Forschungszentrum Karlsruhe
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Studies on the Strength of Green Trees Using the Fractometer III

Model Description and User's Manual

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Studies on the Strength of Green Trees Using the Fractometer III

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

Besides conventional determination of the strength with large machines, strength may also be determined by means of the Fractometer III. The Fractometer III has been developed by the "Instrumenta Mechanik Labor GmbH" in cooperation with the Forschungszentrum Karlsruhe. It is applied for measuring the bending, compressive and shear strengths of green wood. In this case, felling of the tree is not required for specimen fabrication.

Festigkeitsuntersuchungen an grünen Bäumen mit dem Fractometer III

Die konventionelle Ermittlung der Festigkeitskenngrößen von kleinen, fehlerfreien Proben erfolgt durchweg an Druckprüfmaschinen. 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 unterschiedlich durchgeführt.

Neben der konventionellen Ermittlung der Festigkeiten mit Großmaschinen bietet der Fractometer III ebenfalls die Möglichkeit der Festigkeitsbestimmung. Der Fractometer III ist ein vom „Instrumenta Mechanik Labor GmbH“ in Zusammenarbeit mit dem Forschungszentrum Karlsruhe entwickelte Meßvorrichtung mit der Biege-, Druck- und Scherfestigkeitskennwerte von grünem Holz ermittelt werden können. Zur Herstellung der Probe muß in diesem Prüfverfahren der zu untersuchende Baum nicht gefällt werden.

Contents

1 Introduction

The three major functions of wood are strength, water transport and nutrient storage. Each tree is exposed to various environmental influences, such as light, water or nutrient supply. Different mechanical loads, e.g. wind, snow or crooked growth, require various resisting forces.

The tree always tries to find a compromise between strength, water transport and nutrient storage. Depending on the tree's position, one of these major functions may either be neglected or promoted. The appearance and strength of each tree is determined by the optimum relationship of the above three major functions.

For scientific wood research, the relationships among the individual strength characteristics have to be derived and the different strength behaviors inside the tree have to be determined.

Due to the complex anatomical, physical and mechanical properties of wood, the international standardization of strength determination is rather difficult. The following test methods are distinguished:

- Testing of components having the dimensions of structural timber and
- studies on small, clear specimens.

Methodology varies in each case [1].

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

Besides conventional determination of the strength with large machines, strength may also be determined by means of the Fractometer III. The Fractometer III has been developed by the "Instrumenta Mechanik Labor GmbH" in cooperation with the Forschungszentrum Karlsruhe. It is applied for measuring the bending, compressive and shear strengths of green wood. In this case, felling of the tree is not required for specimen fabrication.

2 Strengths

Material strength is determined from the stresses occurring during failure. If the stress exceeds the respective 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.

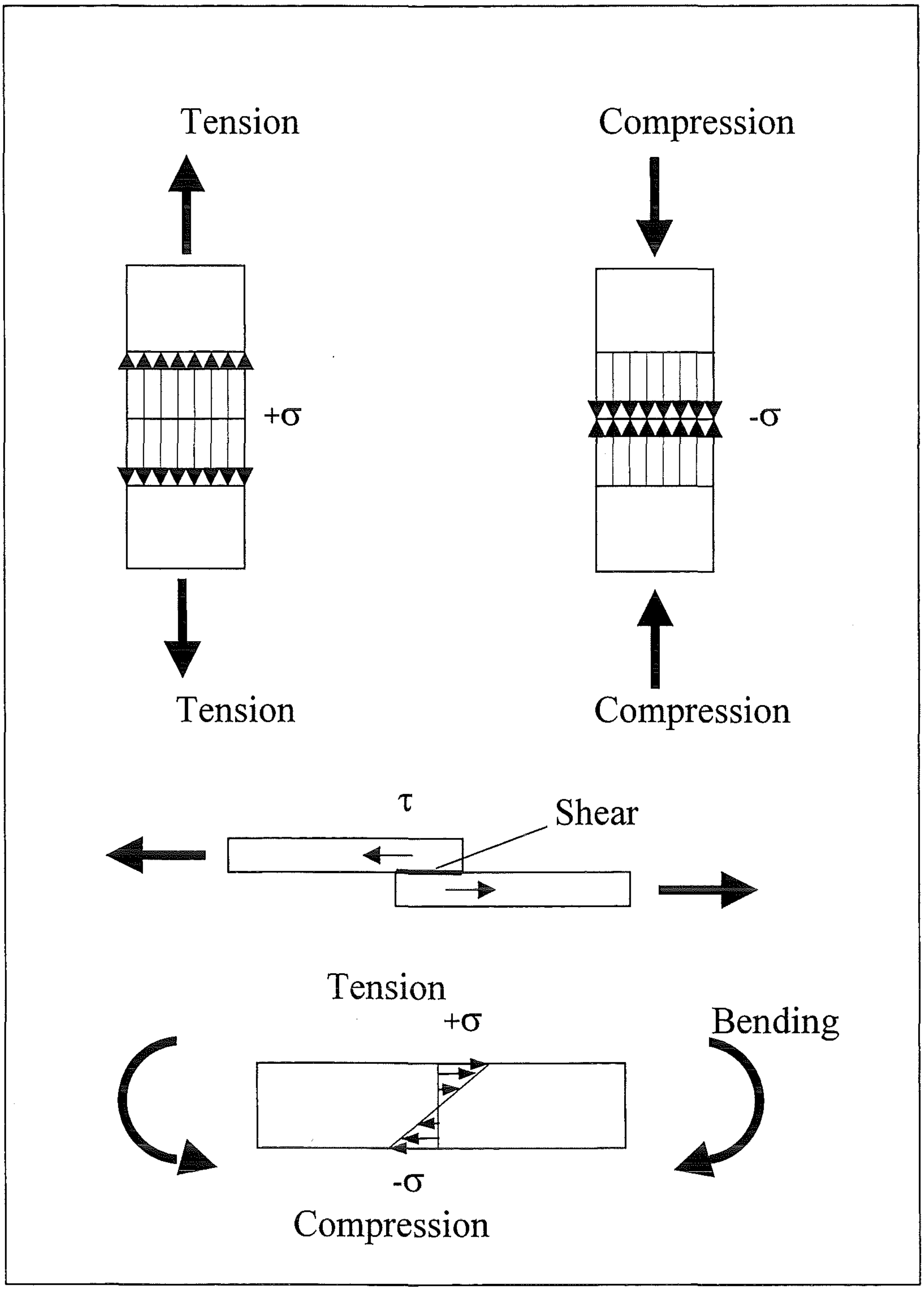
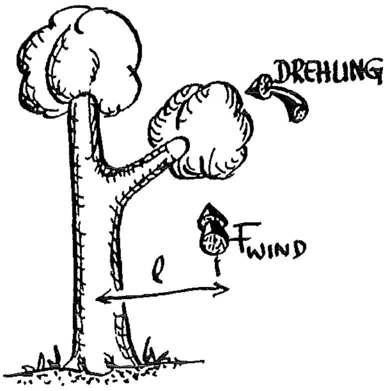


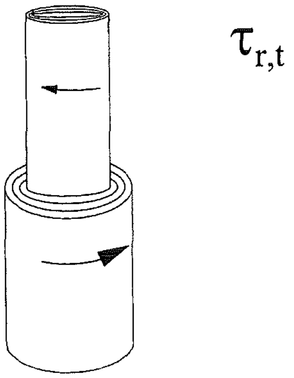
Fig. 1: Simplified classification of internal stresses into tensile, compressive and shear stresses which may be caused by external loads acting on a component.

