MECHANICAL PROPERTIES OF SOME SWEDISH HARD WOOD SPECIES

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Abstract

A large part of Sweden is located within the Taiga area and hence most of the wood species growing here are included in the division of Coniferales. This has also led to major research activities on the needle leaved types in the Pinaceae family. There are, however, many broad leaved trees but because of their relatively low economic importance only a few researchers have had the opportunity to study such woods. For certain branches of our wood manufacturing industry the Angiosperms are of vital importance, e. g. the furniture factories. In this paper we show our efforts in revealing the mechanical properties of two Swedish hard wood genera namely Betula and Alnus. We also compare our findings with those found in literature.

INTRODUCTION

In some recent papers we have used the so called Finite Element Method, FEM, for calculating the necessary cross section areas of members in chairs, see e.g. Gustafsson (1997), Reference [1]. We have also tested a real chair with the same design used in the FEM calculations and found that for some of the chair members severe discrepancies occurred between calculated and monitored strains which in turn led us to examine why so has happened. One possible reason for this is the fact that the material constants used in solid mechanic calculations differs very much from one tree to another and also differs within the same tree. Traditionally, three different modulii are examined, viz. the Young's modulii for tension and compression and further the bending modulus. As wood is built up from cylindrical layers it has an anisotropic behavior but if a small cube is studied, three axis of symmetry emerge i. e. the longitudinal, tangential and radial directions. This leads to nine different elastic constants which must be known if the deformation of a wooden sample should be predicted as a result of an applied force, see Kollman/Côté 1984, p. 293, Reference [2]. Some of these elastic constants might, however, only to a very small part influence the deformation of a structure at least if restrictions on the applied forces occur. The variation in the more important constants might therefore be of higher interest. In the Nordic countries there is a certain "testing code" which must be followed when wood is examined from a solid mechanical view, see Kucera 1992, Reference [3]. All the tests that follow are therefore made in accordance with that code. Two wood species are presented, birch and alder, in this paper.

Even if there are nine constants to be examined only four different cases are shown here, tensile and compression tests along the grain and three and four point bending.

There are a number of different recommendations in literature on how to prepare suitable specimens for testing, see e.g. Bodig and Jayne 1982 p. 425, Reference [4] and Kollmann and Côté p. 324 for tensile tests. The Scandinavian code, Kucera 1992 shows still another type. Most important is, however, that the specimen is significantly thinner in the middle section and that the rupture therefore will be located to that section. Compression test specimens and those for bending tests are much simpler to manufacture because they are made of rectangular beams.

BIRCH

Our first tests show so called stress strain diagrams for tension of birch wood along or parallel to the grain, see Figures 1 and 2.

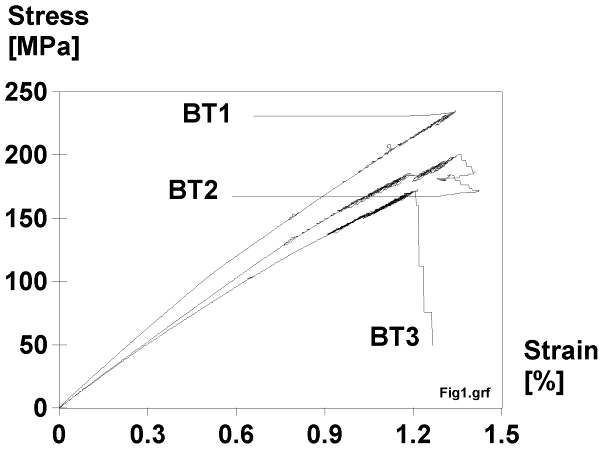

Figure 1: Tensile test for birch along the grain

In Figures 1 and 2 it is obvious that the differences between the tests are very large. The birch tensile test BT1 had a strength in tension of about 225 MPa while the BT7 test only endured 121 MPa. Test BT5 showed a maximum strain of 0.9 % while BT6 could be prolonged with 1.5 % before the rupture occurred. The behavior is also shown in Table 1.

