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(78)

Solid mechanics for ash wood

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Wood is an anisotropic material and, further, because of its natural origin the mechanical properties might significantly differ also between each of the samples tested. Ordinary methods for evaluation of solid mechanic properties often destroy the tested specimens. It is therefore not common practice to evaluate more than one property, e.g. Young's modulus for tension, at the same time using the same sample. Different tests also have different recommendations of how the test specimens should be designed in order to test the property of interest. When calculations are to be made by e.g. the Finite Element Method values for a number of properties must be included and when the resulting construction is examined after this, it is not easy to decide if discrepancies depend on unreliable input data. This paper therefore describes tension, compression and bending tests for one specific detail, namely a wood beam of ash wood. The applied forces are well under those where rupture occurs and hence the material is assumed to be intact during all testing procedures.

Festkörpermechanik des Eschenholzes

Holz ist nicht nur ein anisotropes Material, sondern jeder Prüfkörper kann aufgrund des natürlichen Ursprungs deutlich verschieden sein von anderen Proben. Normalerweise wird bei den Methoden zur Bestimmung mechanischer Eigenschaften die Probe zerstört. Daher ist es nicht üblich, gleichzeitig mehr als eine Eigenschaft, etwa den Young Modulus unter Zugbelastung, an einer einzigen Probe zu bestimmen. Verschiedene Testmethoden erfordern zudem unterschiedliche Abmessungen der Prüfkörper je nach der Eigenschaft, die geprüft werden soll. Wenn Berechnungen durchgeführt werden sollen, z.B. nach der FE-Methode, muß eine Reihe von Eigenschaftswerten in die Berechnung eingeführt werden. Wenn die entsprechende Konstruktion danach getestet wird, ist es nicht einfach zu erkennen, ob etwaige Unstimmigkeiten von unzulänglichen Eingabewerten herrühren. Diese Studie beschreibt daher Zug-, Druck, und Biegeprüfungen an einer spezifischen Probe, einem Balken aus Eschenholz. Die verwendeten Kräfte bleiben deutlich unter der Bruchgrenze, so daß das Material auch nach der Prüfung noch als intakt anzusehen ist.

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1 Introduction

Solid mechanics for wood is very difficult. This is caused by the natural origin of the material where the properties depend on the direction of the applied forces. Traditionally, three directions are studied, viz. longitudinal, radial and tangential, see Kollmann and Côté (1984), p. 293. When wooden structures are to be designed, properties for all those different directions must be considered. However, different samples might also differ very much because of growth conditions etc. For building purposes this has been solved by setting very low allowable stresses for the wooden parts. Pieces of furniture, such as chairs, are not the subject for hazardous consequences if the construction breaks. Hence, higher allowable stresses could be used. In our earlier research we have made calculations by use of the so called Finite Element Method (FEM) for chairs. When the calculations are to be elaborated certain input data must be used, e.g. the Young's modulus. For many construction materials this modulus is assumed to be the same for both tension and compression but for wood this might not always be the case. The breaking strength in tension is about twice the strength during compression. When a beam is bent, e.g. during a three point bending experiment, the compressed side is assumed to break under a lower stress than the tensioned one. The so called neutral axis will therefore move and classic theory can no longer be used. The problem is partly dealt with in Kollmann and Côté (1984), p. 361. Input data in our FEM calculations have been both values found in the literature and those found by own experiments with traditional testing equipment. The FEM calculations lead to internal forces in the structure and we have tried to validate these forces by strain gauge meters applied on the beam members in a chair. These experiments showed that large discrepancies sometimes occurred between calculated and monitored values, see Fig. 1.

For gauge no. 4, the discrepancies were relatively small while gauge no. 3 showed a much larger difference between monitored and calculated values. The question is now if these differences depend on the calculation process or if the material parameters are so unreliable that calculations must be used only for approximate purposes.