2.1 Shear Strengths

Wind power may be transferred to the trunk via strong side branches of the tree. The trunk is subjected to torsional load. Tangential shear strength in vertical direction to the fiber $\tau_{r,t}$ is a measure of the resistance of the trunk against this torsion.

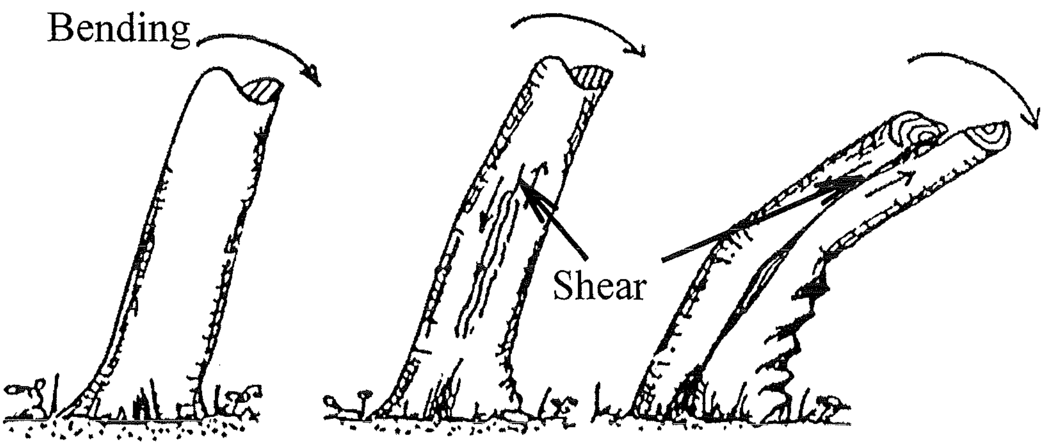


Loads acting on the tree.

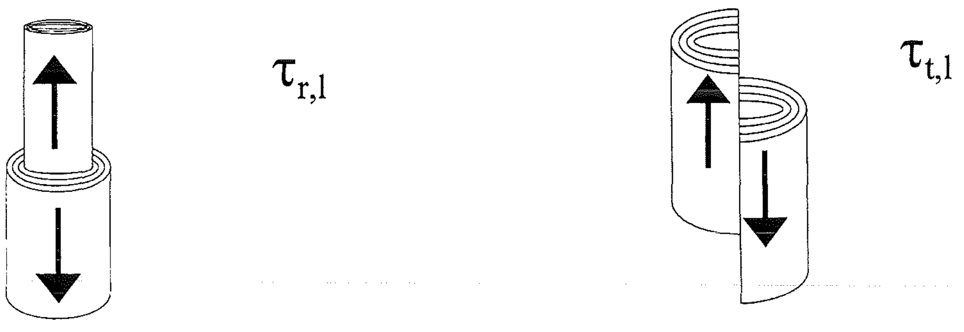


Schematic representation of the shear plane and load direction in the stem.

In addition, the wind power causes a bending load to act on the trunk via the treetop. This bending load gives rise to compressive, tensile and shear stresses in the trunk. The radial shear strength in fiber direction $\tau_{t,l}$ and the tangential shear strength in fiber direction $\tau_{r,l}$ describe the resistance of the trunk against failure due to shear stresses.



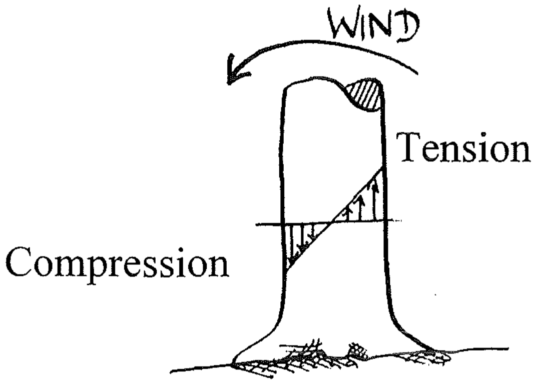
Loads acting on the tree.



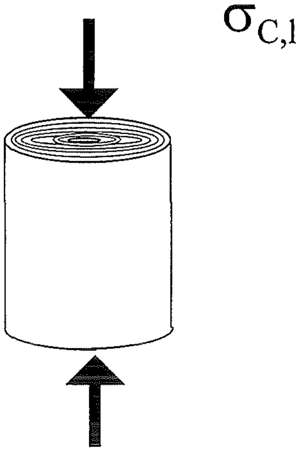
Schematic representation of the shear planes and load directions in the stem.

2.2 Compressive Strengths

By the bending of the stem, the latter is exposed to compressive stress in axial direction. The axial compressive strength $\sigma_{C,l}$ represents the resistance of the tree against failure due to axial compressive load.



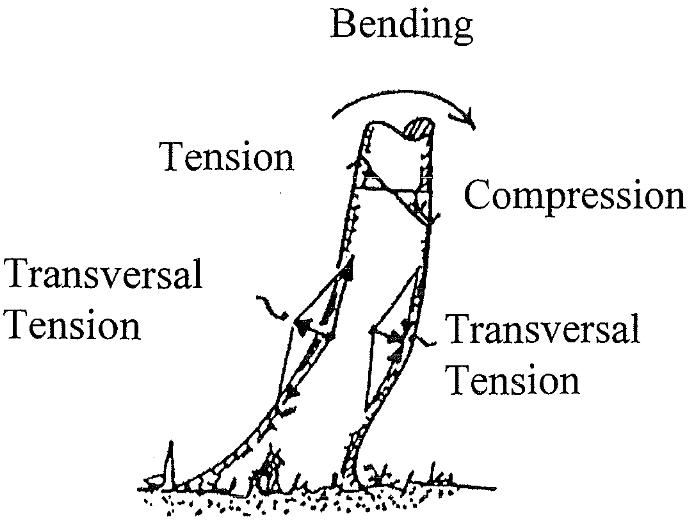
Loads acting on the tree.