In Kollmann and Côté, 1984, p. 295, Young's modulus for birch equals 16,670 MPa and the average in Table 1 shows an almost perfect accordance with that value.

Figures 1 and 2, however, show a problem when Young's Modulus is to be evaluated. The slope in the stress strain graphs are not straight lines but instead have steeper slopes in the beginning of the tests. In the testing equipment computer this is dealt with by using only part of the curve for the calculation

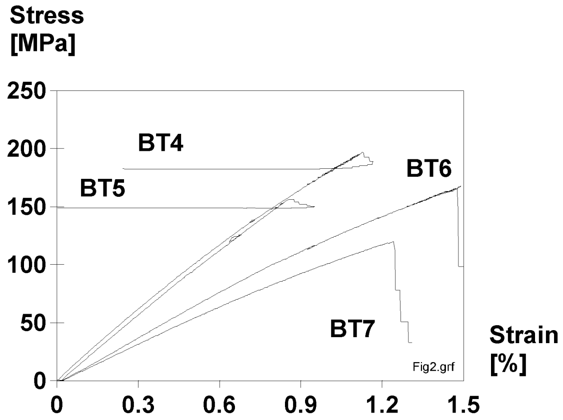

Figure 2: Tensile test for birch along the grain

Test no	Strength [MPa]	Strain [%]	Young's modulus [MPa]
BT1	225	1.35	19,061
BT2	211	1.36	17,854
BT3	164	1.22	14,908
BT4	193	1.14	19,097
BT5	166	0.87	20,591
BT6	168	1.48	13,169
BT7	121	1.23	11,158
Average	178	1.24	16,548

Table 1: Strength and strain just before rupture and Young's modulus for birch. Tension along the grain

of the modulus. It must also be noted that we have used a special device, called an extensometer, when the prolongation of the specimen is to be recorded. This device has a metering length of 25 mm and therefore it is of vital importance that the prolongation really takes place where the meter is located. In some of our tests, see e. g. BT1 and BT2 in Figure 1, the rupture took place outside of that region and the device therefore registered a shortening of the specimen when this rupture had occurred. This did not happen for test BT3.

Compression tests along the grain for birch have also been elaborated. Unfortunately, these tests could not be fulfilled in perfect accordance with the testing code. The code says that specimens with a square area of 0.02 × 0.02 m must be used. The load cell in our equipment could, however, not be used for the high forces that had to be applied in order to compress the specimens to rupture. Therefore, we had to use smaller specimens with a square area of about 0.015 × 0.015 m. This will sometimes lead to problems, such as instability because of misalignment, and some of our tests had to be excluded because of such. Nonetheless, our result is shown in Figures 3, 4 and Table 2.

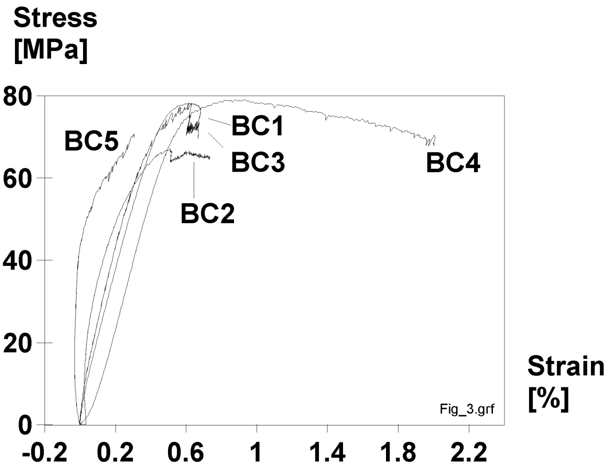

Figure 3: Compression tests for birch along the grain

When Figures 3 and 4 are examined it is obvious that some of the tests are dubious. Tests BC5 and BC 9 even showed negative values for the stress i. e. tension instead of compression. A closer look at the data set, however, showed that these values have a rather small absolute magnitude, only about 0.01 MPa and that they emanate from noise in the electric signal from the load cell. Also the BC2 graph looks suspicious because the slope of the curve seems to be almost vertical in the beginning of the test. In that case there were problems to align the test specimen absolutely vertical and the force could therefore not be applied parallel to the center line. In Table 2 the Young's modulii for those data sets are excluded.