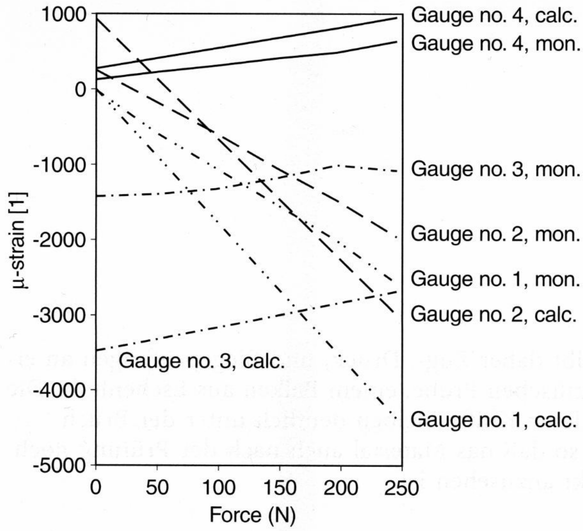

Fig. 1. Monitored and calculated strain for different parts in a chair (Gustafsson 1997)
Bild 1. Beobachtete und berechnete Verformungsspannung für verschiedene Teile eines Stuhls (Gustafsson 1997)

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Case study

The problem with traditional testing of solid mechanical properties for wood is that there are large variations for different trees, different origin from within the same tree, different moisture contents, density and so on. Because of this many specimens of the same type must be examined and the average value after this is assumed to reflect the conditions when e.g. FEM calculations are elaborated. It can therefore not be ascertained whether or not the tested structure is built of wood with the same properties as shown by these average values. The situation is shown in Figs. 2 and 3 which show some compression tests for ash wood, *Fraxinus excelsior*.

In Figs. 2 and 3 ten different tests are presented. The computerised monitoring system has calculated the Young's moduli within the range of 10.1 to 17.9 GPa with an average of 13.3 GPa. The maximum compression

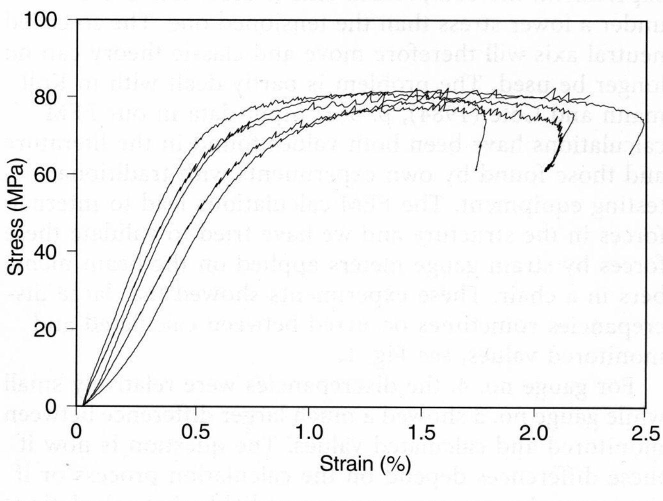

Fig. 2. Compression tests for ash wood (*Fraxinus excelsior*)
Bild 2. Druckprüfung an Eschenholz

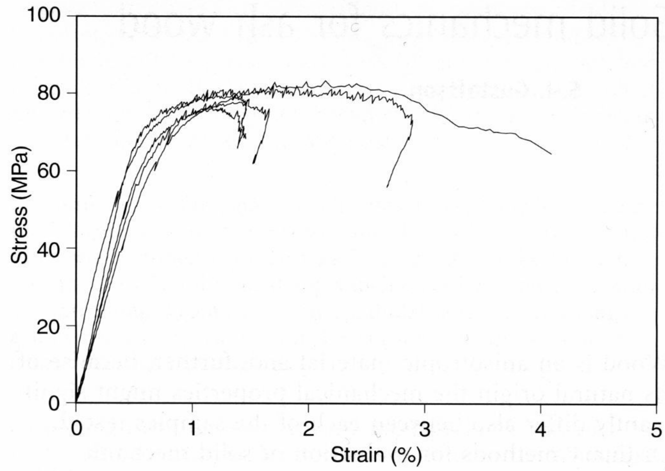

Fig. 3. Compression tests for ash wood (*Fraxinus excelsior*)
Bild 3. Druckprüfung an Eschenholz

