THE TRANSVERSE OFF-AXIS STIFFNESS AND STRENGTH OF SOFTWOODS

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Abstract

Spruce specimen were tested in compression in the transverse plane with annual rings inclined in different angles to the loading direction. Strains were measured using Digital Speckle Photography (DSP) and average strain values from the central portion of the specimen was used to determine modulus as a function of the loading angle. Radial modulus, E_R , was found to be 1.6 GPa, tangential modulus, E_T , was 0.54 GPa and, G_{RT} , is 57 MPa. The strength in the radial direction is about 5 MPa and the tangential strength is 6.5 MPa. The lowest off-axis strengths are in the range of 3-4 MPa.

1 INTRODUCTION

Wood is recognised as a stiff construction material. The longitudinal Young's modulus of softwoods are in the range 10 – 14 GPa. This is, of course, a consequence of the high longitudinal cell wall Young's modulus (35 GPa) [1]. The high cell wall modulus is well comparable to the longitudinal modulus of unidirectional glass fibre composites and is approximately half the Young's modulus of aluminium. The main structural component in the cell wall is cellulose, with a longitudinal modulus of 134 GPa [2], which means that modulus of cellulose is as high the modulus of aramide fibres.

However, in the transverse directions the Young's modulus is no longer dictated by the longitudinal properties of the cell wall, but instead, the cellular composition of the material plays an important role. This makes wood a soft material in the transverse directions. Since the cellular structure of wood is quite complex, micromechanical modelling of the cell might help us understand the transverse properties. Both micromechanical modelling and experiments tell us that the shear modulus (G_{RT}) is very low, and thus of special interest. [3, 4] Due to shear coupling, the very low shear modulus will have a large influence on the performance of wood structures in many loading cases. In the present study, a simple off-axis compression method to determine the in plane shear modulus.

Some pioneering work on angular dependence of the modulus. [5] The angular dependence of the modulus on loading angle was determined for four wood species used in the aircraft industry. This early research on wood lay the foundation for later development composite mechanics. Table 1 shows the elastic properties for a few wood species. Spruce is a typical softwood whereas Ash and birch are hardwoods. It is clear from this data that the elastic shear modulus of spuce, and softwoods in general is exceptionally low.

Table 1: Material Elastic constants used for calculating the Young's modulus angular dependence. [6]

	E_R (MPa)	E_T (MPa)	G_{RT} (MPa)	υ_{RT}
Norway Spruce	710	430	23	0.31
Ash	1510	800	270	0.36
Birch	1110	620	190	0.38

Figure 1 shows the angular dependence of the modulus in the transverse plan of the species from Table 1. A loading angle of 0 corresponds to loading in the radial direction and 90 is a loading in the tangential direction of the wood material. The moduli have been normalised to the radial modulus to facilitate an easier comparison between the different species.

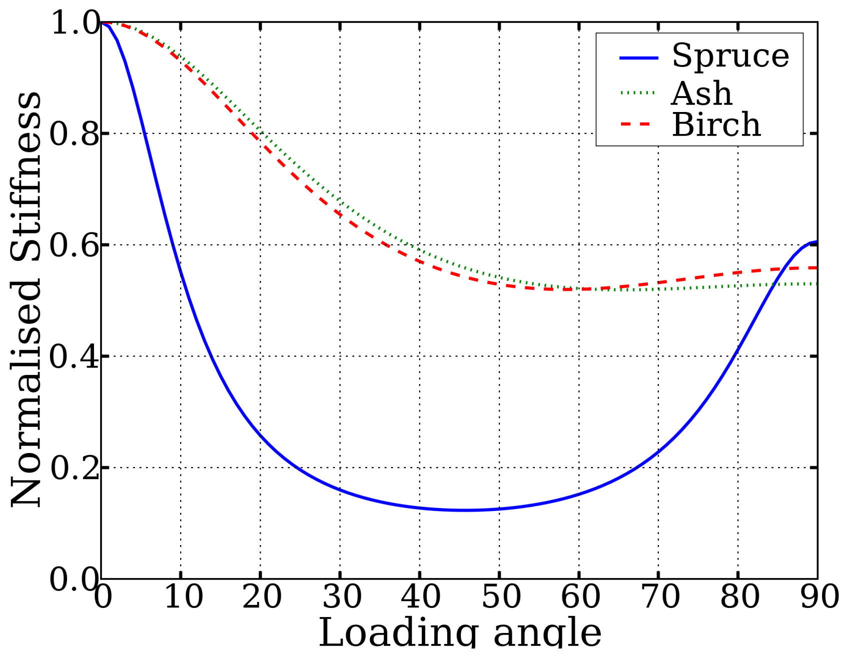

Figure 1: Plot of the angular dependence of Young's modulus in the transverse plane of three species of wood. A loading angle of 0º corresponds to tangential modulus and an angle of 90º corresponds to radial modulus. The y-axis depict the normalised transverse modulus for each specie (E_θ/E_R).

