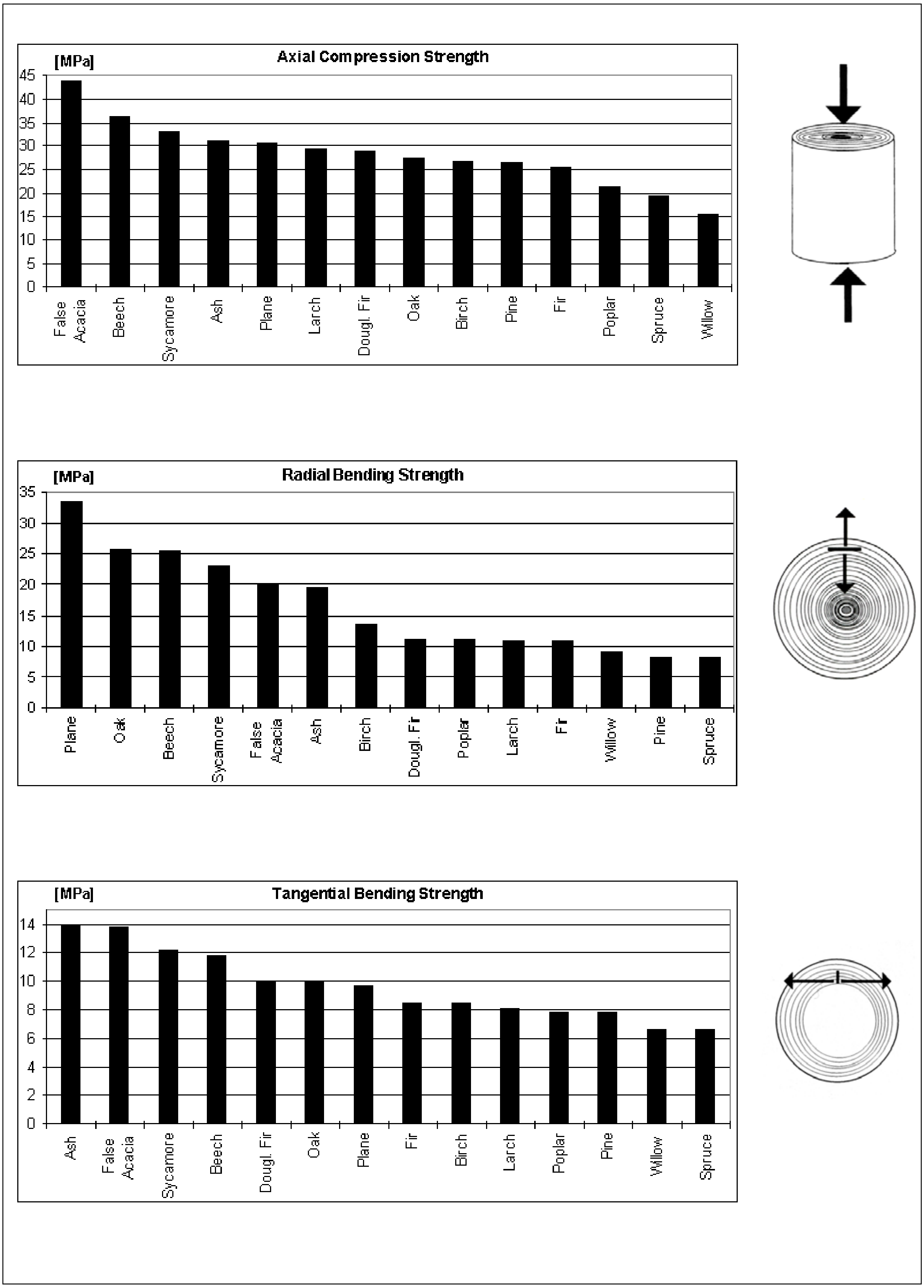


Figure 15: Compressive and bending strengths of green trees

6 Special Features of Compressive Strength Measurements on Dry Increment Cores

When determining axial compressive strength of dry increment cores, the following special features have to be taken into account:

- Lateral support effect of the protruding, unloaded wood specimen area (ears) on the loaded specimen body leads to an increase in compressive strength. Therefore, these protruding ears have to be cut off.