strength varied between 76.7 to 83.4 MPa with an average of 80.5 MPa. The moisture content varied between 4.99 up to 6.95% with an average of 6.25%. In Tsuomis (1991), page 164, the strength is said to be only 51 MPa but then for air dry conditions which equals about 12 or 15% (Tsuomis 1991, p. 111). Compression strength for oven dry ash wood is shown in Kollmann and Côté (1984), p. 343, and the values vary from about 50 to 130 Mpa, depending on the specific gravity. There are no values for the Young's modulus for ash under compression in Tsuomis (1991) but in Kollmann and Côté (1984), p. 295, a value of about 16 GPa is shown, but then it is not mentioned if compression or tension is used, only that the load was applied in the longitudinal direction. The above discussion shows that there is a difficulty in choosing the right calculation data for a structure.

Therefore, in order to study the situation for more constant conditions, we have manufactured a beam of ash wood with a length of 1 m and a cross sectional area of 0.04 × 0.04 m. Strain gauge meters have been applied on two sides with a distance of 0.2 m. The beam has after this been loaded with different weights both under tension and compression and, further, examined under bending. We have tried to use the most simple equipment for the tests in order to exclude all measuring errors. The load has been well under the level where rupture should occur and hence the internal microstructure of the ash wood material should not have been affected during the experiments. The result for tension is shown in Table 1.

The result in Table 1 is very discouraging. Even if a weight of 25 kg was lifted by the beam, some of the strain gauge meters showed that compression actually occurred. Meters no. 1 and 8 are located at the same level but on opposite sides of the beam and about 0.16 m from the hinge, see Fig. 4. For the next pair, no. 2 and 7, the first one showed tension and the other compression which is also valid for the pair no. 3 and 6. The meters applied about 0.16 m from the other hinge, both showed tension but not exactly the same values, see no. 4 and 5. When a high load, see the values for 170.62 kg, was applied, almost all of the meters showed tension but differences are large between the metering devices. Meter no. 8 showed compression during the whole experiment and almost always to the same amount while meter no. 1 showed increasing values. This shows that only one side of the beam takes up part of the work and further that a moment probably was introduced. The beam was therefore slightly bent during the experiment. The moment, however, declines for the lowest strain gauge meters i.e. no 4. and 5, and they show almost identical values, at least for the higher loads. In Fig. 5 values for two opposite meters have been added and then divided by 2 in order to achieve an average. The magnitudes are not equal but the slopes for the curves do not differ very much. By applying a straight line through the four curves in Fig. 5, Young's modulus for tension has been calculated to 13,100 MPa.

The result for compression is shown in Table 2. During this experiment the load has been balanced on the ash rod while keeping it in a vertical position. The data show, however, that tension occurred, see the positive values, no matter what the applied load. In Fig. 6 average values are

Table 1. Strain in μ-strain for varying weight in kg. Tension
Tabelle 1. Verformungsspannung unter verschiedenen Zug-Belastungen in kg

Strain gauge no.	Weight (kg)						
	26.57	51.75	76.89	102.06	127.17	145.51	170.62
1	−9	19	45	73	100	118	142
2	18	37	53	73	91	105	122
3	10	17	27	38	48	55	67
4	14	17	23	30	34	39	44
5	6	4	7	20	26	34	46
6	−15	−5	9	16	28	33	44
7	−12	−6	−5	9	16	18	23
8	−11	−13	−17	−15	−19	−16	−19

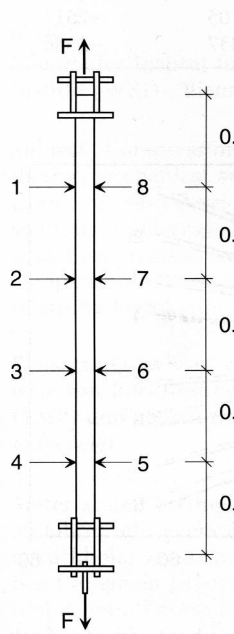

Fig. 4. Experiment set-up for tension of the ash wood rod
Bild 4. Versuchsanordnung für die Zugprüfung an einem Eschenstab

