

Thesises of the PhD. dissertation

Determination of the shear modulus of wood

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Sopron

2011

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Discipline:
Material sciences and technologies

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1. Introduction

Shear modulus is an important elasticity constant. The G-modulus is the third elastic technical constant next to Young-modulus and Poisson-constant. These determine the strain and ductility tensor. If we know the elastic constants, we can determine previous tensors. The shear modulus of wood is important in practice, because 15 % deformation of the bending timber structures based on shear modulus, in contradiction steel. In case steel structures there is only 2 % deformation, which based on shear modulus. We have to know the shear modulus of wood for calculating the exact deformation of timber structures. It is a difficult work to measure the exact value of shear modulus, because there is always other loads near shearing, too. In addition, the measuring of the angle deformation is also a complicated work. Although this theoretical problems, there are several methods for determination of shear modulus nowadays. The methods usually contain something theoretical or technical incorrections. The isotropic materials are described by one elasticity modulus. Anisotropic materials are more complex. Theoretically, one shear modulus is connected for every plane in a point. It is demonstrable for the orthogonal anisotropic materials like wood that if we know the three shear modulus in anatomical plane, then we can calculate the shear modulus in any plane.

2. Target of research

There is a method for anisotropic materials, for example wood for measuring the shear modulus in an indirect way. According to this method we load the specimen by tension or compression and measure the deformation in three directions – parallel with and perpendicular to the load direction and between this two, in 45°. If the orientation of the specimen is 45°degrees, then we need to measure the deformation in perpendicular directions. This indirect method is similar and exact. There are few publications in bibliography. Till now researches concern for small template. It is based on, that measuring the deformation in the same time and in other directions is an expensive and long work.

Two targets were set before I began my PhD research. One is that I determine the shear modulus of wood by tension or compression load. I would like to demonstrate the trueness of method by means of using a large template and different woods. The other target, that I can use practically the optical system for measuring deformations in Institute for Applied Mechanics and Structures.

3. Object of research – materials and methods

After we obtain the indirect method we can determine shear modulus in a similar and short way:

$$G_{ij} = \frac{\sigma^{i'j'} \cdot \sin\alpha \cdot \cos\alpha}{2 \cdot \sin\alpha \cdot \cos\alpha \cdot (\varepsilon_{i'i'} - \varepsilon_{j'j'}) + 2 \cdot \left[\varepsilon_{ij}^{45} - \frac{1}{2} \cdot (\varepsilon_{i'i'} + \varepsilon_{j'j'}) \right] \cdot \cos 2\alpha}$$

where, $i', j' = 1', 2', 3'$, $i, j = 1, 2, 3$ and $1 = L$; $2 = R$; $T = 3$,

$\varepsilon_{1'1'}$ - specific deformation parallel by load,

$\varepsilon_{2'2'}$ - specific deformation perpendicular to load,

ε_{ij}^{45} - between direction of parallel of load and direction of perpendicular to load in 45°degrees,

α - angle between i and i' directions,

$\sigma^{1'1'}$ - normal stress from load.

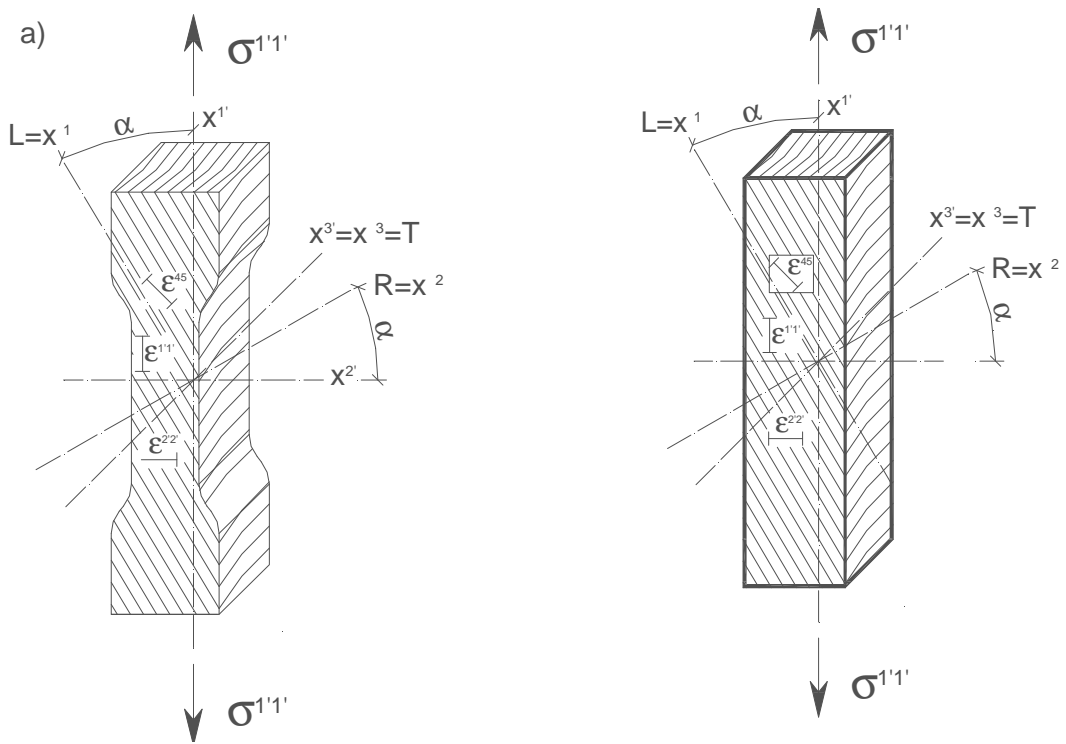
In the special case, when there is $\alpha = 45^\circ$ degrees in orientation of specimen, we can substitute $\alpha = 45^\circ$ degrees into the equal and get the following simplified form:

$$G_{ij} = \frac{\sigma^{i'j'}}{2 \cdot (\varepsilon_{i'i'} - \varepsilon_{j'j'})}$$

In this optimal case, we need to measure the deformation only in two directions, and we can determine the shear modulus.

We made hundreds of preliminary measurements in the first period of research. We made these measures on Spruce (*Picea Abies*) tensioned specimen in every three anatomical plane. The load was given by a universal test machine (FPZ-100), the deformation were measured by a videoextensometer and strain gage.

We had very much problem during learning the work with optical deformation measuring equipment. There was long time, while we made the settings and coordinated it with universal test machine. The curves of deformation-stress were not suitable to use in calculation. We made tensile measuring with spruce specimen in orientation 0° and 45° degrees and with inner tube of vehicle tyre. We measured the deformation always in two perpendicular directions.



Shape of tensile and compression specimen to determine the shear modulus of wood by normal force

In the second period of the research we made 97 pieces tensile spruce specimens in plane of LR to determine the shear modulus. The measuring was made in two different laboratories. Firstly, we worked in Switzerland, laboratory of ETH (Eidgenössische Technische Hochschule) in Zurich. On this way I express my thanks to Peter Niemz professor of ETH and József Garab, PhD student of Institute for Applied Mechanics and Structures. Prof. Niemz gave us chance using his laboratory. We could use his technical equipments in Switzerland. The load was given by a Zwick universal test machine. Deformation in two perpendicular directions was measured by an optical system, by DIC-2D. The measuring was made on nondestructive way under a given damage limit. So we could made our measuring in Hungary on the same specimens. In the second test, the load was given by a FPZ-100 universal test machine. Deformation in two perpendicular directions was measured by another optical system, by an ME-46 videoextensometer.

The third period of research was the final stage. We made altogether 175 pieces of tension and compression specimen of ash (*Fraxinus Excelsior*) for controlling our experiences on an other wood species. We wanted to make sure during this measuring from trueness of theoretical method. The normal stress was made both tensile load and compression load. Theoretically the method is usable in both loading case. The

tension and compression specimens were made from the same wood board. The measuring were made in Sopron, application the FPZ-100 universal test machine and optical equipment ME-46 videoextensometer.

I used the Excel spreadsheet program in each case to process, to evaluate and to compare the data.

4. Summary of results

We can declare in knowledge of the result that oriented method is suitable to determine the shear modulus of anisotropic materials. This is supported by statistical treatment and bibliography comparing of measured data. It is important to say that the technical background of deformation measure equipment (videoextensometer) is suitable only in the simplified loading form.

Summary of results: shear modulus of spruce in L-R anatomical plane

(u=12%, $\rho_{\text{mean}} = 370 \text{ kg/m}^3$)	G_{LR} [MPa]	
	DIC-2D	Videoextensometer
Number of specimens:	97	
Number of values:	94	76
Mean of density [kg/m^3]:	370	
Mean of shear mod. [Mpa]:	519,7	410,7
Standard deviation [Mpa]:	55,05	216,60
Max. [Mpa]:	764,40	944,30
Min. [Mpa]:	443,70	101,40
CV [%]:	10,59	52,73
Mean of R^2 [1]:	0,995	0,835

Summary of results: shear modulus of ash in R-T anatomical plane

(u=12%, $\rho_{\text{mean}} = 670 \text{ kg/m}^3$)	G_{RT} [MPa]	
	tension	compression
Number of specimens:	35	28
Number of values:	33	28
Mean of density [kg/m^3]:	670	
Mean of shear mod. [Mpa]:	284,0	310,7
Mean(tensile-compr.) [MPa]:	297,35	
Standard deviation [Mpa]:	63,6	66,7
Max. [Mpa]:	418,5	551,2
Min. [Mpa]:	165,8	217,7
CV [%]:	22,4	21,5
Mean of R^2 [1]:	0,911	0,980

Summary of results: shear modulus of ash in L-R anatomical plane

(u=12%, $\rho_{\text{mean}} = 670 \text{ kg/m}^3$)	G_{LR} [MPa]	
	tension	compression
Number of specimens:	28	28
Number of values:	27	28
Mean of density [kg/m^3]:	670	
Mean of shear mod. [Mpa]:	1116,6	921,1
Mean(tensile-compr.) [MPa]:	1018,85	
Standard deviation [Mpa]:	333,6	166,8
Max. [Mpa]:	2007	1181
Min. [Mpa]:	461,6	413,3
CV [%]:	29,9	18,1
Mean of R^2 [1]:	0,876	0,978