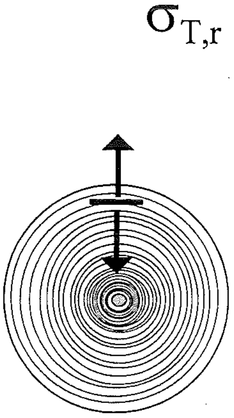
Schematic representation of the load direction in the stem.

2.3 Transversal Tensile Strengths

The bending of the stem causes a tensile stress and compression stress to act on the stem in axial direction. In this case, tangential or radial tensile stresses are generated in the root buttresses as well as in crooked stems. The radial tensile strength $\sigma_{T,r}$ denotes the resistance of the stem against failure due to transversal tensile stress. This strength counteracts the formation of hazard beams.

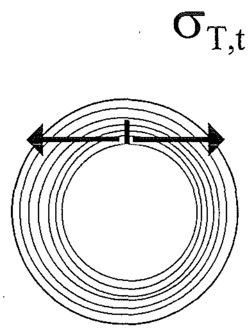


Loads acting on the tree.

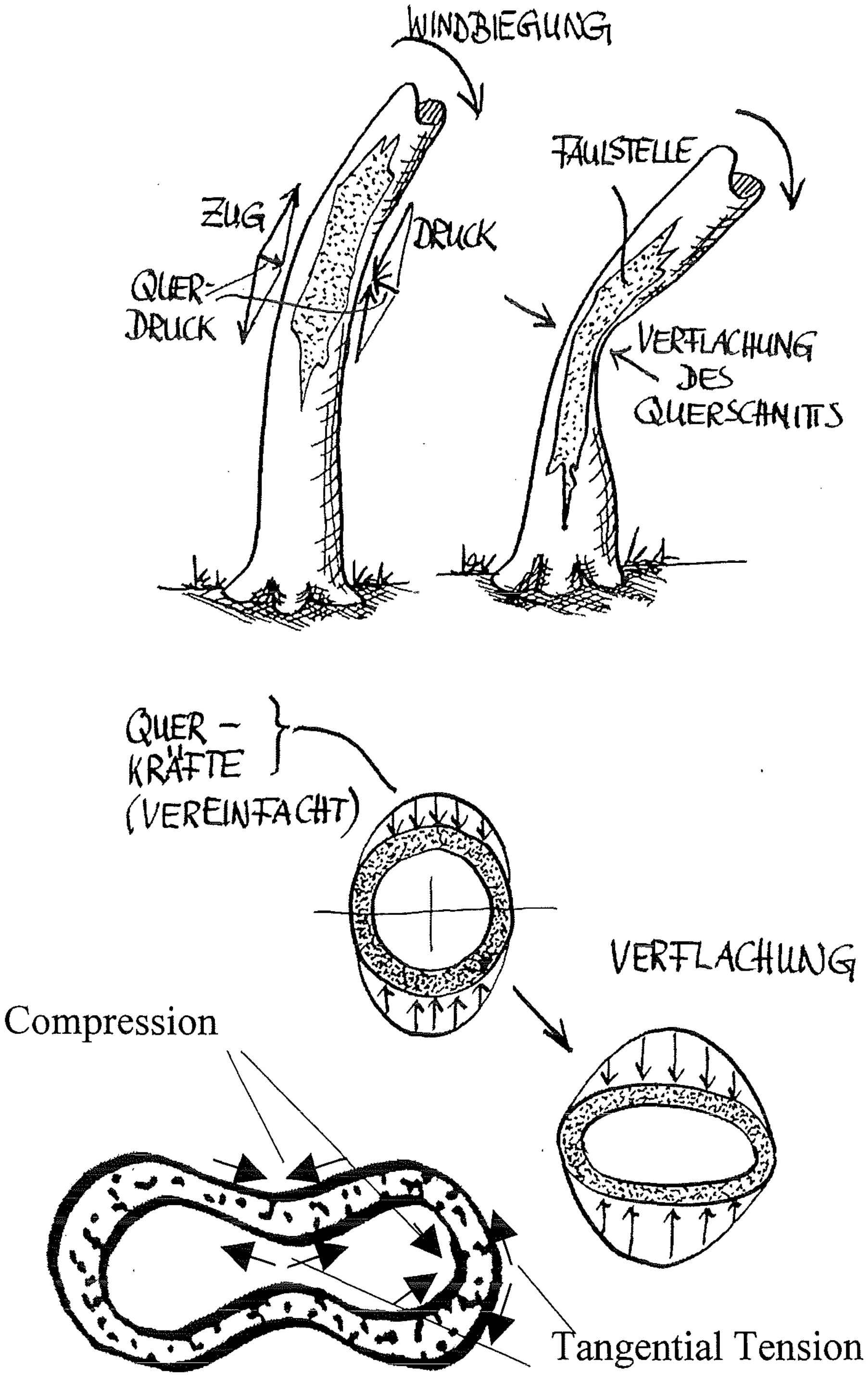


Schematic representation of the load direction in the stem.

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



Schematic representation of the load direction in the stem.



Loads acting on the tree.

3 The Fractometer III

The Fractometer III is a measuring device for the determination of the bending, compressive and shear strengths of green wood. For this purpose, an increment core of 5 mm in diameter is applied. The increment core is withdrawn from the tree in radial or tangential direction by means of an increment borer (Fig. 2).