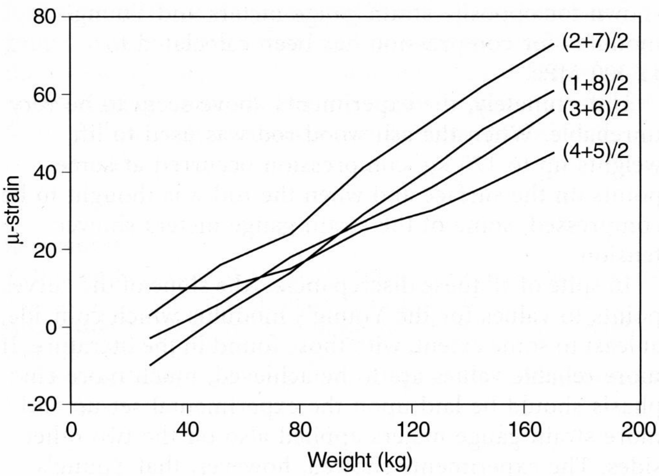

Fig. 5. Average values for opposite strain gauge meters during tension
Bild 5. Mittelwerte gegenüberliegender Dehnungsaufnehmer während der Zugbelastung

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Table 2. Strain in μ-strain for varying weight in kg. Compression
Tabelle 2. Verformungsspannung unter verschiedenen Druck-Belastungen in kg

Strain gauge no.	Weight (kg)						
	26.57	51.75	76.89	102.06	127.17	145.51	170.62
1	−13	−44	−75	−122	−117	−118	−110
2	−2	−13	−30	−89	−54	−45	−44
3	−4	−22	4	−25	19	28	26
4	2	−19	16	−50	49	54	22
5	−8	−18	−57	−28	−117	−136	−150
6	−17	−30	−50	−1	−77	−103	−133
7	−15	−21	−39	6	−51	−90	−107
8	−8	0	−8	17	−3	−37	−50

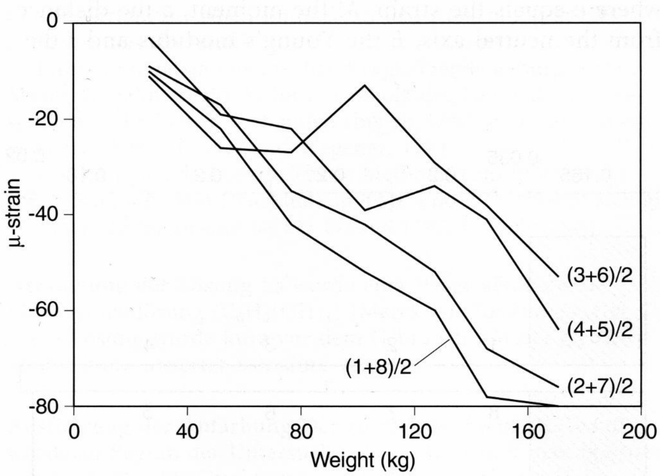

Fig. 6. Average values for opposite strain gauge meters during compression
Bild 6. Mittelwerte gegenüberliegender Dehnungsaufnehmer während der Druckbelastung

shown for opposite strain gauge meters and Young's modulus for compression has been calculated to 12,300 MPa.

Unfortunately, the experiments above seem to be very unreliable. When the ash wood rod was used to lift weights up to 170 kg, compression occurred at some points on the surface and when the rod was thought to be compressed, some of the strain gauge meters showed tension.

In spite of all these discrepancies, the slope of the curves points to values for the Young's modulus which coincide, at least to some extent, with those found in the literature. If more reliable values are to be achieved, much more emphasis should be laid upon the experimental set-up and more strain gauge meters applied also on the two other sides. The experiments showed, however, that Young's modulus for compression is somewhat lower than that for tension. The question is now, if this could be detected when the rod is bent. The most simple bending experiment we could think of was the one of a loaded console beam firmly connected to a table, see Fig. 7.

The strain for meter no. 1 and 8, however, became so large that only three weights from our set could be tested, see Table 1.

