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# MECHANICAL PROPERTIES OF TIMBER FOR ENGINEERING APPLICATIONS

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## Introduction

Before timber was replaced by concrete and steel, it was extensively used as a building material. Today, although the use of timber as building components has declined, it is still preferred in some areas. To evaluate timber for its use in structural or non-structural applications, several testings need to be carried out to determine its strength and elastic properties. Mechanical property of timber is the ability of timber to withstand maximum load or force before ultimate deformation takes place. Timber has an anisotropic feature whereby the mechanical properties differ between the grain directions i.e. along the grain or across the grain. Beginning from the inner side, timber is made up of pith, rays, vascular cambium, bark, cork cambium and cork (Figure 1) that differentiate a species from another. Timber mechanical properties are also affected by the cutting pattern i.e. tangentially, radially or longitudinally.

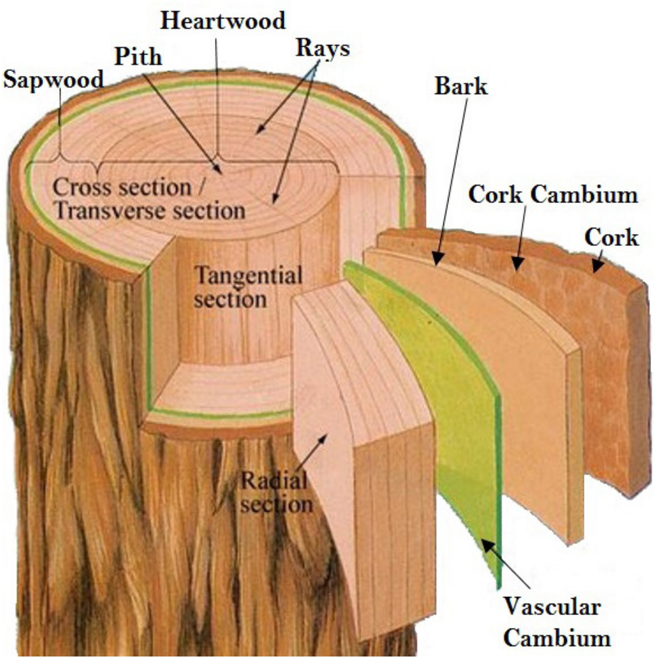


**Figure 1** Cross section of a timber (http://www.doitpoms.ac.uk)

To use timber in structural applications, the relevant mechanical properties to be determined are the modulus of elasticity, modulus of rupture, maximum compressive stress along the grain, maximum shear stress along the grain and maximum tensile stress along the grain. Table 1 shows the importance of the timber mechanical properties.

**Table 1** Mechanical properties of timber (Haygreen, JG & Bowyer, JL (1989) Forest Products and Timber Science)

| Properties | Importance of the properties |
|---|---|
| **Strength properties** | |
| Bending strength (modulus of rupture) | To determine the load a beam will carry |
| Compression strength parallel to the grain | To determine the load a short post will carry without bending |
| Tension strength parallel to the grain | Needed in the design of connections between structural members |
| Shear strength parallel to the grain | Needed in the design of beams and connections |
| **Elastic properties** | |
| Modulus of elasticity in bending | To measure resistance to bending (factor in the strength of a long post) and to predict beam deformation |
| Modulus of elasticity parallel to the grain (Young's modulus) | To measure the resistance to elongation or shortening of a specimen under uniform tension or compression. |

The importance of mechanical properties of timber can be observed in everyday life. For example, elasticity defines the stiffness of timber (Haygreen & Bowyer, 1989). It is a feature of the timber to regain its original shape after an applied stress is removed. When a house is constructed from timber, these properties are taken into consideration to ensure safety. Figure 2 shows a house model depicting how bending, tension and compression exist and give effect to the timber structure.