- In the compressive test, the measurement range of the Fractometer II ends at 60 MPa. For this reason, the ears have to be cut off and specimen length has to be reduced to e.g. L = 2.5 mm for extremely hard woods. Then, the real stress value is:

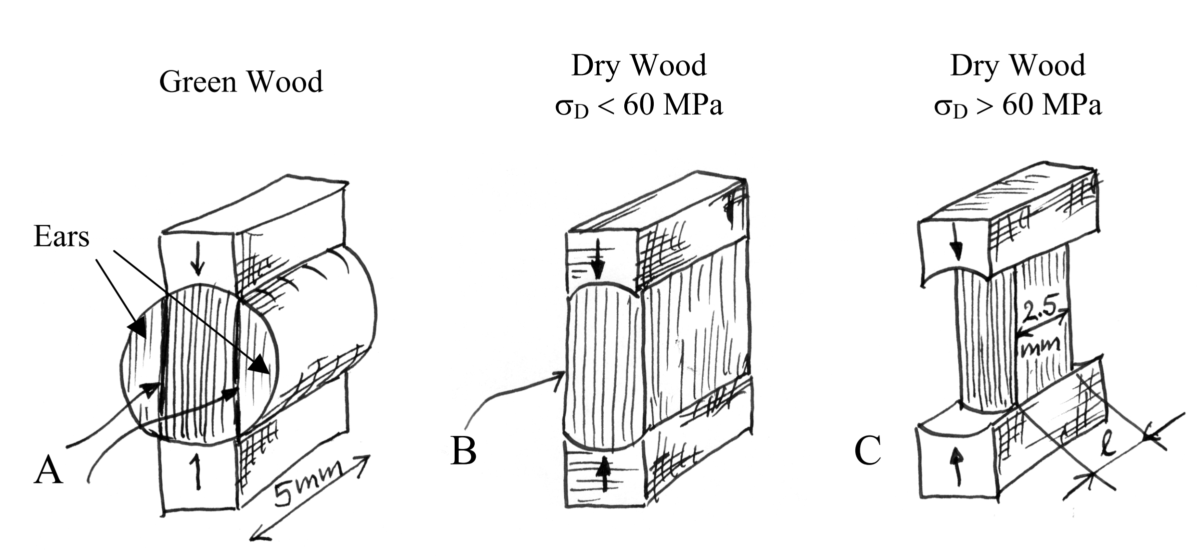
$$\sigma_D(real) = \frac{5\,mm}{L} \bullet \sigma_D(measured) = \frac{5\,mm}{2.5\,mm} \bullet \sigma_D(measured) = 2 \bullet \sigma_D(measured)$$

With a length of L = 2 mm, maximum compressive strengths of

$$\sigma_D^{Max} = \frac{5\text{ mm}}{2\text{ mm}} \bullet 60\text{ MPa} = 150\text{ MPa}$$

can be measured.

Figure 16 below shows the method of determining the compressive strength of green wood (A) and dry wood with an expected compressive strength to be smaller than 60 MPa (B) or larger than 60 MPa (C).



(A) Hardly any lateral support effect by the lateral "ears"

(B) "Ears" cut off due to high lateral support effect

(C) Lateral "ears" cut off and reduction of specimen length

Figure 16: Method of compressive strength determination

7 References

[1] KOLLMANN, F. (1982) *Technologie des Holzes und der Holzwerkstoffe,* Springer Verlag, Berlin

[2] LAVERS, G. M. (1983) *The strength properties of timber*, Building Research Establishment Report, 3rd edition, Her Majesty's Stationery Office, London

[3] MATTHECK, C. (1999) *Stupsi erklärt den Baum*, 3. erweiterte Auflage, Verlag Forschungszentrum Karlsruhe GmbH, Karlsruhe

[4] MATTHECK, C., BURKHARDT, S. (1991) *Der Unglücksbalken - Biomechanik der Holzstrahlen*, Allg. Forst und Jagdzeitung, 8, Seite 143 - 147

[5] MATTHECK, C. (1997) *Design in der Natur - der Baum als Lehrmeister*, 3. Auflage, Rombach Verlag, Freiburg

[6] MATTHECK, C. KÜBLER, H. (1995) *Wood - the internal optimization of trees*, 2. Auflage, Springer Verlag, Berlin

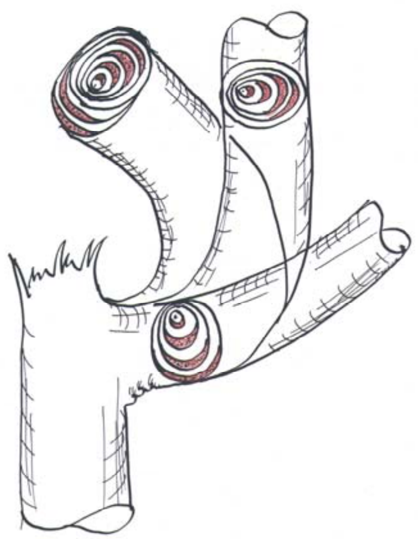
[7] GÖTZ, K. (2000) *Die innere Optimierung der Bäume als Vorbild für technische Faserverbunde - eine lokale Approximation*, Dissertation am Institut für Zuverlässigkeit- und Schadenskunde, Universität Karlsruhe (TH), Bericht FZKA 6552 (Dezember 2000)