For this experiment, the strain gauge meters showed values that were more in coincidence with theory. On the upper side the rod was tensed while it was compressed on the lower side. The strain also increased for longer distances to the load. The fact is that all the meters, except for no. 2 and 7 showed that the strain was larger on the upper side than the corresponding values on the bottom. This must lead to the assumption that the Young's modulus for compression is larger than the tension ditto. This contradicts the result found for pure tension and compression where the opposite was valid. It is also interesting to examine how the strain in Table 3 corresponds to the theoretical values calculated by use of the Young's moduli found above. The moment is calculated as F multiplied by the distance, while the strain is calculated as:

$$\varepsilon = M \cdot z/(E \cdot I)$$

where ε equals the strain, M the moment, z the distance from the neutral axis, E the Young's modulus and I the moment of inertia. The resulting strain values for E equal to 13,000 MPa are shown in Table 4.

Comparing Tables 3 and 4, it is obvious that the rod had higher strain than expected only for gauge no. 1 while all other meters showed the opposite behavior. All monitored values seem, however, to follow straight lines, see Fig. 8.

Table 3. Strain in μ-strain for varying weight in kg. Bending
Tabelle 3. Verformungsspannung unter verschiedenen Biege-Belastungen in kg

Strain gauge no.	Weight (kg) 26.57	51.75	61.75
1	1466	2960	3510
2	1020	1999	2385
3	608	1217	1437
4	289	570	680
5	−275	−541	−647
6	−573	−1104	−1329
7	−1028	−2008	−2413
8	−1323	−2610	−3134

Table 4. Calculated strain in μ-strain for varying weight in kg. Bending
Tabelle 4. Berechnete Verformungsspannung unter verschiedenen Biege-Belastungen in kg

Strain gauge no.	Weight (kg) 26.57	51.75	61.75
1	1457	2837	3386
2	1081	2105	2512
3	705	1373	1638
4	329	641	765
5	−329	−641	−765
6	−705	−1373	−1638
7	−1081	−2105	−2512
8	−1457	−2837	−3386

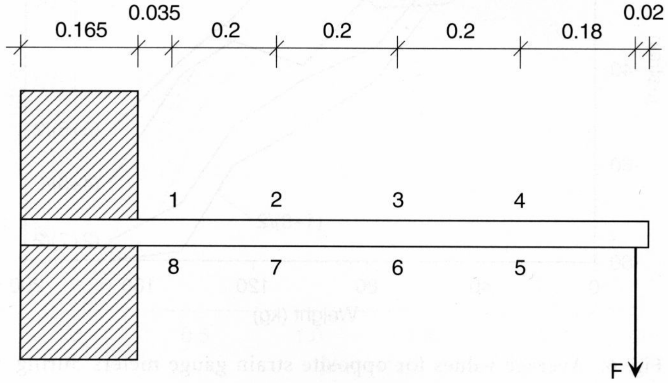

Fig. 7. Bending experiment with a firmly fixed console
Bild 7. Biegeprüfung an einer fest eingespannten Konsole

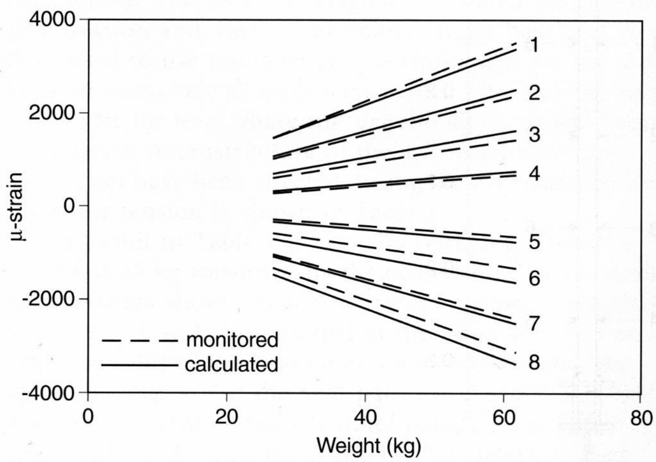

Fig. 8. Monitored and calculated values for a bent console of ash wood
Bild 8. Beobachtete und berechnete Verformungsspannung für eine gebogene Konsole

