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THE STRENGTH PROPERTIES OF SWEDISH OAK AND BEECH

Because of their economic impact most research on wood in Sweden is aimed at our needle-leaved species, i.e. pine and spruce. Sawmills and other industrial enterprises using these conifers are also in vast majority, both in number of employees and number of companies. However, there is a viable industrial branch in Sweden, i.e. furniture companies, dealing with broad-leaved species such as oak, birch, and alder. Such industries often import all the wood they use, even if the same type of wood grows in the vicinity. In order to make the Swedish broad-leaved trees more interesting to the wood manufacturing sector, we examined the strength properties of some common Swedish woods, viz. oak and beech. The result shows that our oak specimens had a modulus of elasticity of 12.243 MPa measured by using four-point bending. So-called the Young's modulus was 11.761 MPa for tension and 15.610 MPa for compression in the fibre direction, i.e. there was a very high difference. The stress just before rupture was measured to 85 MPa for tension and 76 MPa for compression, i.e. there was a surprisingly small difference. For beech, our corresponding values were 13.017 MPa for four-point bending, the Young's modulus during tension was 13.954 MPa and 130.4 MPa in maximum stress, whilst under compression these values were 13.101 MPa and 84 MPa, respectively.

Keywords: wood, testing, oak, beech, MOE, MOR, the Young's modulus

Introduction

Sweden is a long and narrow country. The northern part reaches far beyond the polar circle, whilst the southern-most peak is located some 15 latitude degrees below on the Earth surface. Our country is therefore spanning several growth regions. Most of the country is covered by forests with needle-leaved species, especially pine and spruce. The utilisation of these trees in the form of timber and paper is of significant importance for the standard of living in Sweden.

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Broad-leaved species, such as birches, alder and oaks more seldom create forests by their own, but such trees are scattered within the conifer wood lands instead. Sawmills for such hardwoods are hard to find, and if you find them they are usually old fashioned and have only a very small-scaled business, even if there are one or two exceptions. Many of these companies are likely to die and disappear when the now ageing owners and workers retire. In order to reduce this risk, much more emphasis must be put on the fact that Sweden has interesting resources of broad-leaved species, and also that timber from these trees can be interesting alternatives to conifers in a number of different applications. As a designer of wooden constructions you must be aware of physical properties of wood. For conifer constructions there are building codes, rules and regulations showing the designer the values of allowed strain and stress that are accepted for different building parts, but there is lack of such recommendations for gymnosperms, or hardwoods. This is unfortunate, because many of the broad-leaved types are much stronger than the needle-leaved ditto. This can be found for example in [Gustafsson 2001] where some species were examined. Another example can be found in a report on birch, alder and aspen which was published not long ago [Enquist, Petersson 2000].

You also have to use the values from the experiments and reference [Gustafsson 1997] shows some Finite Element Method (FEM), calculations for one of the strongest hard-woods available in Sweden viz. ash (*Fraxinus excelcior*). Fortunately, it seems there is a growing interest in FEM and due to this the examining of such hardwoods has emerged. A number of studies dealing with FEM analysis, see e.g. [Smardzewski 1998; Miskara, Sain 2007; Ollson et al. 2004], have been published during recent years. New FEM programs are developed all the time, but in spite of the rapid growth of computer programs for solving even very complex structures, see e.g. [Kasal et al. 2006] for a 3-d study with wood composites, it must be stressed that there still is a need for thorough testing under reality-like conditions. There are some studies dealing with this, for example [Erdil et al. 2004; Ratnasingam et al. 1997]. However, testing under such conditions is a time-consuming and expensive activity, and that is why FEM still has a role to play when designing furniture. Such calculations also makes it important to study the solid mechanics of the material itself.

Testing solid mechanical properties

Wood is a very special material due to its anisotropic and heterogeneous structure. If you apply forces in the same direction as the fibre orientation, i.e. acting so that the wood is tensed along the fibres, wood is surprisingly strong. If the forces are applied in the opposite direction, and hence wood is compressed, only half of the strength is found, according to the literature. Even lower values are found if you apply the forces perpendicular to the fibre direction. Bending strength, for example, as it is a form of mixture between tension and compression, will therefore probably be located between these corresponding values. In Kollmann, Côté [1984], page 292, a graph of this behaviour is shown. A suitable way to start our tests is therefore to see how much stress our specimens can endure at tension.