Shipsha and Berglund [3] showed that the curvature of the annual rings and shear coupling effects caused very different mechanical properties of boards taken from the centre of a spruce tree and one taken from the perimeter. In the centre specimen a larger part of the specimen is loaded in the very compliant 45º-direction. However, the question on how well experimental data matches the theory is still not completely clear as the effects from curvature and shear coupling also may cause a considerable effect on the board.

The present paper studies the strength and stiffness as a function of the loading angle in the transverse plane. Experimental data is compared to what would be expected from elasticity.

1. EXPERIMENTAL METHOD

Small clear wood specimen of spruce were sawed to *l*=21 mm, *b*=21 mm, *h*=56 mm, according to Figure 1. The *l*-direction corresponds to the longitudinal direction and the specimen is tested in compression in the *h*-direction. Samples were cut out with different inclinations between annual rings to the loading direction to be able to test how strength and modulus is dependent on loading angle in the radial-tangential plane.

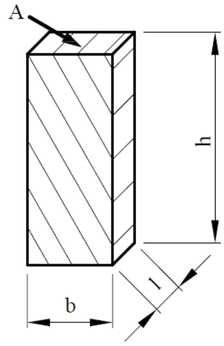

Fig. 2: Dimensions of the specimen. Cross-head movement during the testing is in the h-direction.

The specimens were tested in compression with an Instron testing machine and full strain fields were monitored using a GOM Aramis 1.3M Digital Speckle Photography (DSP) system. DSP is an optical, contact free method that measures all components of the strain field. [3] The strain fields were the used to calculate the average strains from the central part of the specimen where there is no stiffening effects from the pressing plates. [6] The effective modulus and strength, defined as 1% plastic deformation, of the central regions of each specimen were determined. The annual ring angle was also determined and recorded for each specimen.

The modulus and strength values were then used to determine elastic and strength properties in the transverse plane. Value for the Poisson ratio is determined from the specimens loaded in radial and tangential directions.

2. RESULTS

Stress-Strain curves from some representative specimens are displayed in Figure 5. The curves are indicated with the angle between the radial material direction and the loading direction. Strains are averages from the central portion of the specimens measured with the DSP-equipment. The large scatter seen for high loads on the 0º-specimens is caused by the specimen being crushed, causing the image recognition technique to fail in the crushed parts of the specimen.

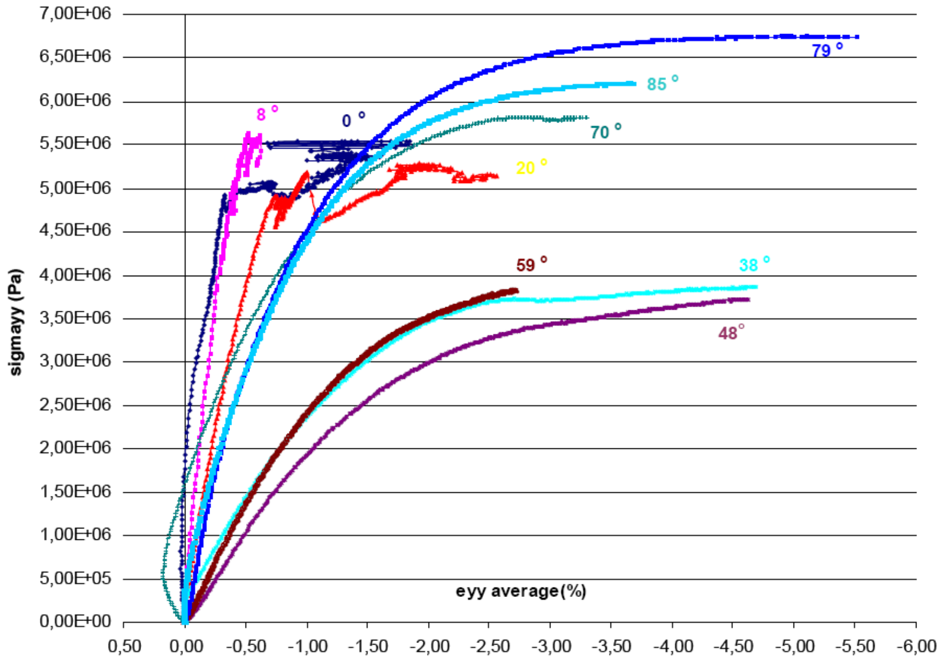

Figure 3: Stress-strain curves forsome selected specimen.