If Tables 1 and 2 are compared it is also obvious that the strength in compression is less than half the value found for tension, 78 compared to 178 MPa. Both values are higher than those found in literature, see e. g. Tsuomis 1991 page 164, Reference [5] where the values are 50 and 134 MPa. To a part this might be explained by the moisture content which is relatively low in our specimens, with an average of 4.7 %. The ratio between compression and tension strengths is also somewhat higher in our tests compared to the ones in the reference, 0.44 and 0.37 respectively. For tension, the average Young's modulus was about 16,600 MPa while it was about 15,000 MPa for compression. It is not possible from our few tests to confirm that there really is a difference in the Young's modulus if tension or compression are considered. In literature, such as Kollmann and Côté 1984, they are often supposed to be equal but the authors mentioned that this is not always the case, see page 361. In e.g. Tsuomis 1991 only the Modulus of Elasticity for bending, MOE, is mentioned and for birch it is said to be 16,170 MPa. The MOE must have a value between the Young's

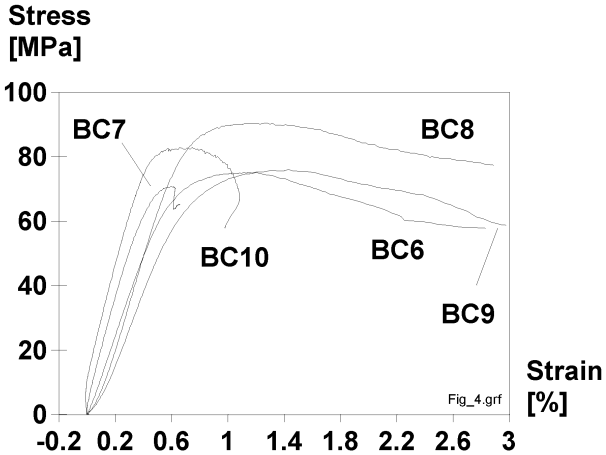

Figure 4: Compression tests for birch along the grain

Modulus for tension and compression and our tests show that this is the case.

We have also made tests of so called three point bending for birch. This test is different from the others because the monitored values are the force applied on the specimen and the achieved deflection from that force. The MOE3 must therefore be calculated according to:

$$MOE_3 = \frac{P \times L^3}{4 \times y \times w \times h^3} \qquad \text{and}$$

$$MOR = \frac{3 \times P \times L}{2 \times w \times h^2}$$

where P is the force, y is the deflection, L is the span, w is the width and h is the depth (thickness) of the tested beam, see Figure 5.

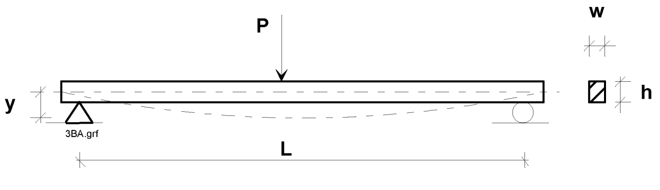

Figure 5: Three point bending test

Test no	Density (g/cm^3)	Moisture (%)	Strength (MPa)	Strain (%)	Young's modulus (MPa)
BC1	0.60	4.6	78	0.62	17,007
BC2	0.64	4.5	66	0.51	-
BC3	0.68	4.7	77	0.62	19,214
BC4	0.65	4.7	79	0.93	15,846
BC5	0.70	5.0	71	0.30	-
BC6	0.61	4.5	75	1.11	12,800
BC7	0.64	4.7	71	0.59	-
BC8	0.70	4.8	90	1.27	14,106
BC9	0.62	4.7	75	1.43	11,141
BC10	0.66	4.8	81	0.75	-
Average	0.65	4.7	78	0.81	15,019

