Correlation between Stress and Strain of wood used in construction

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Abstract: Wood is a biomaterial and its used for different purposes in construction. The testing of any material is very important to decide its suitability, quality and making decision whether it will be used or not so it is necessary to determine the mechanical properties of wood inorder to have an idea about its behavior during loading of structure. The aim of this research is to investigate the mechanical characteristics of wood used as a building material through studying the stress-strain diagram of this constructional material and calculating the modulus of elasticity of wood in various methods which is considered as the main property of wood. The experimental part of this study included testing of many prisms with dimensions of $75 \times 5 \times 5 \text{cm}$. Under bending and measure the deflection during the stages of loading until occurrence of failure and draw the stress-strain graph for each specimen. The conclusion and recommendation will be written especially that concerning the using of wood as a structural material in formworks.

Keywords: Wood, timber, Modulus of Elasticity, Modulus of rupture, Stress - strain.

1. Introduction

Wood is a natural polymers material composed of cells in the shapes of long thin tubes with tapered end. The cells wall consists of crystalline cellulose aligned parallels to the axis of the cells. The cellulose crystal are bonded together by a complexes amorphous lignins consists of carbohydrate compound. Wood composed of 50 to 60% cellulose and 20 to 35% lignin, while remaining being other carbohydrate and mineral matters.

Most of the cells in the tree are oriented vertically, but some of this are radially oriented to serves as reinforcements against spread of the vertical fiber under the natural compressive loaded of the tress trunks. Because of the direction of cells structure, wood has larger strength and stiffness in the longitudinal direction than in the others directions[1].

Kulman, et.al.[2] studied the Modulus of rupture and modulus of elasticity of MDF at different density and different temperature. Result show the modulus of rupture and modulus of elasticity affected by temperature, density and strain rate of the standard tensile testing machine.

Samson and Sotomayor-Castellanos[3] also studied the modulus of elasticity of lumber numbers and show that the modulus of elasticity is affected by the method of testing.

2. Properties of wood

Wood has three basic mutually perpendiculars axes of symmetry: longitudinal, or parallel to the grains; tangential; and radials. Strengths and elastic property differs in these directions because of the direction of the calls structure of the wood[1].

The most important effect of the structures of the wood, however, is apparent in the different of wood, which means that the property of wood vary significantly with the direction[4].

Wood passes dimensional changes from causes different from those for dimensional changed in the different most other structur materials. For example, thermal expansion of timber is so small as to be unimportant in usage. Dimensional changes occur because of gain or loss moisture content. Swelling and shrinkage from this cause different in the three of gain direction; size changed between 6 to 16% tangentially, 3 to 7% for radially, but only from 0.1 to 0.3% longitudinally.

Wood possess the number of advantages never the less in the constructions application – beautiful, durability, workability, low cost, high strength – to – low weight ratio, very good electrical insulation,
very low thermal conduct, and perfect strength at low temperatures. It is highly resistant to many chemicals that are corrosive to other the material. It can hold up large overload of short time period. It can be bent very easily to sharp curve.

3. Defects of wood
- shakes are longitudinal crack in the lumber, sometimes are result from heavy winds or follow the growth rings.
- knots are consists at the base of branches and extended into the timber of the tree.
- Pitch pockets are gathering of resins in opening between the annual rings.
- Bark pocket are consists when bark is completely or partially encased in timber.
- The effects of fungus and insect attack also can be considered defects in wood[5].

4. Experimental work
Twenty two samples of different types of wood were used for test according to ASTM D4761-19[6]. All specimens are prismatic of (50 × 50) mm in cross section and 750 mm lengths, resting on a span of 650mm, were used to determine the modulus of rupture and bending modulus of elasticity.

4.1 Modulus of Elasticity
The Modulus of elasticity in wood is considered high relative to the compressive strength in wood, compared to the other building materials[7]. However, the wood does not exhibit a good – defined yield point, therefore the proportional limit is used in this work to measure elastic strength from the ‘equation’.

Where:

$$E = \frac{PL^3}{48I\Delta \ell}$$  \hspace{1cm} (1)

E = Modulus of elasticity (Mpa)
P = Bending Load (N) at the proportional limit.
L = Clear span between the sport = 650 mm
$\Delta \ell$ = Deflection (mm$^2$) at the proportional limit.
I = Moment of inertia (mm$^4$).

$I = \frac{bh^3}{12}, b = \text{width of the specimen} = 50\text{mm}, h=\text{height of the specimen} = 50\text{mm}$.