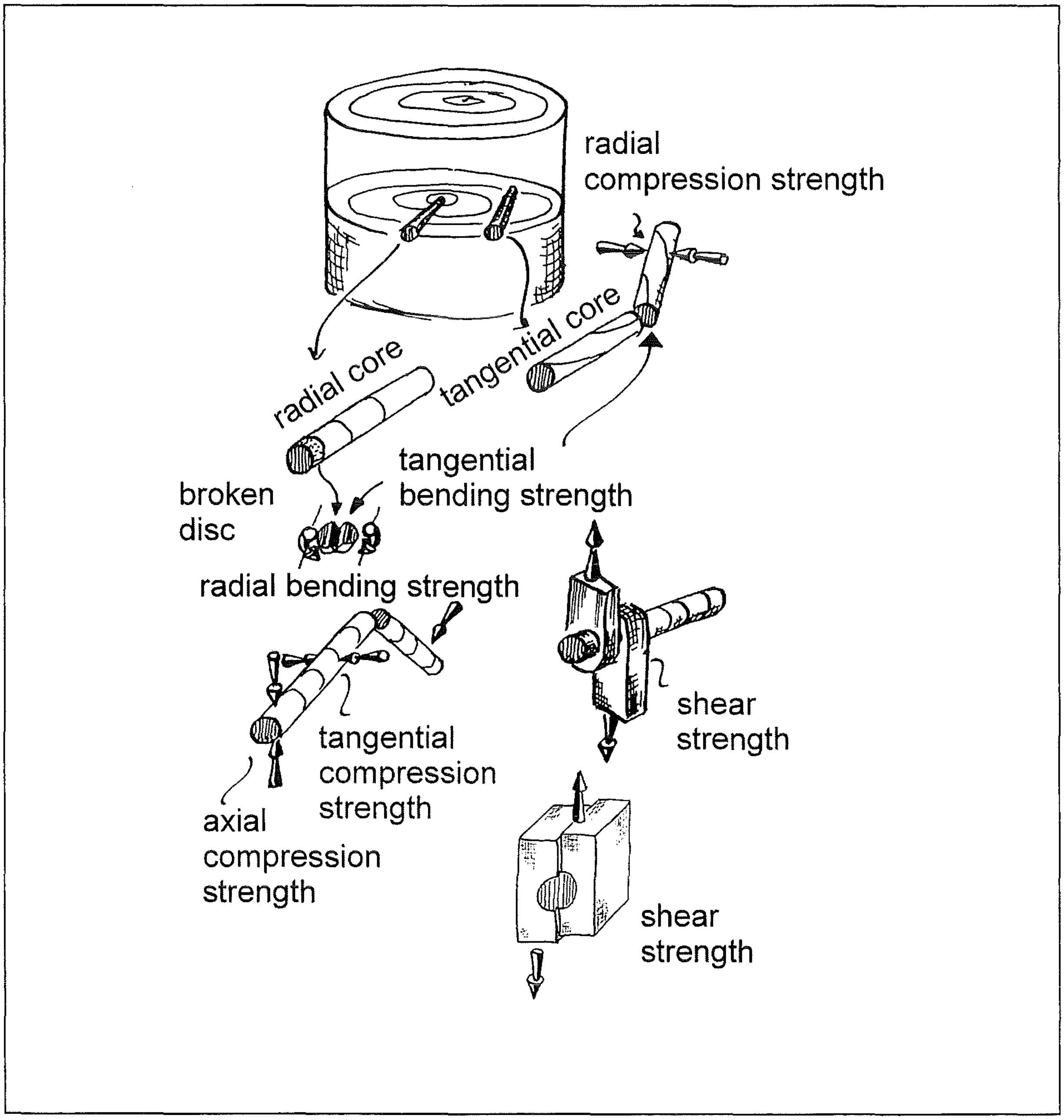


Fig. 2: Strength characteristics that can be determined from a radial or tangential increment core [2].

3.1 Setup of the Fractometer III

The Fractometer III consists of the following five major components (Fig. 3):

- (a) handwheel for force introduction;
- (b) load meter;
- (c) adjustable lever arm;
- (d) specimen fixing unit;
- (e) displacement transducer.

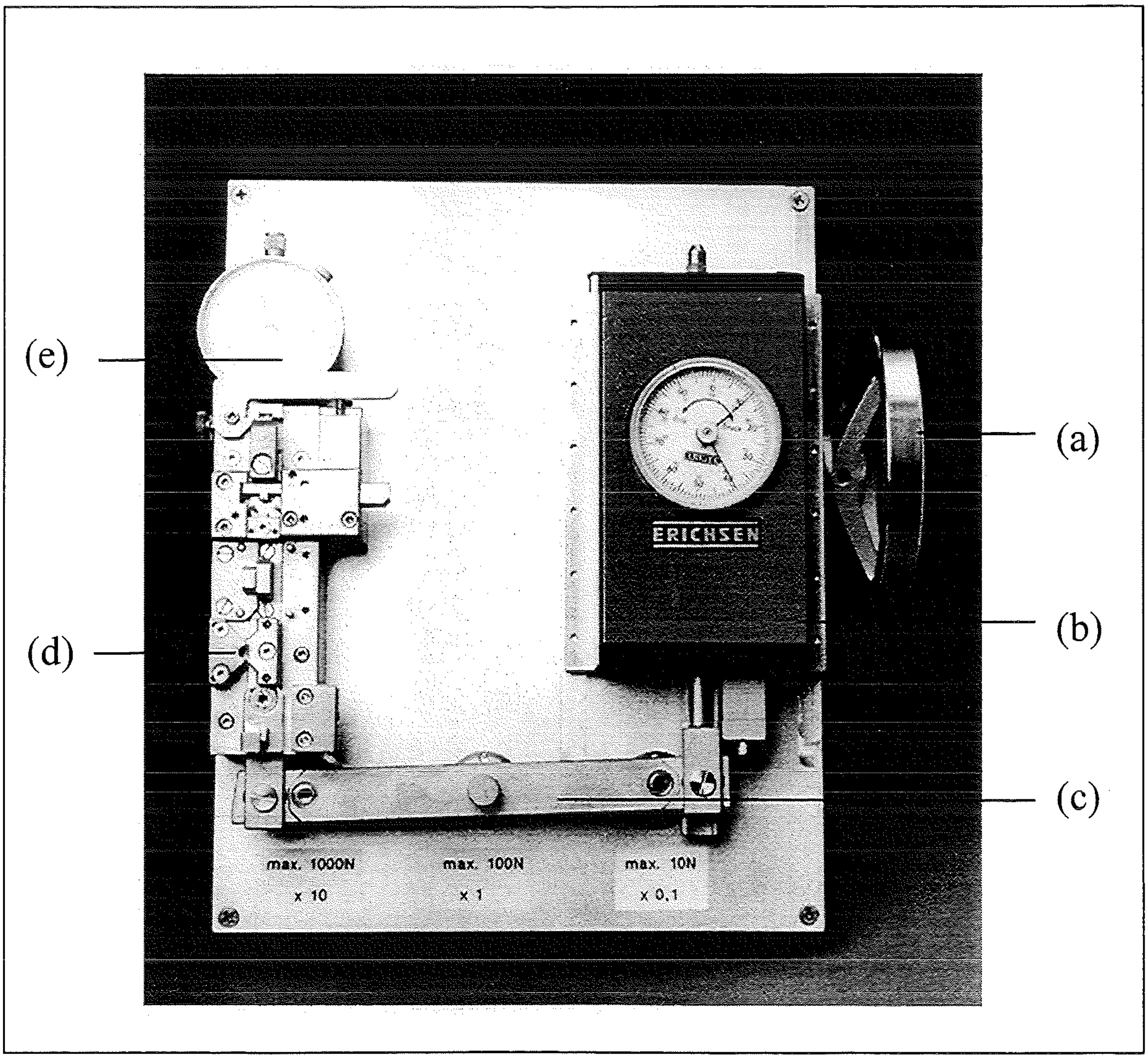


Fig. 3: The Fractometer III with its five components.

The specimen fixing unit (Fig. 4) also consists of five components. The following strength characteristics can be determined:

- (1) radial bending strength;
- (2) radial shear strength;
- (3) tangential shear strength;
- (4) axial compression strength;
- (5) tangential bending strength.