Table 2: Strength and strain just before rupture and Young's modulus for birch. Compression along the grain

Kollmann and Coté 1984, pages 300 and 364 or Bodig and Jayne 1981, page 431 show variants of this equipment. MOR is called the Modulus of Rupture which is only used for bending tests. A few such tests for birch are present in Figures 6, 7 and Table 3 and it is obvious that there are larger differences between the curves than before.

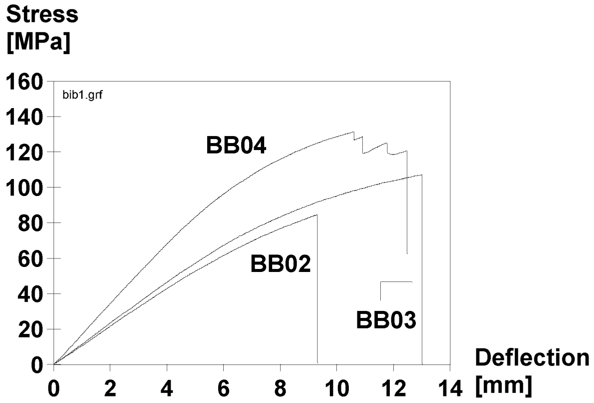

Figure 6: Three point bending tests for birch

The Modulus of Rupture, MOR, varies from about 80 up to about 150 MPa. In Tsuomis 1991 the MOR for birch wood is 144 MPa.

In the Kucera 1992, the three point bending tests is only used for finding the Modulus of Rupture, MOR. For the Modulus of Elasticity, MOE, it is instead recommended to use four point bending and in Table 3 these values can be found, see MOE4. It should be noted that Bodig and Jayne 1982 p. 434, calls

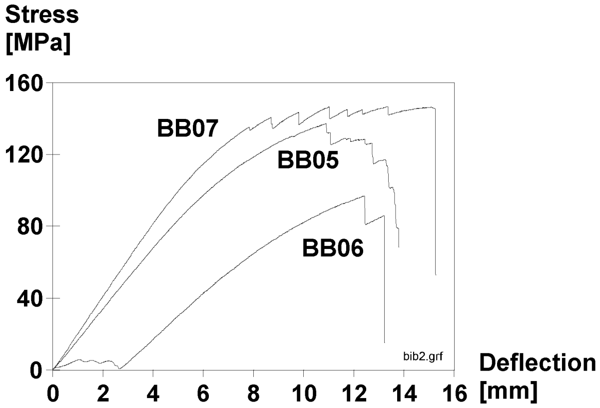

Figure 7: Three point bending tests for birch

Test no.	MOE3 (MPa)	MOE4 (MPa)	MOR (MPa)	Deflection (mm)
BB02	8,113	13,220	84.8	9.3
BB03	8,670	12,505	107.3	13.0
BB04	12,837	17,626	131.4	10.6
BB05	12,835	14,680	137.3	10.9
BB06	9,562	11,824	97.0	12.4
BB07	15,426	19,361	146.6	11.0
Average	11,241	14,869	117.4	11.2

Table 3: Bending tests for birch.

our MO4 test ”third point loading”. This might, however, be a printing error. The specimens are not loaded up to rupture in the MOE4 test and therefore they can be used also in the MOE3 experiments. The modulus of elasticity for four point bending is calculated as, see Kucera 1992, page 45:

$$MOE4 = \frac{F \times L^3}{36 \times w \times h^3 \times y}$$

From Table 3 it is obvious that the MOE4 method yields higher modulii than MOE3, with a ratio about 1.3, and they are closer in magnitude to the tension and compression tests in Tables 1 and 2. The moisture content has been calculated to 5.4 % and the density to 0.62 g/cm^3. The average values in Table 3 for MOE3, MOE4 and MOR are lower than those found in Tsuomis 1991 which are 16,170 for MOE and 144 for MOR. Table 3 also presents values that are lower than both our tensile and compression tests. According to classic theory, this should not happen.