4.2 Modulus of rupture
Reflected the maximum load – carry capacity of a member in bending and is proportional to the maximum moment borne by the testing specimen[8]. The maximum modulus of rupture of samples was calculated using the following ‘equation’.

$$M.R = \frac{M.C}{I}$$  \hspace{1cm} (2)

Where:
M.R = Modulus of rupture (Mpa).
M = Bending moment (N – mm$^2$).

$$M = \frac{P\ell}{4}$$
P = Failure load (N), $\ell = \text{distance between the sport} = 650\text{mm}$
C = Distance between the neutral axis and the extreme level for the section (mm) = 25mm.
I = Moment of inertia (mm$^4$).

$I = \frac{bh^3}{12}, b = \text{width of the specimen} = 50\text{mm}, h=\text{height of the specimen} = 50\text{mm}$.
4.3 Stress – Strain Relation Models
In the bending area, one of the simplest stress – strain relation models is that the stress – strain relation is linear up to proportional limit, but stress reduced to the linear with the increased strain[9,10].

5. Discussion and Results
5.1 Load – deflection diagram
The ‘figure 1.1’ to ‘figure 22.1’ showed the relationship between the deflection measured at center point of prism and the applied load.

The failure load is ranged between (4050 – 115200) N and the deflections are ranged (7 – 71.5) mm. This differences is due to the nature of material i.e the wood is not homogenous materials as well as samples were take from different sources. The values obtained from previous diagrams were used to construct the stress – strain diagrams for the wood specimens. Which were the ‘figure 1.2’ to ‘figure 22.2’. The graph shows a certain ductility to the tested wood materials.

5.2 Modulus of elasticity
The modulus of elasticity of wood is considered as one of the main mechanical properties of any material.

The modulus of elasticity of wood is calculated from the bending test using the following formula

\[ E = \frac{PL^3}{48IΔℓ} \]

This ‘equation’ represents the elastic behavior of material. (table 1) showed the values of modulus of elasticity. Also the modulus of elasticity was obtained from stress – strain relationship by measuring the slope of the elastic range of the tested specimens.

The values of modulus of elasticity obtained from ‘as in equation (3)’ are approximately similar to the values obtained from stress – strain diagrams.

There is a big difference between the values of modulus of elasticity. The researchers attribute this difference to the following reasons:

a. The specimens of wood were brought from different sources.
b. The wood is considered as biomaterial which make this material have different hardness which may be due to the same less rate of growth.
c. The wood is directional material which means that its properties are dependent on the direction of their fibers with respect to the direction of testing.
d. The wood is hygroscopic material which means that its properties are changed with respect to its moisture content.
e. The wood is considered also as a composite material because its composition includes the three state of material (Solid, liquid and gaseous) state (multiphase material).
f. From the above mentioned points, the following statement may be written: the big difference in results may be related to heterogeneity of the wood. This means that wood is not homogenous material.

ESSERT., et al. [11], determined the bending modulus of elasticity of subfossil ELM wood in the longitudinal direction and the different angles between the direction of load and the annual growth orientation. The obtained values of the modulus of elasticity are within the range between (7.6-9.5) Gpa.

5.3 The modulus of rupture
The modulus of rupture of wood which is representing the tensile strength of this material was calculated by using the ‘equation’ of bending theory which is written below.

\[ M.R = \frac{M.C}{I} \]

The obtained values are showe in (table 1). The maximum value was 898.56 Mpa while the minimum value was 35.1 Mpa. There is big difference between the result and this may be caused by non-homogeneity of the material and also to these reasons mentioned previously.
Mohammed G. [12] studied the flexural strength of hard wood and softwood and show that the modulus of rupture of hardwood was about 20% greater than the modulus of rupture of softwood, where the modulus of rupture of hardwood was about 82 MPa while the modulus of rupture of softwood was 65.5 Mpa.

Baar. et. al. [13] also studied the modulus of rupture of different types of hardwood and obtained the valves of modulus of rupture ranged between (110.46 and 133.28) Mpa this because ranged may be due to different grain characteristics of hardwood.