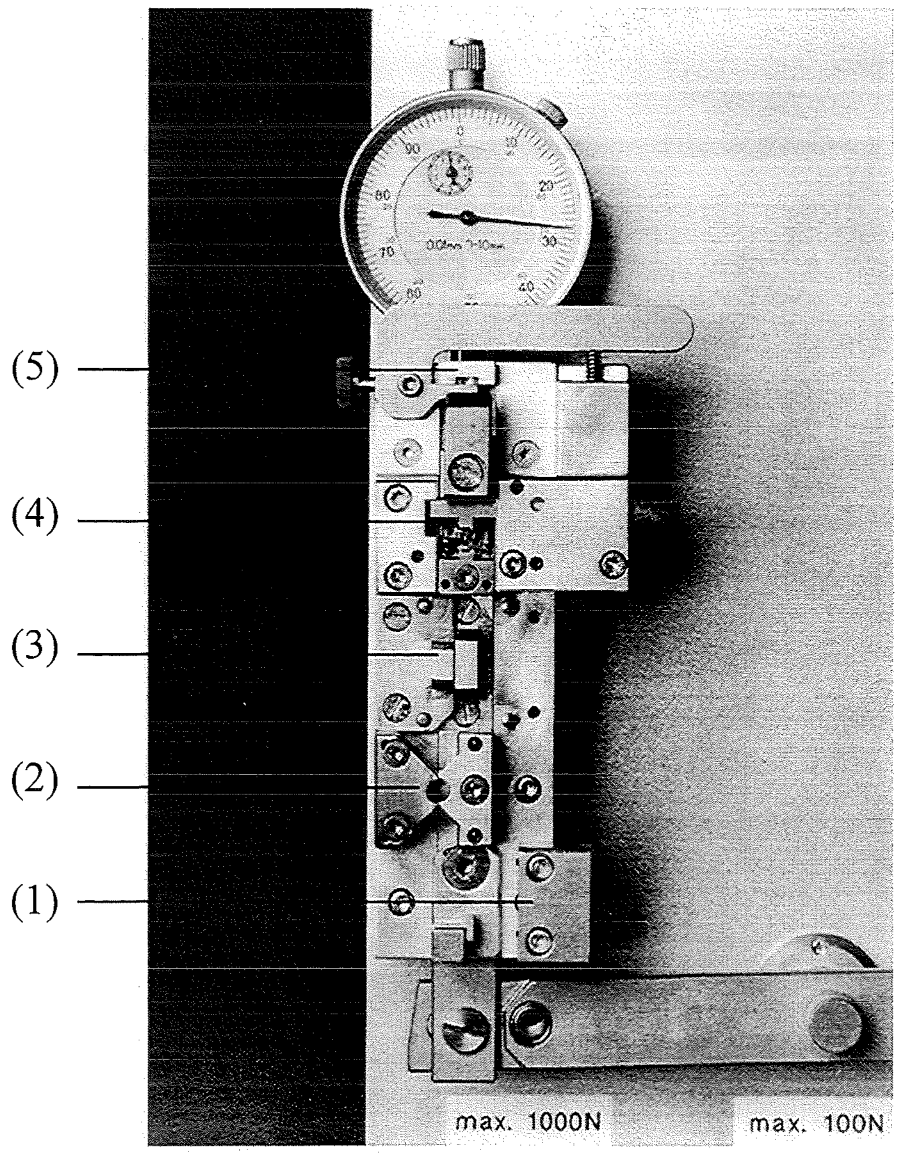


Fig. 4: The fixing unit of the Fractometer III.

3.2 Functioning Principle of the Fractometer III

For the determination of a strength parameter, a specimen or specimen segment is inserted into the respective fixing unit and oriented in accordance with the fiber direction. By slow, continuous turning of the handwheel, a force is transferred to the fixing unit and, hence, to the specimen via the adjustable lever arm. The force is increased until failure of the specimen. The maximum force applied until failure of the specimen is measured. This force is indicated by the maximum pointer of the load meter. From the leverage ratio and the geometry of the Fractometer, the strengths occurring can be calculated. The distance covered until failure of the specimen is measured by means of the displacement transducer.

3.2.1 Fractometer III Measurements with Radial Cores

Radial bending strength is determined in the component no. 1 of the fixing unit (Fig. 4). Due to the following measurements planned, the increment core is broken into 35 mm long specimen pieces and the maximum force until failure is determined (Fig. 5). In case of radial bending rupture, the specimen first fails on the tension side. Therefore, the radial bending strength can be used as a measure of radial tensile strength.

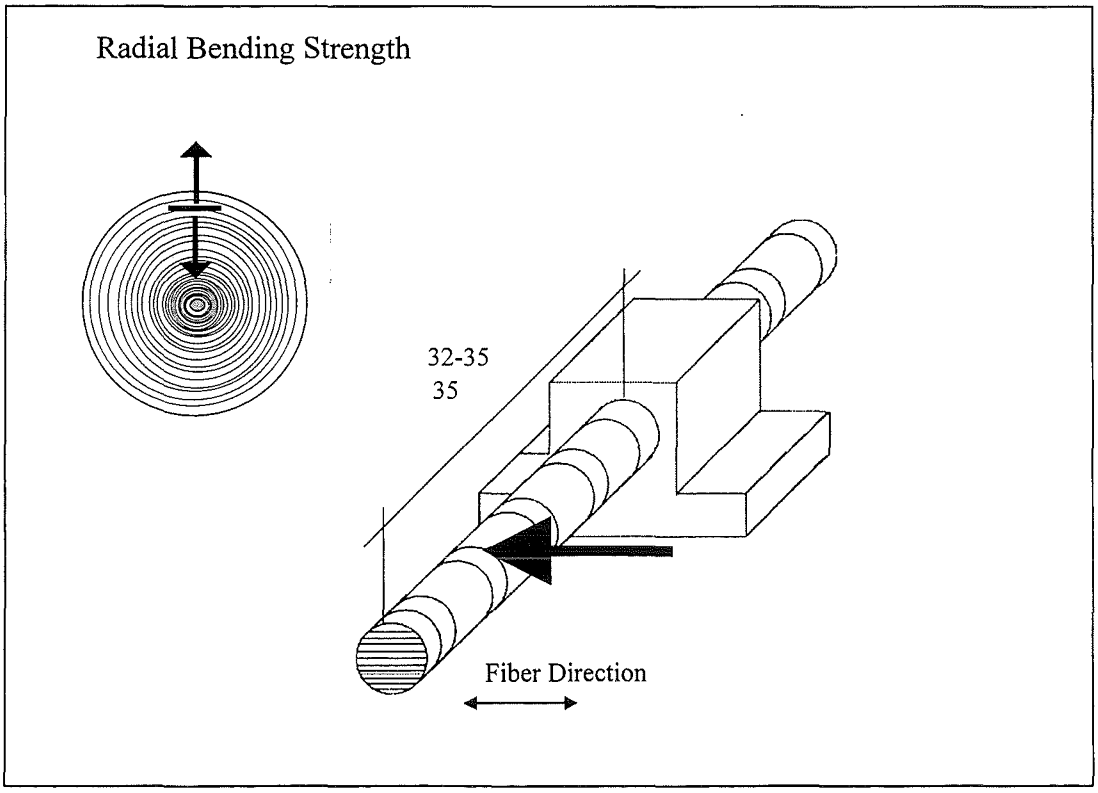


Fig. 5: Schematic representation of the loading and orientation of the specimen to be investigated when determining radial bending strength.