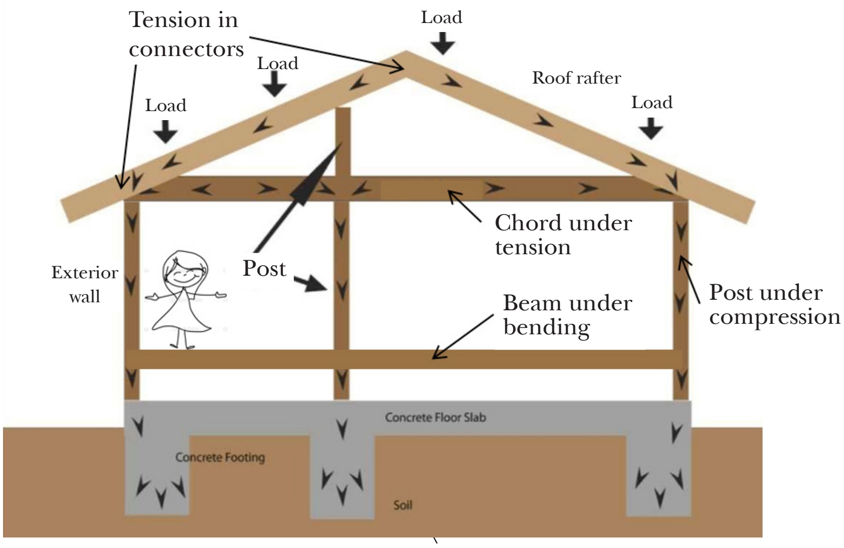


**Figure 2** A model of a wooden house (https://www.i.ytimg.com)

The roof truss or roof rafter will transfer force (load) downwards evenly to every post or column that is supporting it. The force is exerted by the roof tiles, purlins, self-weight of the roof truss, workers and downward wind. The truss chord will experience tensile force when downward force is acting on both rafters of the truss. The floor beam will bend under point or distributed load due to the weights of the occupants, furniture or equipments. In a bent beam, the fibres in the bottom region of the neutral axis will be under tension while the fibres in the upper region will be under compression (Figure 3). Loads gathered from floor boards are initially transferred to the joists, then to the beams before transferred to the posts. The posts of a house receives the major amount of compressive force along the grain. For that reason the posts are the strongest elements of the structure to support the total force from the roof and floor system.

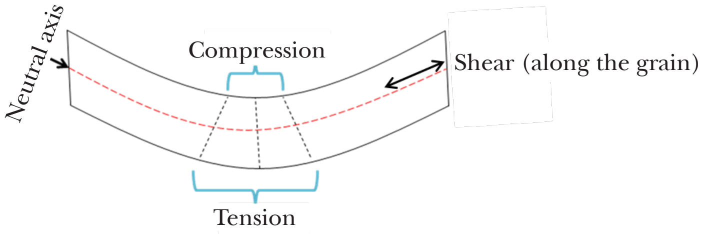


**Figure 3** A schematic of a bent timber beam

## Stress and strain

To correctly measure the mechanical properties of timber, a universal testing machine is essential in every engineering laboratory. During bending, tension and compression tests, timber experiences stress and strain. Stress is defined as the force per unit area of the timber while strain is the ratio between the deformation and the original dimension parallel to the applied force. When a force acts upon a timber component, a stress is produced which causes the timber to deform from an elastic to a plastic character before it reaches the ultimate deformation or breakage.

## Bending

A three-point (two supports and one load) load test can be used to measure the bending strength and elasticity of timber. When a load, $F$, is applied at the centre, it will experience a vertical deflection (or deformation), $\Delta$, as can be observed in Figure 4.

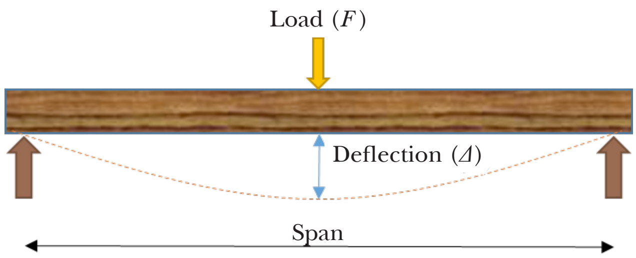


**Figure 4** A deflection, $\Delta$, occurs when a load, $F$, is applied onto the timber

When the corresponding values of load, span, specimen dimensions and deflection are known, the modulus of elasticity (MOE) can be evaluated, whilst when the values of the maximum breaking load, span and specimen dimensions are known it is possible to evaluate the modulus of rupture (MOR) based on the following formulae:

$$\text{Modulus of elasticity} = \frac{1}{4}\left(\frac{F}{\Delta}\,\frac{L^3}{bd^3}\right) \quad \text{N/mm}^2$$

$$\text{Modulus of rupture} = \frac{3}{2}\left(\frac{F_{max}L}{bd^2}\right) \quad \text{N/mm}^2$$

Where,
$F$ = load (N)
$F_{max}$ = maximum load (N)
$\Delta$ = deflection (mm)
$b$ = width of specimen (mm) (measured perpendicular to load)
$d$ = depth of specimen (mm) (measured parallel to load)
$L$ = span between supports (mm)
$\frac{F}{\Delta}$ = slope of the load vs deflection graph
(Explanation on the derivation of MOE is shown in the Appendix.)