3
Conclusions

A rod of ash wood has been used for tension, compression and bending experiments. The measurements of Young's modulus showed slightly higher values for pure tension than for pure compression, 13,100 compared to 12,300 MPa. It seems however, very difficult to predict the precise strain on specific spots on the rod if classic theory is used. The differences between eight strain gauge meter values were large. This might depend on a poor experiment design but also on an inhomogeneous microstructure of the ash wood. The two moduli showed that the rod should show a higher strain on the compressed side when it was bent but the measurements contradict this behaviour. For three of the comparable four points the strain gauge meters showed that the opposite occurred. When the rod was bent, the meters showed a linear behavior for an increasing moment, but the strain values did not perfectly follow classic theory when their magnitude was considered.

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Zum mikroskopischen Nachweis von Reaktionsholz (Druckholz) in thermo-mechanischem (TMP) und chemo-thermo-mechanischem Holzstoff (CTMP) der Fichte

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Subject Compression wood can be qualitatively identified in thermo-mechanical and chemo-thermo-mechanical pulps by the colour reaction developed by Wiesner (1878) using an ethanolic solution of phloroglucinol ($C_6H_3(OH)_3$) acidified by hydrochloric acid. Compression wood cells appear dark red coloured in comparison to spring and summer wood cells. This is due to the relatively high lignin content in compression wood.

Zielsetzung Es wird eine Methode zum mikroskopischen Nachweis von Reaktionsholz (Druckholz) in thermo-mechanischem (TMP) und chemo-thermo-mechanischem Holzstoff (CTMP) aufgezeigt

Material und Methode Fichtendurchforstungsholz (Alter ca. 50 Jahre) mit einem teilweise relativ hohen Reaktionsholzanteil (Druckholz) wurde zu Hackschnitzeln zerkleinert und anschließend in einem Laborrefiner unter thermo-mechanischen (TMP) und chemo-thermo-mechanischen Bedingungen (CTMP) aufgeschlossen und zerfasert (Aufschlußtemperatur 140–180 °C, Aufschlußdauer 5–11 min). Die TMP und CTMP wurden im Trockenschrank bei 70 °C bis zu einer Feuchte von ca. 5% getrocknet.

Es zeigte sich, daß die bei niedrigen Aufschlußtemperaturen hergestellten TMP und CTMP einen relativ hohen Splittergehalt gegenüber den bei hohen Aufschlußtemperaturen hergestellten TMP und CTMP aufwiesen. Dies hängt einerseits mit dem Einfluß der Aufschlußbedingungen des TMP- bzw. CTMP-Verfahrens auf den Aufschlußgrad des Holzstoffs zusammen. Darüber hinaus haben vermutlich die ligninreichen Druckholzzellen in Abhängigkeit von den Aufschlußbedingungen des TMP- und CTMP-Verfahrens einen Einfluß auf den Aufschlußgrad des entstehenden Holzstoffs.

Literaturangaben entsprechend (vgl. Trendelenburg und Mayer-Wegelin, 1955) ist im Druckholz des Fichtenholzes wesentlich mehr Lignin vorhanden (bis zu 37%) als in normalem Holz (ca. 28%) (Fengel und Wegener, 1984).

Die im folgenden beschriebene Methode zum mikroskopischen Nachweis von Druckholz in TMP und CTMP lehnt sich an Wiesner (1878) an und ist bei Freund (1970) beschrieben.

Herstellung der Lösung Es wurde eine 1%ige alkoholische Phloroglucinlösung ($C_6H_3(OH)_3$) (Merck Nr. 7069) angesetzt. Diese Lösung wurde kurz vor dem Gebrauch mit der gleichen Menge konzentrierter Salzsäure versetzt.

Ausführung der Anfärbung Der zu untersuchende Holzstoff wurde zu Beginn der Untersuchung von Grobstoff bzw. Splittern gereinigt. Anschließend wurde eine kleine Probe des Holzstoffs sorgfältig auf einen Objektträger gebracht und mit einem Deckgläschen abgedeckt. Das Deckgläschen wurde von 3 Seiten mit Paraffin eingegossen, anschließend wurden 1–2 Tropfen der Farblösung zum Faserstoff gegeben. Nachdem alle Luftein-