After this, a disk of 1 - 2 mm in thickness is cut from each specimen piece obtained by means of a razor blade. This is done to remove the wood fibers and beams that had been delaminated during the bending strength test. Then, the specimen piece of 32 mm in length is cut into three segments of 5 mm length each and a segment of 2 mm and 15 mm length, respectively (Fig. 6).

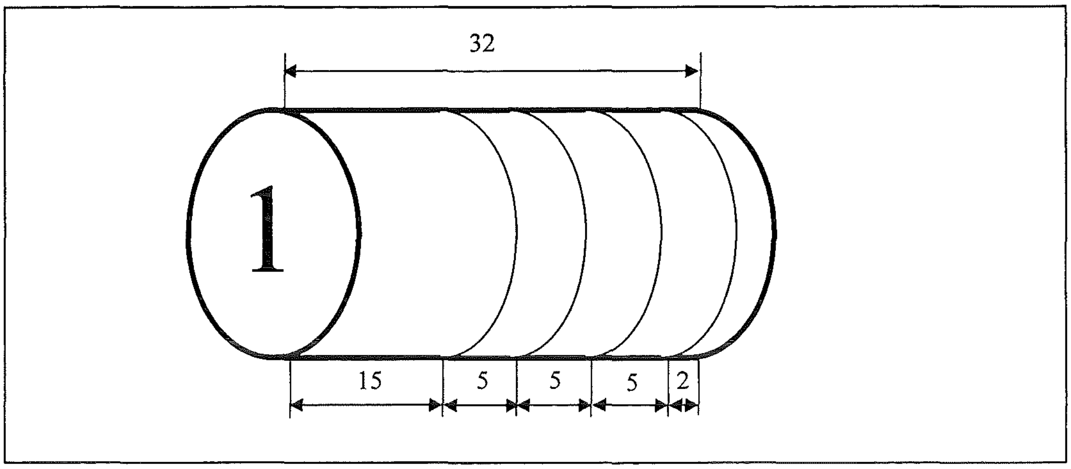


Fig. 6: Cutting of specimen no. 1 into five segments for subsequent measurements.

Tangential shear strength in the fiber direction and vertical to it is determined by means of component no. 3 of the fixing unit (Fig. 4). Here, a piece of 5 mm is sheared off from the 15 mm long specimen segment. When determining the tangential shear strength in fiber direction, the specimen is loaded until shear in parallel direction to the fiber and the maximum shearing load is determined (Fig. 7). After this, the segment sheared off from the specimen is removed. For determination of the tangential shear strength in vertical direction to the fiber, the remaining specimen is turned by 90° until the wood fibers are directed vertically to the load direction. Again, the specimen is loaded until failure (Fig. 8).

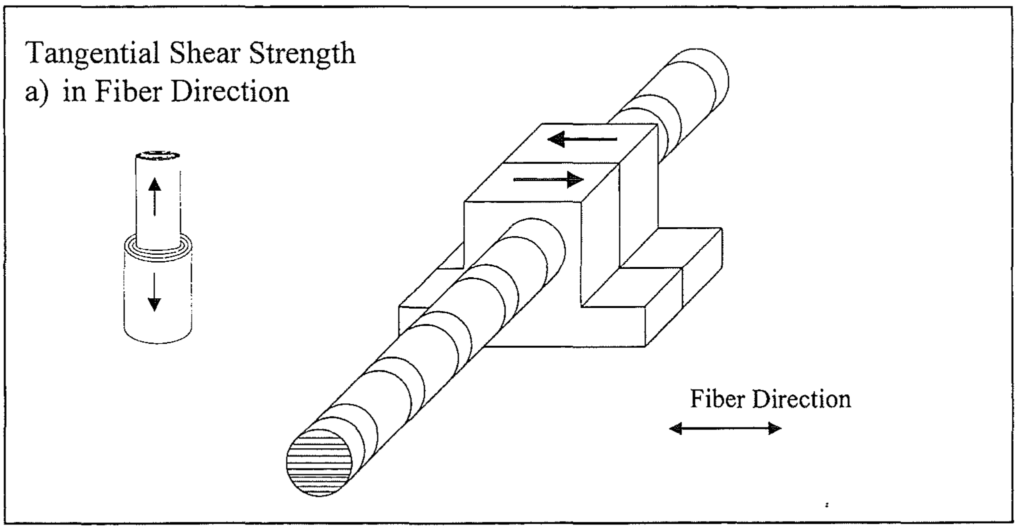


Fig. 7: Schematic representation of the loading and orientation of the specimen to be investigated when determining tangential shear strength in the fiber direction.

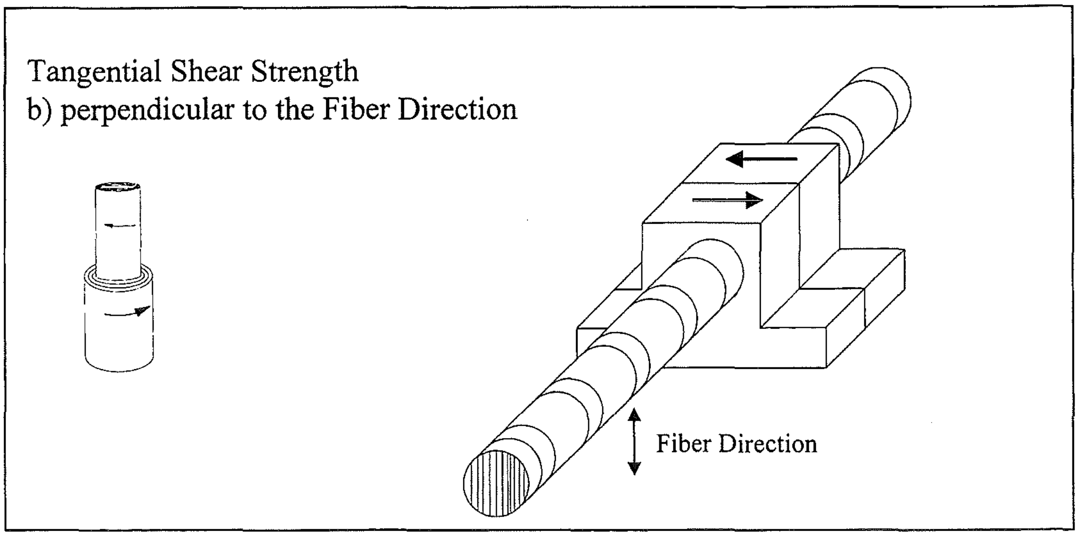


Fig. 8: Schematic representation of the loading and orientation of the specimen to be investigated when determining tangential shear strength in vertical direction to the fiber.