ALDER

The second species that found our interest was alder, Alnus glutinosa. In Figure 8 and Table 4 the result is shown for our tensile tests along the grain.

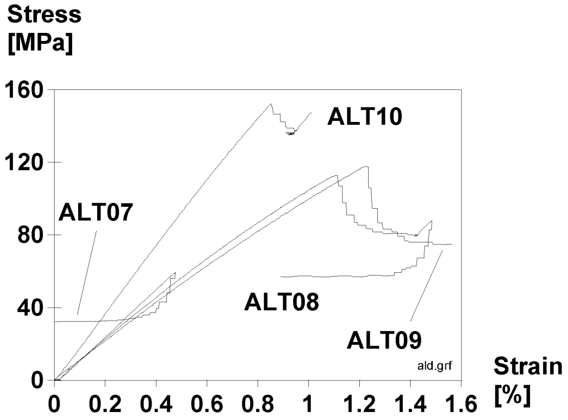

Figure 8: Tensile tests for alder along the grain

Test no	Strength (MPa)	Strain (%)	Young's modulus (MPa)
ALT06	108	0.61	17,663
ALT07	-	-	-
ALT08	112	1.09	11,310
ALT09	119	1.23	10,518
ALT10	154	0.86	19,106
Average	123	0.95	14,649

Table 4: Strength and strain just before rupture and Young's modulus for alder. Tension along the grain

Also here it is obvious that the variations between different specimens are large. The ALT10 test shows a Young's modulus of about 19 GPa while the same modulus for ALT09 only was 10 GPa. The strength before rupture varied between 154 MPa to 108 MPa. In Tsuomis 1991, the strength is said to be 92 MPa so our tests showed, in average, somewhat larger values. Also for these tests an extensometer has been used. The high modulus and low strain values for test ALT10 might be explained by this because the prolongation might have occurred outside the range of the metering device. One test, ALT107 had to be stopped before rupture and the result is therefore excluded in Table 4.

Compression tests along the grain were made on 15 different specimens of alder. Test no ALC04, however, had to be excluded from the set. The result is shown in Figures 9, 10, 11 and in Table 5.

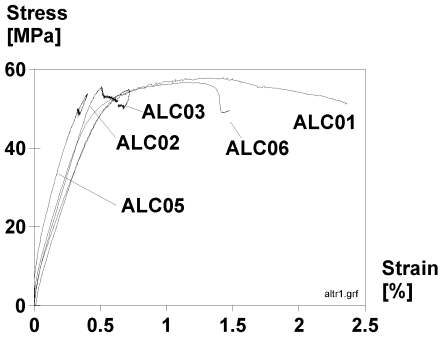

Figure 9: Compression tests of alder along the grain

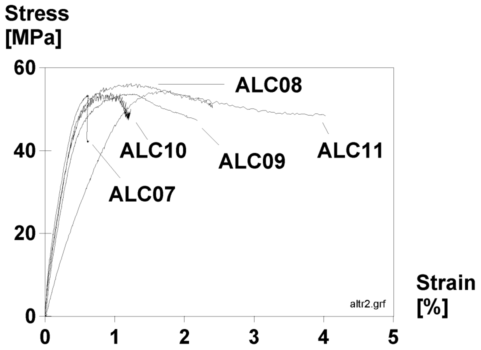

Figure 10: Compression tests of alder along the grain

According to our tests, alder has a strength in compression of about 56 MPa which is significantly lower than that for birch. Our value corresponds well with the one found in Tsuomis 1991 where 54 MPa is mentioned. Kollmann and Coté 1984, do not show any values for alder but in Boutelje and Rydell 1989, see Reference [6] an interval of 39 - 52 MPa is mentioned which is somewhat lower than the values found in both Tsuomis and in our tests.