In Figure 4 the relationship between transverse modulus and and loading angle is shown. The blue crosses represent measured modulus from the different specimen. The green line is modelled using the equation

$$\frac{1}{E}=\cos^4\frac{\theta}{E_T}+\sin^4\frac{\theta}{E_R}+\cos^2\theta\sin^2\theta\left(\frac{1}{G_{RT}}-\frac{\nu_{RT}}{E_T}\right) \quad . \tag{1}$$

Values for radial modulus, E_R, and tangential modulus, E_T, are determined from specimens with a loading angle of 0º and 90º respectively. Transverse Poissons ratio ,ν_{RT}, is also determined from these specimen and is determined to be 0.45. The transverse shear modulus, G_{RT}, is determined using a least square fitting procedure and is determined to 57 MPa.

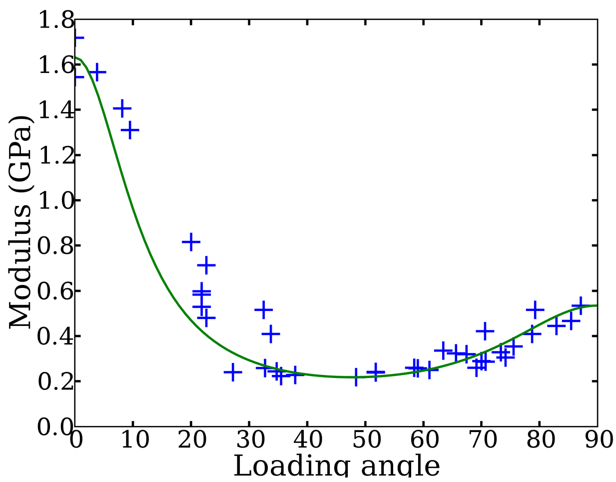

Figure 4: The modulus as a function of transverse loading angle for Spruce. Green line is expected elastic properties from the measured elastic constants from the testing.

3. DISCUSSION

From Figure 3 it can be noted that there are tree groups of stress-strain curves. The first group is the ones that have a parallel or almost to parallel to radial loading. for these specimen the stiffness is high. and the strength is about 5 MPa. The group with specimen were loading direction was almost parallel to the tangential material direction have a lower modulus but a higher strength, ranging up to 6.5 MPa. For the intermediate angles a much lower stiffness and strength were recorded. Strength values of about 3-4 MPa were typical.

The in plane anisotropy is quite large, with a radial modulus about 8 times larger than that of the effective modulus in the 45º-direction. The theoretical curve fits very well to the measurements in a loading angle range of about 40º – 90º. for angles of about 20º there is a deviation. A possible reason for this discrepancy is that the annual rings, with low density earlywood and high density latewood regions, give a non uniform stress state. It is also not clear how the transverse shearmodulus scale with density.

The failure mechanisms are also dependent on the angle of loading. For the radially loaded specimens, the mechanism is local crushing failure of one annual ring at the time. The crushing starts in the earlywood of one ring that is supposedly weaker than the rest of the annual rings. When the weak earlywood is crushed, another annual ring starts to collapse, while the rest of the specimen is still behaving elastic. For the off-axis specimen the failure is appearing over a larger portion of the specimen. The earlywood of several annual rings gets a large shearing and compressive deformation. The specimen loaded in the tangential direction fail mainly due to buckling, since there is a slight curvature of the annual rings in the specimen. It cannot be ruled out that there might be an effect of the selected specimen size for the transverse strength measurements.

4. CONCLUSION

The low transverse shear modulus, G_{RT}, of softwoods gives a large in plane anisotropy, where the radial modulus, E_R, is about 8 times larger than the 45º-modulus. The anisotropy in strength is less pronounced and tangential strength is about double the strength. The modulus measurements fits the theoretical elastic curve for a homogeneous anisotropic material well, except for loads about 20º to radial directions were the material is stiffer than expected from theory. The shearing behaviour within the annual ring should be further examined to fully understand this phenomenon.

5. ACKNOWLEDGEMENT

The authors would like to acknowledge KTH Biofibre Materials Centre (BiMaC) for funding.

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