The radial shear strength in fiber direction is determined by component no. 2 of the fixing unit (Fig. 4). In this case, one of the three 5 mm long specimen segments is applied. The specimen segment is subjected to loading until failure in parallel direction to the fiber and the maximum shearing load is determined (Fig. 9).

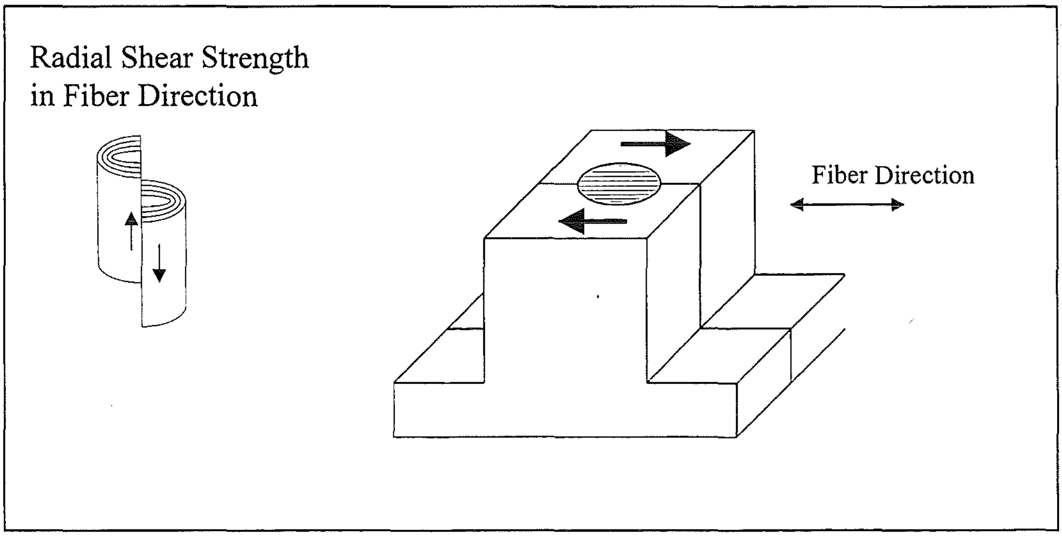


Fig. 9: Schematic representation of the loading and orientation of the specimen segment to be investigated when determining radial shear strength in fiber direction.

Axial compressive strength is determined by component no. 4 of the fixing unit (Fig. 4). Again, one of the three 5 mm long specimen segments is applied. The specimen segment is subjected to loading until failure in parallel direction to the fiber and maximum compressive load is determined (Fig. 10).

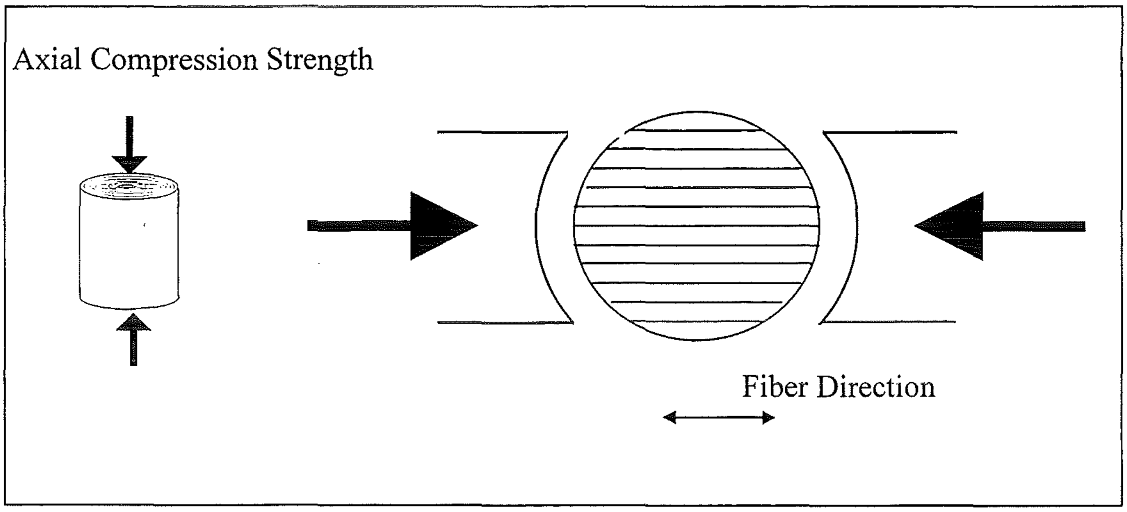


Fig. 10: Schematic representation of the loading and orientation of the specimen segment to be investigated when determining axial compressive strength.

Tangential bending strength is determined by component no. 5 of the fixing unit (Fig. 4). The 2 mm long segment serves as the specimen. The specimen segment is subjected to loading until failure in vertical direction to the fiber and the maximum load until failure is determined (Fig. 11). In case of tangential bending rupture, the specimen first fails on the tension side. Therefore, tangential bending strength can be applied as measure of tangential tensile strength.

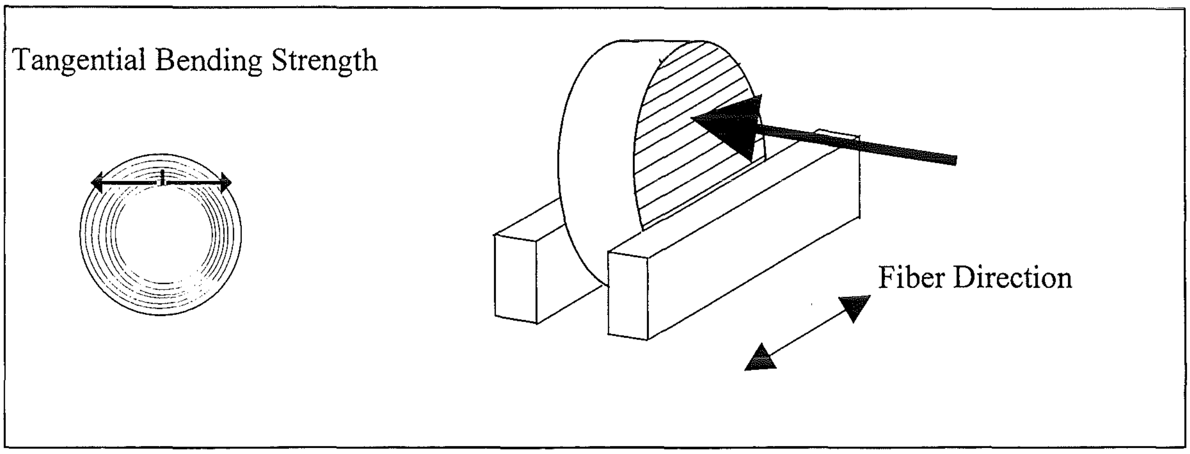


Fig. 11: Schematic representation of the loading and orientation of the specimen segment to be investigated when determining tangential bending strength.