Tension and compression tests

In Sweden, as we are a part of Scandinavia, certain testing regulations for wood apply, see Kucera [1992]. Other countries have other ways for testing wood and this goes especially for the recommended design of the test specimens. See e.g. Kollmann, Côté [1984], page 324, and Hoadley [2000], page 84 and 85, for different types of design. In order to identify mechanical properties we must use machinery where we can apply known forces on our specimens and also monitor how much longer the specimens become due to the forces applied. All specimens for tensile tests have a marked waist of about 0.1 m. This is so because we want the specimens to achieve most of their prolongation in this waist section. Normal practice is also to monitor the prolongation with so-called extensometer with a monitoring gap, L, of 0.025 m. Because of the waist we want our specimens to break in this specific section and also be able to monitor the added length within the extensometer gap. The machinery is connected to a computer which registers both the applied forces and the prolongation at a fast pace, here set to 10 times each second. Therefore, each resulting data file contains hundreds, or even thousands, of values. Even if we actually measure the extension, δL and the force, F, we are more interested in the stress, σ and strain, ϵ. These values are calculated as:

$$\sigma = \frac{F}{A} \quad \text{and} \quad \epsilon = \frac{\delta L}{L}.$$

By using the formula:

$$E = \frac{\sigma}{\epsilon}$$

for the first interval of 200 values we calculated so-called the Young’s modulus. This modulus can also be depicted as the slope of the curve in so-called $\sigma\ \epsilon$ graph.

Bending tests

Because wood, many times, shows so large differences in strength at tension compared to compression, bending tests are important. Another fact is that most parts in wooden constructions are not under ”clean” axial tension or compression, but instead it is part of constructions that bends. For furniture and other small structures, axial forces can often be neglected without any hazards, because the internal stress in each member will be very small compared to the strength of the material. Note that compression along the axis of slender wooden parts might lead to so-called buckling, where the structure might collapse without any warning at all, see Gustafsson [1996] for a study on this. However, a beam that is bent is actually tensed on one side of the neutral layer and compressed on the other. A bending test, therefore, should give us an average value of the strength. Most of larger actual structures in buildings, bridges, scaffolds and other such common artefacts use wooden beams under bending.

A very straightforward test is called 3-point bending, because a beam is supported at each end and the force is applied in the middle of the beam, see fig. 1.

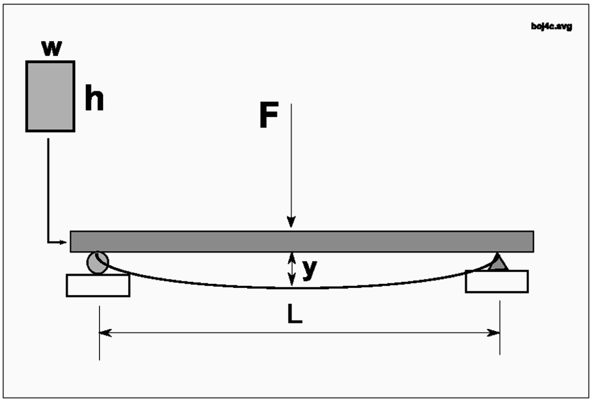

Fig. 1. Three-point bending tests. Experimental setup
Rys. 1. Próby zginania trzypunktowego. Układ eksperymentalny

The things actually measured are the force and the deflection of the beam under the applied force. In this type of test so-called shear stress is introduced which results in a too large a value for the deflection and hence 3-point bending is mostly used just for monitoring so-called Modulus of Rupture (MOR), which is the largest tension/compression achieved when the beam is cracked. See e.g. Kollmann, Côté [1984], p. 300, and Tsuomis [1991], p. 184. Because of this fact only so-called 4-point bending tests was used in our study, see fig. 2.