In Table 5 an average value for Young's modulus in compression is presented, about 11,000 MPa. This is also significantly lower than the value found for birch but unfortunately no reference for alder is found in our available literature. Tsuomis 1991 shows a MOE of 11,470 MPa which is close to our value for Young's modulus. An interval of 9,000 to 12,000 is shown in Boutelje and Rydell 1989, but they do not say anything about how this interval is achieved.

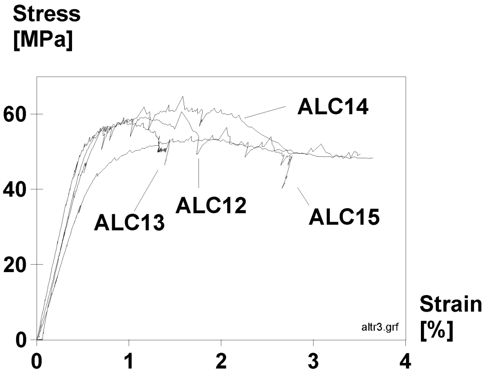

Figure 11: Compression tests of alder along the grain

We have also made MOE3 and MOE4 tests for alder, see Figures 12, 13 and Table 6.

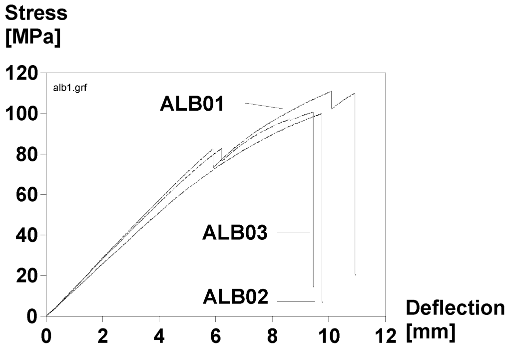

Figure 12: Three point bending tests for alder

Also for alder it is obvious that the MOE4 tests yield higher modulii compared to MOE3 and the ratio is likewise about 1.3. The MOE4 values are also higher than those mentioned in Tsuomis 1991, 11,470 MPa, and so are all the MOR values compared to the value is Tsuomis which is 83 MPa. The moisture content in our specimens were 5.4 % and the density 0.52 g/cm^3.

MODULII OF ELASTICITY

Our tests on birch and alder showed that theory and practice not always correspond. According to classic theory, see e.g. Kollmann and Côté 1984 p. 360, the MOE must be located between or equal to the values of Young's modulii

Test no	Density (g/cm^3)	Moisture (%)	Strength (MPa)	Strain (%)	Young's modulus (MPa)
ALC01	0.513	4.02	57.90	1.43	10,886
ALC02	0.506	3.97	55.18	0.51	12,012
ALC03	0.510	3.81	54.73	0.72	11,739
ALC04	0.519	3.98	-	-	-
ALC05	0.510	3.99	53.16	0.41	-
ALC06	0.509	3.98	56.41	1.18	12,167
ALC07	0.488	3.86	52.67	0.62	12,712
ALC08	0.506	3.47	53.06	1.28	10,427
ALC09	0.502	3.66	55.37	1.23	11,044
ALC10	0.509	3.80	52.79	0.8	11,055
ALC11	0.498	4.18	55.46	1.67	-
ALC12	0.488	4.49	60.18	1.57	11,013
ALC13	0.488	4.67	58.64	0.95	11,356
ALC14	0.503	4.25	63.79	1.59	9,567
ALC15	0.501	4.48	56.98	2.06	8,147
Average	0.503	4.04	56.16	1.14	11,007