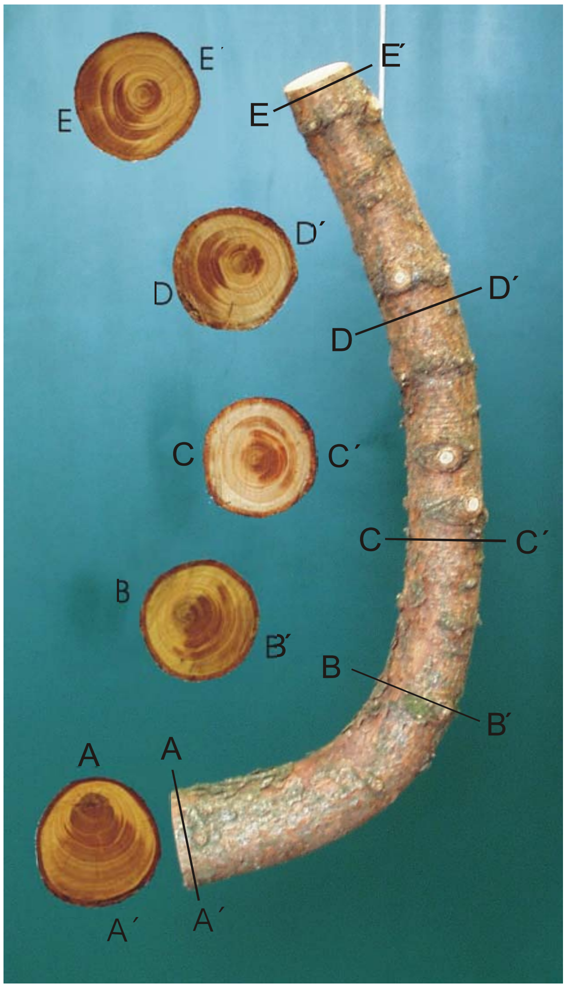
[8] MATTHECK, C. (2002) *Tree mechanics - explained with sensitive words by Pauli the bear,* Verlag Forschungszentrum Karlsruhe GmbH, Karlsruhe, to appear in summer 2002

Annex I:

Alternating Compression Wood and Meander Formation of a Coniferous Tree

After the leading sprout has disappeared, the side branch straightens up and tries to bring its end into a vertical position.

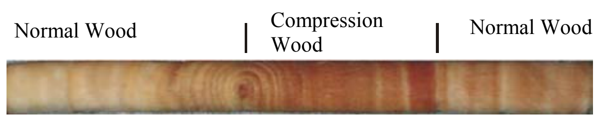


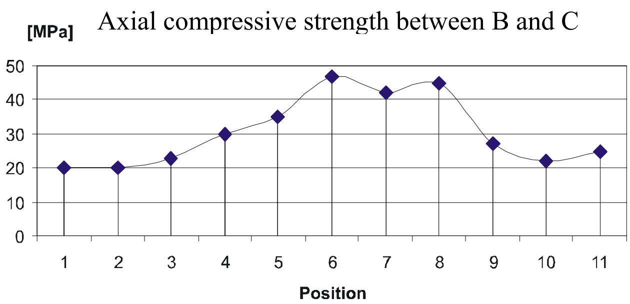


Coniferous trees, as shown here by the example of a spruce, form compression wood on the side facing the ground. This compression wood often has a dark, reddish color (red wood) and can easily be recognized in a saw cut.

In the cases A and B, the compression wood is exclusively found on that side of the trunk, which always remained at the bottom. An overcorrection did not take place. Cut C shows an area at the edge, where no reaction wood was formed, as the branch was in vertical position.

Examples D and E were cut from overcorrected areas which bent back again. The ground-facing side changed after geotropic overcorrection.





Strength measurements of an air-dry increment core taken from the section between positions B and C by means of the **Fractometer II** reveal the relationship between wood anatomy (compression wood or normal wood) and axial compressive strength.

Areas containing red wood exhibit a much higher axial compressive strength than normal wood areas.

Annex II:

Measurement of Compressive Strength of a Dry Larch Disk Using the Fractometer II

The radial increment core was taken from a dry larch, as shown schematically below. This increment core can be divided into three areas:

Area 1: Sapwood
Area 2: Core wood with narrow annual growth rings
Area 3: Core wood with wide annual growth rings

Compressive strength measurement using the Fractometer II clearly shows an increase in axial compressive strength in the core wood region with the narrow annual rings. The high late wood fraction in this area is responsible for this significant increase. The sapwood area and the core wood area with wider annual rings exhibit smaller compressive strengths.

Fractometer II