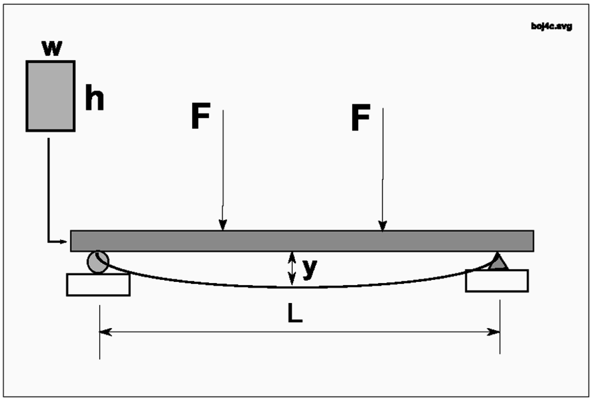

Fig. 2. 4-point bending test
Rys. 2. Próby zginania czteropunktowego

In such tests the influence of shear stress could be neglected because of the constant moment in the middle of the beam and this type of test is therefore assumed to give us a more accurate value of the Modulus of Elasticity (MOE). Also in this test the force, F, and the deflection, y, are measured. Together with the height of the beam, h, the width, w, and the length, L, this modulus is calculated as:

$$MOE = \frac{FL^3}{36wh^3y}.$$

In tension and compression tests the Young's modulus is calculated based on the slope of the stress and strain graph. Each experiment gives us one graph and one modulus. In bending tests one MOE can be calculated for each registered level of the force and deflection. This fact also makes it possible to test MOE without destroying test specimens. In the Scandinavian code for wood testing, see Kucera [1992], p. 45, the procedure is described in detail. The basic idea is to calculate two moduli for much specified forces. These forces depend on the density of wood (see below under the parts devoted to each type of wood).

Moisture content

The ability to withstand different forces from the outside to a large extent depends on the density of wood, but also on the moisture content, i.e. the ratio of the weight of water contained in wood to the weight of wood itself, see e.g. Kollmann, Côté [1984], page 310, for a graph of this. Therefore the measurement of water content in wood is vital when studying the solid mechanics properties of wood. A fool-proof way to measure this is to use a good scale and note the weight of each specimen before and after it was in an oven for a day or two. All water in wood will then be changed into steam, which in turn is transported from wood by diffusion.

Testing of oak, *Quercus robur*

Tension tests of oak

Just as an example of testing we show a graph of our first five tensile tests, see fig. 3.

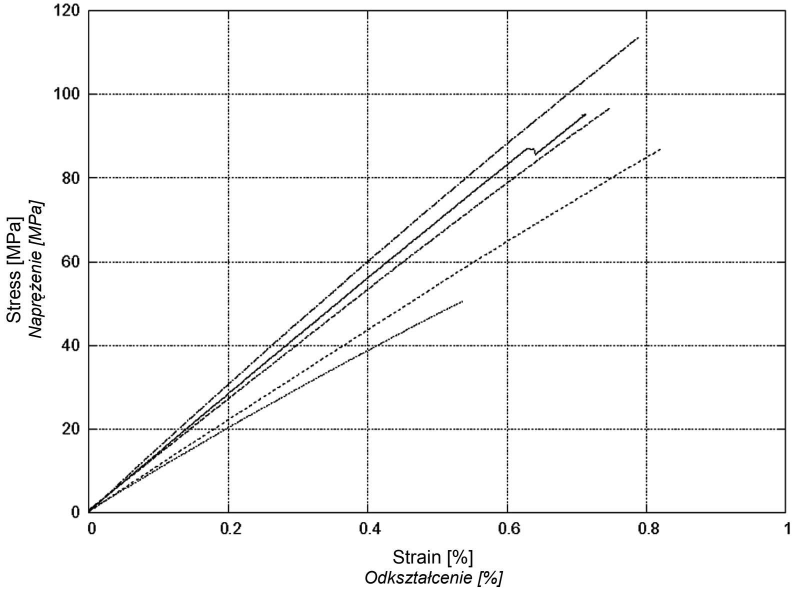

Fig. 3. Five tensile tests of oak, *Quercus robur*
Rys. 3. Pięć prób rozciągania drewna dębu, Quercus robur

Even if there is few tests, only five in fig. 3, it is possible to get a grasp of the strength in terms of endured stress and strain. It is also important to note that the traditional look, i.e. for metals, of a stress and strain graph does not apply when oak wood is tensed to rupture. For instance, we cannot see any plastic region where the curve becomes non-linear.

Instead it is an almost perfect linear relationship between the strain and stress from the starting point of the graph to rupture. Study for instance our first test in fig. 3. The corresponding line is drawn using a normal line in the graph, also identified as the second line to the right from the stress scale, i.e. the ordinate axis, at the level of 60 MPa. It is obvious that the line starts almost in the point (0, 0) and continues in a straight line up to (0.62, 85), where some rupture occurs. However, the specimens did not break in two until the stress became of about 92 MPa.