Table 5: Compression tests of alder along the grain

Test no.	MOE3 (MPa)	MOE4 (MPa)	MOR (MPa)	Deflection (mm)	
ALB01	10,957	13,161	111.0	10.0	
ALB02	9,626	10,982	99.9	9.7	
ALB03	10,573	11,887	100.7	9.4	
ALB04	10,654	15,334	109.2	10.8	
ALB05	9,863	12,873	97.3	9.2	
ALB06	10,304	16,466	103.7	9.5	
	Average	10,330	13,451	103.6	9.8

Table 6: Bending tests for alder

for tension or compression. In our tests this is true for the MOE4 but not for MOE3 which are lower than both modulii found for tension and compression. This could be the result of weak parts in the specimens used in the bending tests. In order to find out if this is so tests must be elaborated with a greater number of specimens on order to get statistically safe results. Another reason for this could be that the deflection registrations, which in turn are used for the MOE3 calculations, are located too high in the stress region. As can be found in the bending stress versus deflection graphs the relation can not be depicted by a straight line but instead the tests show a high MOE3 for low stress while the MOE3 gets lower and lower when the stress increases. In Figure 14 the MOE3 values in GPa are plotted as a function of the stress calculated from the registered values in the ALB01 test.

In Figure 14 it is shown that the MOE3 values for a very low stress are unpredictable. They range from about 9 up to 27 MPa. When the test proceeds the MOE values shows very stable values of about 10 GPa up to say, 85 MPa

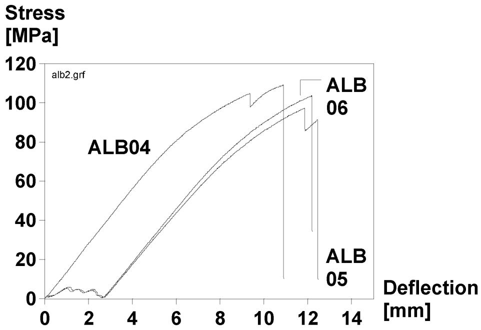

Figure 13: Three point bending tests for alder

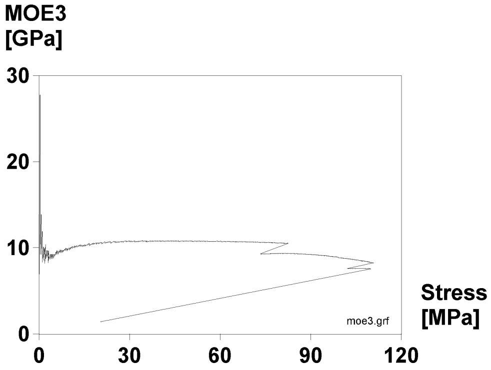

Figure 14: Modulii of elasticity from three point bending tests of alder versus calculated stress values.

where a minor rupture occurred. After this the MOE3 values are about 9 GPa but decreases to 7.5 GPa just before the total rupture. It must be noted that the straight line below about 7 GPa in Figure 14 emanates from only one registered value after rupture. In our case the MOE3 values never were higher than about 10.7 GPa if the few initial values are excluded. It seems therefore that three point bending shows too low modulii compared to four point ditto and tensile and compression tests.

CONCLUSIONS

We have tested two species of Swedish hard woods, birch and alder. Young's modulii have been calculated both from tension and compression and further, three and four point bending tests have been elaborated. The result is presented in Table 7.

	Young's modulii		Bending modulii	
Species	Tension	Compression	MOE3	MOE4
Birch	16,548	15,019	11,241	14,869
Alder	14,649	11,007	10,330	13,451

Table 7: Modulii of elasticity for birch and alder in MPa

The three point bending modulii are lower than the Young's modulii for compression both for birch and alder. This should not be the case according to classic theory. Four point bending yields about 1.3 times larger values compared to three point dittos and they are therefore inside the Young's modulii interval for alder but not for birch. The result, however, is achieved from only a very limited number of tests and it might therefore not be used as a general rule.

ACKNOWLEDGEMENT

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