Summary of results: shear modulus of ash in L-T anatomical plane

(u=12%, $\rho_{\text{mean}} = 670 \text{ kg/m}^3$)	G_{LT} [MPa]	
	tension	compression
Number of specimens:	26	30
Number of values:	24	30
Mean of density [kg/m^3]:	670	
Mean of shear mod. [Mpa]:	806,6	1042,7
Mean(tensile-compr.) [MPa]:	924,65	
Standard deviation [Mpa]:	241,4	189,0
Max. [Mpa]:	1531	1456
Min. [Mpa]:	511,7	723,5
CV [%]:	29,9	18,1
Mean of R^2 [1]:	0,865	0,986

In my opinion, the oriented method become complete due my research. The method could be perfect, if we would have possibility to apply a measuring system, which can measure the deformation in three different directions in the same time. In this case, we could apply the three-argument model of indirect method. So we could choose the angle between load direction and grain different from 45° degrees. Using this method, the prefabrication of the specimens would be more simple, too. Precise measuring of deformation in three different directions ensure the precise shear modulus determination in every anatomical plane. In this way, the calculated G modulus would be a real elastic constant, which is independent of technology of examination.

Thesises

1. thesis

Based on theoretical consideration and results of experiences I established that there is not any explicit and accepted general method to determinate the shear modulus of isotropic and anisotropic materials, as an exact characteristic of materials. The applied methods are not suitable for measuring the shear modulus in the anatomical planes. The shear modulus determined by directly methods depends on the applied method. We get not the real characteristic of the material, because the result describes the method, not the material. The values of the shear modulus determined by different methods are not compatible to each other.

Disadvantages of the direct methods:

a/ It is very difficult to make exact shear load in a cross section. Some old methods cause bending – moment, as a secondary bearing force. This means that normal stress is wakening perpendicular to the sheared cross section nearby the shear stress (the stress stage is a complex shear stage instead of clear shear stress).

b/ Using one of the new methods we can create clear shear, but we can not ensure the equable shear stress and deformation distribution in the cross section. Determination of the exact distribution is difficult, and the results are not exact (we should know other elastic constants near the shear cross section).

c/ There is a complicated equipment to make the shear deformation, the angle of the load is also can be changed. Generally, not the angle is measured, but the changing of length in convenient directions. Conversation of the result can cause new mistakes.

d/ If we want to measure the shear modulus of anisotropic materials, there is not possibility to do it in some orientations using the direct methods.

2. thesis

Based on technical literature I deduced an experimental measure using elastic basic equals of anisotropic materials (indirect method, orientation theory). This method is good for determination the shear modulus of anatomical planes. This method eliminates the disadvantages of the direct methods.

Advantages of the indirect method:

a/ It is not necessary to prefabricate special formed specimens and complicated grip equipment.

b/ The deformation and stress stage is spread evenly in the middle of the specimen, far away from the fixed places.

c/ It is not necessary to measure the changing of the angle. Measuring the changing of the length in three directions is enough to calculate the shear modulus.

3. thesis

Based on indirect method I made tension measuring on Spruce specimens. Based on measuring data I have determined the shear modulus of spruce in LR anatomical plane. I used two different videoextensometer based deformation measure systems: ME-46 and DIC 2D.

4. thesis

Based on indirect method I made tension and compression measuring on Ash specimens. Based on measuring data I have determined the shear modulus of ash in every anatomical plane. I used the ME-46 videoextensometer system for measuring the deformation.

5. thesis

Based on examinations I have diagnosed that indirect method is suitable for determination the shear modulus of anisotropic materials.

Arising problems indicate to make research with three argument model of the indirect method. In this case, we choose the angle between load and orientation of specimen directions different from 45°degrees.

It is necessary to measure the deformation in three different directions. None of the measured values will be small, so the measuring can be more or less exact. These précised measured deformations guarantee the exact value of the shear modulus The modulus calculated in this way is a real elastic constant, which is independent from method of examination. The disadvantage of this method is that it is necessary to apply a deformation technique, which is suitable to measure the specific deformation in three different directions in the same time. These special equipments are expensive today.

6. thesis

During I surveyed the two arguments model of shear modulus determination, I demonstrated that Poisson factor is small (it is maybe negative) in 45° orientation. This statement could cause large inexactness during measuring the specific transversal deformation. Major error could be in value of shear modulus. If I would like to eliminate this problem, I have to make measuring with specimens out of 45° orientations. For this, we need a special equipment, which can measure the specific deformations in three directions in the same time.

7. thesis

Based on my measuring experience the indirect way determined shear modulus is very sensitive for condition of research. Depend on the measured wood specimen the applied loads and deformations are small, the measuring these two values causes always problems in precision. The specimen slips in the wedge type clamps using small load, and the deformation diagram also slips. The connected stress and deformation pairs have a major deflection. As a conclusion, grip type clamps must be used, so the specimen cannot slip during the test. The results of the ash measuring show the importance of fixing method: standard deviation of shear modulus is 18% at the compression and 30 % at tension.

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