These graphs show that both the endured strain and corresponding stress, and also the slope of each curve, differ significantly between different specimens. By using the slope in the tensile $\sigma\,\epsilon$ graphs we calculated the Young's modulus as found in table 1. In this table we also included maximum stress for each specimen just before rupture.

Table 1. The Young's modulus and maximum stress at tension for ten specimens of oak, *Quercus robur*

Tabela 1. Moduł Younga i maksymalne naprężenie przy rozciąganiu dla dziesięciu próbek drewna dębu, Quercus robur

Specimen number *Numer próbek*	Young´s modulus [MPa] *Moduł Younga [MPa]*	Maximum stress [MPa] *Maksymalne naprężenie [MPa]*
1	13,922.9	95.17
2	13,113.4	96.68
3	10,776.2	91.02
4	9,339.0	50.48
5	14,821.4	108.01
6	12,045.1	98.68
7	10,395.8	94.47
8	12,985.6	79.53
9	10,043.2	66.20
10	10,171.3	67.87
Average *Średnia*	11,761.4	84.81
Stand. dev. *Odchylenie standardowe*	1,874.5	18.12

Now it is interesting to find out if other researchers have found similar results. In Kollmann, Côté [1984], page 295, a value of 58,100 kp/cm^2, i.e. ≈ 57 MPa, is shown, but the authors write that this value probably is too low. Instead 130,000 kp/cm^2 should apply. Noteworthy is the fact that the value is monitored in 1935, more than 70 years ago. Another value can be found in Tsuomis [1991], page 164, and there the value of maximum tension stress is found to be 109 MPa. No value of the Young's modulus for tension is presented. From the figures in table 1 it is obvious that the values differ very much between different specimens and also that they are lower than some corresponding values found in literature.

Above we mentioned that the moisture content had a significant influence on the strength. Dryer specimens are stronger than those containing more water. In table 2 we show the results of our measurements for our oak specimens.

Table 2. Moisture content, M.C. in % for the oak, *Quercus robur*, tensile test specimens

Tabela 2. Wilgotność w % dla drewna dębu, Quercus robur, próbki do prób rozciągania

Specimen no. *Nr próbki*	M.C. in % *Wilgotność w %*	Specimen no. *Nr próbki*	M.C. in % *Wilgotność w %*
1	5.46	6	5.58
2	5.44	7	5.52
3	5.53	8	5.53
4	5.60	9	5.59
5	5.50	10	5.60

In Tsuomis [1991] the author mentions that the shown values are calculated for specimens in air-dry condition, but it is not exactly clear what moisture content this would imply. The cited references in Tsuomis [1991] are published in Romania and in Germany and hence the M.C. was probably higher than for our own specimens. Due to the fact that the strength should grow when the moisture content gets lower, it is a little disappointing that our test showed lower values even if we used dryer samples. However, this was the result of the test.

Compression tests of oak

We also tested a number of oak specimens under compression. The tests are supposed, due to Kucera [1992], page 28, to be made using small rectangular pieces, but with quadratic cross sectional areas. Each side is supposed to be 0.02 m, whilst the length is set to be 0.06 m. Unfortunately, we did not have such samples but instead we used specimens of the size $0.015 \times 0.015 \times 0.045$ m. Table 3 shows the moisture content for the specimens.

Table 3. Density in g/cm^3 and moisture content, M.C., in % for the oak, *Quercus robur*, compression test specimens

Tabela 3. Gęstość w g/cm^3 oraz wilgotność w % dla drewna dębu, Quercus robur, próbki do prób ściskania

Spec. no. *Nr próbki*	Density [g/cm^3] *Gęstość [g/cm^3]*	M.C.[%] *Wilgotność w %*	Spec. no. *Nr próbki*	Density [g/cm^3] *Gęstość [g/cm^3]*	M.C. [%] *Wilgotność w %*
1	0.734	6.66	6	0.745	4.62
2	0.655	5.18	7	0.757	5.05
3	0.741	5.10	8	0.680	5.18
4	0.645	5.19	9	0.727	5.05
5	0.749	5.25	10	0.760	5.36
Average/*Średnia*				0.719	5.26

When a piece of wood is compressed to the level of rupture the inner structure is crushed. Normally the piece does not break into two parts but instead it only becomes shorter and shorter. Therefore the graph for a compression test looks significantly different from the corresponding graphs for tensile tests, see fig. 4. The very start of testing is also different. As can be found in the graphs the stress did not increase when the test started, but the curves are located a little bit to the right instead. This is probably so because of the small gaps between the testing equipment and the specimens. These gaps must be closed before the stress gets higher, i.e. when the force is actually increasing.