| Sample No. | Modulus of Rupture (Mpa) | Modulus of Elasticity (Mpa) |
|------------|-------------------------|-----------------------------|
| 1          | 842.4                   | 26017.10526                 |
| 2          | 877.5                   | 49432.5                     |
| 3          | 898.56                  | 49432.5                     |
| 4          | 842.4                   | 26017.10526                 |
| 5          | 877.5                   | 49432.5                     |
| 6          | 870.48                  | 26017.10526                 |
| 7          | 631.8                   | 19773                       |
| 8          | 561.6                   | 19773                       |
| 9          | 702                     | 5955.722892                 |
| 10         | 210.6                   | 10985                       |
| 11         | 193.05                  | 8238.75                     |
| 12         | 210.6                   | 10985                       |
| 13         | 157.95                  | 9886.5                      |
| 14         | 263.25                  | 10517.55319                 |
| 15         | 105.3                   | 32955                       |
| 16         | 157.95                  | 7605                        |
| 17         | 35.1                    | 988.65                      |
| 18         | 31.59                   | 760.5                       |
| 19         | 35.1                    | 988.65                      |
| 20         | 28.08                   | 1235.8125                   |
| 21         | 31.59                   | 1098.5                      |
| 22         | 59.67                   | 1235.8125                   |

**Figure 1.1.** the relationship between load and deflection for sample (1) of wood

**Figure 1.2.** the relationship between stress and strain for sample (1) of wood

\[ E = \text{Slope} = 22814.993 \text{ MPa} \]
Figure 2.1. the relationship between load and deflection for sample (2) of wood

Figure 2.2. the relationship between stress and strain for sample (2) of wood

Figure 3.1. the relationship between load and deflection for sample (3) of wood

Figure 3.2. the relationship between stress and strain for sample (3) of wood

Figure 4.1. the relationship between load and deflection for sample (4) of wood

Figure 4.2. the relationship between stress and strain for sample (4) of wood
Figure 5.1. the relationship between load and deflection for sample (5) of wood

Figure 5.2. the relationship between stress and strain for sample (5) of wood

Figure 6.1. the relationship between load and deflection for sample (6) of wood

Figure 6.2. the relationship between stress and strain for sample (6) of wood

Figure 7.1. the relationship between load and deflection for sample (7) of wood

Figure 7.2. the relationship between stress and strain for sample (7) of wood
Figure 8.1. the relationship between load and deflection for sample (8) of wood

Figure 8.2. the relationship between stress and strain for sample (8) of wood

Figure 9.1. the relationship between load and deflection for sample (9) of wood

Figure 9.2. the relationship between stress and strain for sample (9) of wood

Figure 10.1. the relationship between load and deflection for sample (10) of wood

Figure 10.2. the relationship between stress and strain for sample (10) of wood
Figure 11.1. the relationship between load and deflection for sample (11) of wood

Figure 11.2. the relationship between stress and strain for sample (11) of wood

Figure 12.1. the relationship between load and deflection for sample (12) of wood

Figure 12.2. the relationship between stress and strain for sample (12) of wood

Figure 13.1. the relationship between load and deflection for sample (13) of wood

Figure 13.2. the relationship between stress and strain for sample (13) of wood
Figure 14.1. the relationship between load and deflection for sample (14) of wood

Figure 14.2. the relationship between stress and strain for sample (14) of wood

Figure 15.1. the relationship between load and deflection for sample (15) of wood

Figure 15.2. the relationship between stress and strain for sample (15) of wood

Figure 16.1. the relationship between load and deflection for sample (16) of wood

Figure 16.2. the relationship between stress and strain for sample (16) of wood
Figure 17.1. the relationship between load and deflection for sample (17) of wood

Figure 17.2. the relationship between stress and strain for sample (17) of wood

Figure 18.1. the relationship between load and deflection for sample (18) of wood

Figure 18.2. the relationship between stress and strain for sample (18) of wood

Figure 19.1. the relationship between load and deflection for sample (19) of wood

Figure 19.2. the relationship between stress and strain for sample (19) of wood
The relationship between load and deflection for sample (20) of wood

The relationship between stress and strain for sample (20) of wood

The relationship between load and deflection for sample (21) of wood

The relationship between stress and strain for sample (21) of wood

The relationship between load and deflection for sample (22) of wood

The relationship between stress and strain for sample (22) of wood
6. The conclusions and recommendations

From the tests made for the wooden specimens the following conclusion can be written:

a. The load – deflection diagrams of wood were draw and they have a small linear part and large curvilinear part. The graph shows that the wood material is closer to ductile behavior than brittle one.

b. There are different values of modulus of elasticity ranging from 760.5 Mpa to 49432.5 Mpa. These values are about close to the values of concrete.

c. The values of modules of rupture of wood specimen were between 35.1 to 898.56 Mpa which are much larger than the values of concrete.

d. The stress – strain diagrams of wood can be drawn from the load deflection diagram. The maximum strain was 0.07 while minimum strain was 0.00169.

e. The modulus of elasticity and the modulus of rupture is the mean important mechanical properties of wood.

f. The researchers recommend that the engineers must be careful when they select the specimen of wood for testing.

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