3.2.2 Fractometer III Measurements with Tangential Cores

Tangential bending strength is determined by component no. 1 of the fixing unit (Fig. 4). Here, the increment core is subjected to radial loading and the maximum load until failure is determined (Fig. 12). As compared to radial increment cores, the possibilities of determining the tangential bending strength with tangential cores are rather limited.

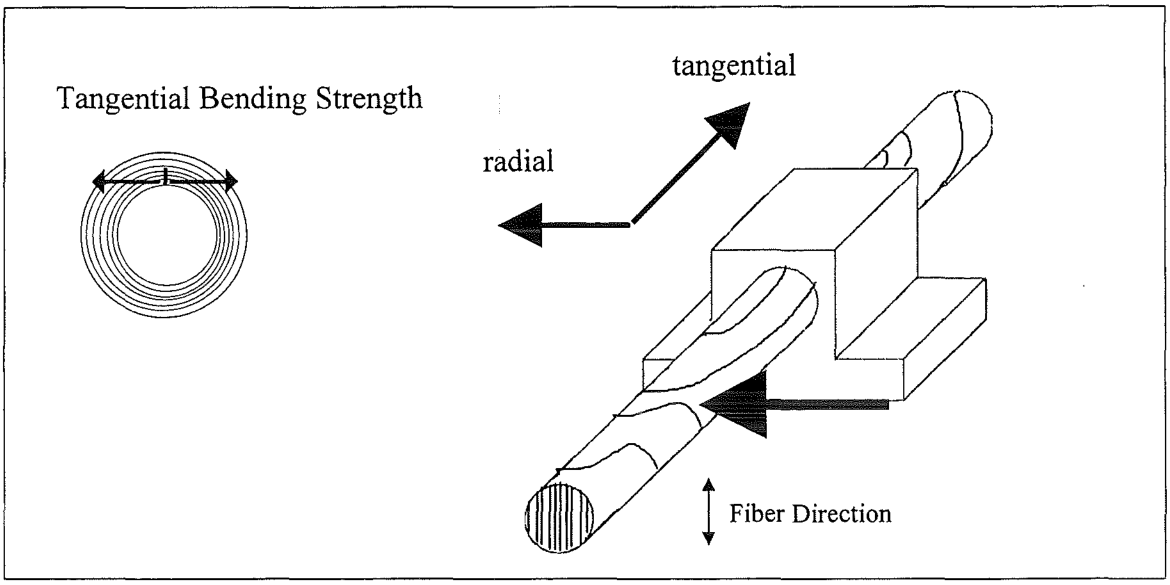


Fig. 12: Schematic representation of the loading and orientation of the core to be investigated when determining tangential bending strength.

3.3 Conversion Factors for the Fractometer III

After having determined various rupture forces, they have to be converted into the respective strengths. The different fulcrums of the lever arm and the geometrical dimensions of both the specimen to be investigated and the Fractometer III are of crucial importance. The linear load cell with the analog display is designed for the range of 10 N to 100 N. Depending on the parameter to be determined and the wood quality, the leverage ratios have to be changed:

Left position of the fulcrum: The force indicated by the load meter is transferred at a ratio of 1:10, i.e.:

$$F_{\text{actual}} = F_{\text{load meter}} \cdot \text{x } 10$$

Central position of the fulcrum: The force indicated by the load meter is transferred at a ratio of 1:1, i.e.:

$$F_{\text{actual}} = F_{\text{load meter}}$$

Right position of the fulcrum: The force indicated by the load meter is transferred at a ratio of 10:1, i.e.:

$$F_{\text{actual}} = F_{\text{load meter}} \cdot \text{x } 0.1$$

The factor for converting the rupture force F_{actual} into the resulting strength has to be determined for each of the five components of the measuring system.

Component no. 1:
Radial bending strength $\sigma_{B,r}$ of the radial core and tangential bending strength $\sigma_{B,t}$ of the tangential core:

$$\sigma_{B,r} = \sigma_{B,t} = \frac{M}{W} = \frac{F \cdot l}{\pi \cdot d^3 / 32} = 0{,}85 \cdot F \qquad \text{in MPa}$$

where

F = the load indicated by the load meter
M = momentum
W = section modulus of the circular cylinder
l = distance between force introduction and fixing unit (10.5 mm)
d = core diameter (5 mm)

Component no. 2:
Tangential shear strength in fiber direction and vertical to the fiber direction ($\tau_{r,l}$, $\tau_{r,t}$):

$$\tau_{r,t} = \tau_{r,l} = \frac{F}{A} = \frac{F}{\pi \cdot r^2} = \frac{F}{19{,}6} \qquad \text{in MPa}$$

where

F = load indicated by the load meter
r = core radius (2.5 mm)

Component no. 3:
Radial shear strength in fiber direction ($\tau_{t,l}$):

$$\tau_{t,l} = \frac{F}{A} = \frac{F}{b \cdot h} = \frac{F}{24} \qquad \text{in MPa}$$

where

F = load indicated by the load meter
b = width of the shear plane (5 mm)
h = height of the shear plane (4.8 mm)

Component no. 4:
Axial compressive strength ($\sigma_{C,l}$) of the radial core:

$$\sigma_{C,l} = \frac{F}{A} = \frac{F}{b \cdot h} = \frac{F}{15{,}6} \qquad \text{in MPa}$$

where

F = load indicated by the load meter
b = width of the pressure piston (3.075 mm)
h = height of the pressure piston (5.075 mm)

Component no. 5:
Tangential bending strength $\sigma_{B,t}$ of the radial increment core (disk specimens):

$$\sigma_{B,t} = \frac{M}{W} = \frac{F \cdot l}{b \cdot h^2 / 6} = 0{,}57 \cdot F \qquad \text{in MPa}$$

where

F = load indicated by the load meter
l = distance between force introduction and fixing unit (1.9 mm)
b = width of the disk (5.0 mm)
h = height of the disk (2.0 mm);
Note: The height of the disk is entered into the above equation as a square. A height of h = 1.9 mm yields: $\sigma_{B,t} = 0.63 \cdot F$

4 Literature

[1] Kollmann F.:
Technologie des Holzes und der Holzwerkstoffe
Springer-Verlag, 1982

[2] Mattheck C.:
Wood - The Internal Optimization of Trees
Springer Verlag, Heidelberg, 2nd edition, 1997