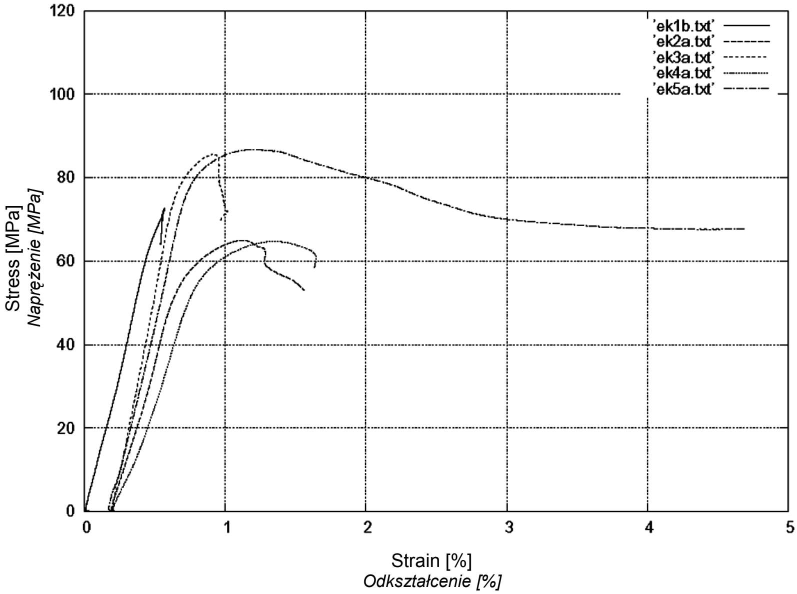

Fig 4. The first five compression tests of oak, *Quercus robur*
Rys. 4. Pięć pierwszych prób ściskania drewna dębu, Quercus robur

One of our tests was completed for a strain of about 0.6%, whilst another went on up to over 4%. The strain for maximum stress was found to be between the values of 0.57% and 1.44%, see table 4. It can be also found in the table that one of the specimens, i.e. number 10, had a significantly higher the Young's modulus than the others.

If tables 4 and 1 are compared, it is obvious that values of maximum stress under compression are lower than the values found for tension. However, the difference is small compared to the expected. In Tsuomis [1991], p. 164, oak is expected to have the tension strength along the fibres of about 108 N/mm^2, whilst the compression strength is about 42 N/mm^2. In our tests the corresponding average values are 85 and 76 N/mm^2. The Young's modulus for test number 10 is surprisingly high, about 29,000 MPa, compared to the other values about 15,000 MPa. Even if the modulus is high the stress before rupture was approximately the same as for the other specimens. If number 10 is excluded from the average, we still get the Young's modulus under compression of about 14,000 MPa. It must be noted here that we used software provided by the manufacturer of the testing equipment, an Instron 5582, in order to test our specimens. Each compression test has been made with a sample rate of 10 ”points” per second and with so-called cross-head speed of one mm per minute. The test is stopped when the force gets lower than the preset value or when the number of registrations becomes too large. Hence, during each test a different number of points was registered. Just as an example, in test number 1, 2,536 lines are present in the data file, whilst for test number 10 2,296 are present.

Table 4. Ten compression tests in the fibre direction for oak, *Quercus robur*
Tabela 4. Dziesięć prób ściskania wzdłuż włókien dla drewna dębu, Quercus robur

Specimen Number *Numer próbki*	Max. Load kN *Maksymalne obciążenie kN*	Stress at Max. Load MPa *Naprężenie przy maksymalnym obciążeniu MPa*	Strain at Max. Load % *Odkształcenie przy maksymalnym obciążeniu %*	Young´s Modulus MPa *Moduł Younga MPa*
1	15.74	72.69	0.5728	15,720
2	13.94	65.01	1.1180	13,840
3	18.37	85.61	0.9145	18,100
4	13.90	64.75	1.3430	11,400
5	18.66	86.76	1.2190	15,070
6	18.59	86.27	1.1200	15,810
7	18.54	86.04	1.1060	14,730
8	13.94	64.69	1.1740	10,570
9	16.25	75.29	1.4410	11,610
10	15.68	73.12	0,6860	29,220
Average: *Średnia:*	16.36	76.02	1.0690	15,610
Stand. dev.: *Odchylenie standardowe:*	2.04	9.48	0.2729	5,320

Bending tests of oak

The procedure for four point bending tests was described above. These tests are done using different forces. In order to find them it is necessary to calculate the density of the specimen. In our case the length was measured to 341 mm and the width and height to 20 mm, which gave us a volume of 136.4 cm^3. The weight was found to be 91.62 g and hence the density was calculated to 0.672 g/cm^3. Three forces are used actually. We found these three forces in the table in Kucera [1992], p. 44: $F_1 = 288.3$ N, $F_2 = 720.7$ and $F_a = 201.5$ N. The specimen was then to be loaded with F_2 force; however, it split on the two forces shown in fig. 2. After this the load was reduced to F_a level. This was done twice. The beam was then to be reloaded again up to F_1 level. The force and the deflection were monitored ten times, each 0.1 second. This gave us an average value of the lower force of 290 N, whilst the average deflection was 0.092 mm, i.e. we tried to set it to zero. The force was then increased to F_2 level, i.e. 720 N. That time as well the actual force and the deflection were measured each 0.1 second giving us ten new values for force and deflection. The average was calculated to, by coincidence, 720 N and the deflection to 0.26 mm. The difference between the average forces, 430 N, and the average deflections, 0.17 mm, was then used to calculate MOE. The result was, without approximations:

$$MOE = \frac{430 \times 0.300^3}{36 \times 0.020^4 \times 0.00017} = 11{,}873\ MPa.$$

Four measurements were to be made for each specimen resulting in three more values, 12,164, 12,249, and 12,130 MPa. This led us to a new average which was calculated to 12,104 MPa. In all we had ten specimens and each resulted in four calculated MOEs. The average for each specimen is shown in table 5.

Table 5. Average MOE$_4$ and standard deviation values for oak, *Quercus robur*
Tabela 5. Średnie wartości MOE$_4$ i odchylenia standardowego dla drewna dębu, Quercus robur

Test number *Numer próby*	MOE$_4$ [MPa]	Test number *Numer próby*	MOE$_4$ [MPa]
1	12,104	6	12,125
2	11,916	7	13,464
3	8,992	8	12,630
4	13,315	9	12,021
5	13,634	10	12,231
Average:/*Średnia:*			12,243
Stand. dev.:/*Odchylenie standardowe:*			1,311.6

Our findings were then compared to values found in literature. In Tsuomis [1991], page 164, MOE for white English oak is said to be 12,250 MPa, whilst red oak is slightly ”weaker” characterised by MOE of 11,560 MPa. The writers of Boutelje, Rydell [1989] gave us the values from 10,000 to 13,000 MPa. Hence, it seems that our oak is well in the vicinity of the values found by other examinations.

Testing of beech, *Fagus sylvatica*

Tensile strength tests, beech

The method dealt with was exactly the same as before. The specimen was equipped with an extensometer with a gap of 25 mm and the load in kN was registered each 0.1 second until the specimen broke in two pieces.

As for the oak tests the properties differed between different specimens. We can also see that our beech wood is significantly stronger than the oak ditto, see table 6. After testing the tensile strength, each piece of the specimen was dried in the oven in order to evaporate all water. Using the weight before drying and after drying, the moisture content could be calculated. Table 6 also shows these resulting conditions.

Table 6. The Young's modulus and maximum stress at tension for ten specimens of beech, *Fagus sylvatica*
Tabela 6. Moduł Younga i maksymalne naprężenie przy rozciąganiu dla dziesięciu próbek buka, Fagus sylvatica

Specimen no. *Numer próbki*	M.C. [%] *Wilgotność [%]*	Young´s modulus [MPa] *Moduł Younga [MPa]*	Maximum stress [MPa] *Maksymalne naprężenie [MPa]*
1	5.73	12,464.1	128.8
2	5.65	15,795.2	150.9
3	5.61	14,324.1	132.3
4	5.60	15,741.2	135.5
5	4.29	13,653.3	126.1
6	5.68	13,757.6	122.4
7	5.57	13,899.0	112.3
8	5.50	12,103.1	129.5
9	5.62	14,240.0	143.8
10	5.58	13,564.9	122.3
Average:/*Średnia:*		13,954.3	130.4
Stand. dev:/*Odchylenie standardowe:*		1,189.4	11.09

The average of all specimens was calculated to 130.4 MPa, which value corresponds to the one found in Tsuomis [1991], page 164, which was 130 MPa. Furthermore, in Boutelje, Rydell [1998], page 70, it is said to be 135 MPa. Unfortunately, the Young's modulus is not presented neither in Tsuomis [1991] nor in Boutelje, Rydell [1998], but the E_y value for red beech in Kollmann, Côté [1984], page 295, is said to be 144,100 kp/cm^2 which equals 14,100 MPa. The values in table 6 seem to correspond very well with the values found in literature. It is also obvious that beech wood has a higher Young's modulus compared to the oak ditto.

Also in this case our specimens contained less water, about 5.5%, than those mentioned in literature (between 12 to 15%). Hence, our tensile strength values should perhaps be even higher, even if the Young's modulus is the least sensitive of the strength properties to changes in the moisture content, see Kollmann, Côté [1984], page 310.

Compression tests of beech

Like in the case of oak we studied strength under compression for 10 specimens of beech.

In graphs, not presented here, it is shown that the tests went on for a longer period of time, i.e. the samples were compressed to a higher level than the oak ditto. There were also less problems at the beginning of the tests and the stress, i.e. the force was actually increasing from the very moment when the machine cross-bar started to move. The differences between the Young's moduli also seemed to be slightly less than before but that to some extent depended on different scaling. These graphs also show that the samples can endure significant load even if maximum crushing strength was exceeded. Furthermore, those experiments showed a closer relationship with traditional tests of the Young's modulus, because maximum load was found well to the right of the linear sections of the graphs. We put together our findings in table 7 as well.

Table 7. Density, moisture content, the Young's modulus and maximum stress under compression for ten specimens of beech, *Fagus sylvatica*

Tabela 7. Gęstość, wilgotność, moduł Younga i maksymalne naprężenie przy ściskaniu dla dziesięciu próbek buka, Fagus sylvatica

Spec. no. *Numer próbki*	Density [g/cm^3] *Gęstość [g/cm^3]*	M.C. [%] *Wilgotność [%]*	Young´s m. [MPa] *Moduł Younga [MPa]*	Max. stress [MPa] *Maksymalne naprężenie [MPa]*
1	0.792	6.45	16,426.1	93.8
2	0.789	12.81	15,130.3	84.6
3	0.763	6.13	11,867.7	81.4
4	0.748	6.07	13,141.6	85.5
5	0.745	6.35	11,503.4	77.9
6	0.802	6.42	12,334.6	90.7
7	0.765	6.11	12,047.1	83.7
8	0.761	6.15	13,362.6	81.9
9	0.771	6.08	13,410.9	87.5
10	0.748	6.14	11,788.2	76.2
Average:/*Średnia:*			13,101.3	84.3
Stand. dev.:/*Odchylenie standardowe:*			1,592.9	5.41

The compression values in table 7 also show that beech is a stronger type of wood compared to oak, see the Maximum stress column in table 4. If looking at the Young's modulus oak seems to be somewhat less elastic than beech, i.e. oak has a higher modulus. This is a little surprising, because the same seems to be invalid at tension, compare tables 6 and 1.

Naturally, we also measured the moisture content of our beech specimens and they were slightly less dried than the oak ditto. The M.C. was about 6%, with one exception of sample number 2. Perhaps this was due to some measuring error.

Four-point bending tests of beech

The method used is exactly the same as for the oak tests. First we had to find the density and we measured it to 0.771 g/cm^3. If we compare this density with the one found for our oak specimens it is obvious that beech is a denser type of wood. This also leads to a higher strength. However, the measured density value gave us the input in order to get the higher force level, F_2, equalling 827.9 N, the lower level of F_1 = 331.1 N and F_a = 231.5 N. As before these values were found in Kucera [1992]. The monitored MOE_4 values are shown in table 8.

Table 8. Average MOE_4 values for beech, *Fagus sylvatica*
Tabela 8. Średnie wartości MOE_4 dla drewna buka, Fagus sylvatica

Test number *Numer próby*	MOE_4 [MPa]	Test number *Numer próby*	MOE_4 [MPa]
1	10,557	6	14,912
2	14,222	7	11,011
3	10,828	8	11,640
4	16,068	9	12,431
5	13,880	10	14,621
Average:/*Średnia:*			13,017
Stand. dev:/*Odchylenie standardowe:*			1,965

The modulus of elasticity for beech is said to be 13,130 in Tsuomis [1991] and between 10,000 to 16,000 MPa in Boutelje, Rydell [1998]. Both references therefore apply to our measured value. Also here we find that the species beech is stronger than oak, even if the difference is smaller than expected, MOE_4 for beech was found to be 13,017 compared to 12,243 MPa for oak.

Conclusions

In this paper we tested about 60 specimens made of oak, *Quercus robur*, and beech, *Fagus sylvatica*. Due to the higher density of our beech specimens, 0.771 compared to 0.671 g/cm^3 for the oak ditto, it was assumed that beech was a stronger type of wood. However, this was not the case for the Young's modulus under compression. Oak had a higher value, 15,610 MPa, than beech, 13,101 MPa. It was impossible for us to find out why it was so. It is also interesting that the Young's modulus for tension differed from the one under compression, even if the differences were rather small, at least in the case of beech where the modulus was 13,954 for tension and 13,101 for compression. The corresponding values for oak were 11,761 and 15,610 MPa, respectively. At least for oak those differences might be significant when using such moduli in FEM calculations and we have not yet seen computer programs that can take such discrepancies into consideration.

It must be noted again that our number of specimens was rather small. It might be necessary to test several hundred, or even thousand, specimens sampled from the same board and the same location within the tree to ascertain that there are in fact differences with significant implications. The bending tests were used in the form of four-point bending, a method assumed to give us better values than the three-point ditto. For oak we calculated an average modulus of 12,243 MPa, whilst for beech it was 13,017. The breaking strength during tension was higher than that under compression, but for oak that difference was surprisingly small, i.e. 76 MPa for compression and 85 MPa for tension. The corresponding values for beech were 84 and 128 MPa, respectively.

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WŁAŚCIWOŚCI WYTRZYMAŁOŚCIOWE SZWEDZKIEGO DREWNA DĘBOWEGO I BUKOWEGO

Streszczenie

Ze względu na znaczący wpływ na gospodarkę, większość badań drewna w Szwecji koncentruje się na gatunkach drzew iglastych, w szczególności na sośnie i świerku. Drewno drzew liściastych stosowane np. w meblarstwie jest w większości importowane. W celu zwiększenia zainteresowania szwedzkim drewnem liściastym wśród producentów, podjęto badania właściwości wytrzymałościowych drewna dębowego i bukowego pozyskiwanego w Szwecji.

Określono wartości wytrzymałości przy rozciąganiu i ściskaniu oraz modułu sprężystości przy rozciąganiu, ściskaniu i zginaniu. Oznaczono gęstość i wilgotność badanych próbek. Badania przeprowadzono zgodnie ze szwedzkimi normami. Zginania dokonywano w schemacie czteropunktowym, jako dającym precyzyjniejsze wyniki modułu sprężystości niż badania w schemacie trzypunktowym. Wilgotność drewna określano metodą suszarkowo-wagową.

Badaniom poddano stosunkowo niewiele próbek, w sumie 60 sztuk dla obu gatunków i wszystkich badanych właściwości. W celu uzyskania bardziej reprezentatywnych wyników należy przeprowadzić badania kilkuset lub nawet kilku tysięcy próbek.

Na podstawie uzyskanych wyników można stwierdzić, iż szwedzkie drewno bukowe jest bardziej wytrzymałe niż drewno dębowe, co można było założyć na podstawie większej gęstości drewna bukowego. Ponadto wartości wyznaczonych wielkości odpowiadają wartościom znalezionym w literaturze.

Słowa kluczowe: drewno liściaste, dąb, buk, wytrzymałość, moduł sprężystości, Szwecja