## Relationship between Load, $F$ and Deflection, $\Delta$

Referring to Figure 5, at the beginning of a bending test, a timber specimen is experiencing linearity such that the graph shows a straight line. This linear part of the curve is also known as the elastic zone, and it is the region where the Young's Modulus of Elasticity value is evaluated. Timber will always preserve its original shape when an applied force is removed while in the elastic zone i.e. before it reaches the limit of proportionality or elasticity. As the applied force is increased, the graph starts to become curvilinear (plastic zone) after passing the limit of proportionality until it reaches the rupture point which is considered as the maximum load the specimen can withstand.

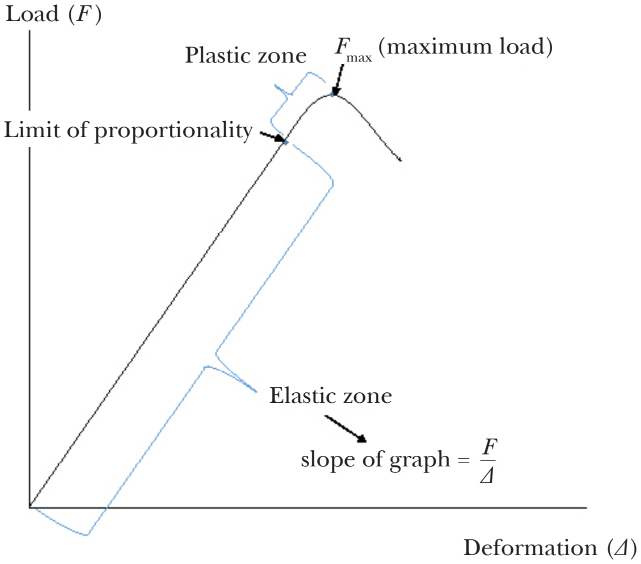


**Figure 5** A graph of load (or force) versus deflection

## Tension

Tensile strength of timber is vital for the design of fabricated timber structures such as trusses, panels, laminated beam, and other manufactured composites (Haygreen & Bowyer, 1989). The regular component that receives tensile force would be the chord of a roof truss when the loading on the roof is downwards as shown in Figure 6. Another situation where timber would normally receive tensile force would be at the end fibres of a flexured beam i.e. below the neutral axis as shown previously in Figure 3. Maximum tensile stress along the grain is evaluated by testing specimens that are cut into dumb bell shape as in Figure 7.

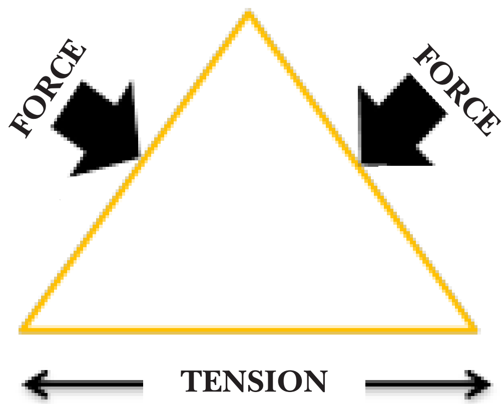


**Figure 6** A triangle resembling a roof truss shows how downward forces result in tension going outwards at the bottom chord

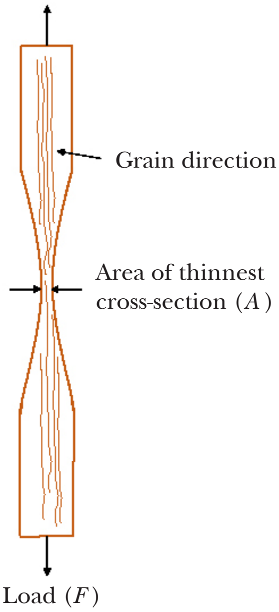


**Figure 7** Tensile test on timber

The maximum tensile stress parallel to grain, $\delta_{Tensilemax}$, is evaluated as,

$$\text{Maximum tensile stress, } \delta_{Tensilemax} = \frac{\text{Maximum force}}{\text{Area of cross} - \text{section}} = \frac{F_{max}}{A} \ \text{N/mm}^2$$

Where,

$F_{max}$ = maximum tensile load (N)

$A$ = area at the thinnest cross-section of the specimen ($mm^2$)

## Compression

Compression parallel to the grain test of timber also produces similar load versus deformation graph as in bending or tension. However, the graph is steeper due to the very small deformation in compression as compared to bending. Figure 8 shows the typical types of failure that can be obtained during a compression parallel to the grain test.

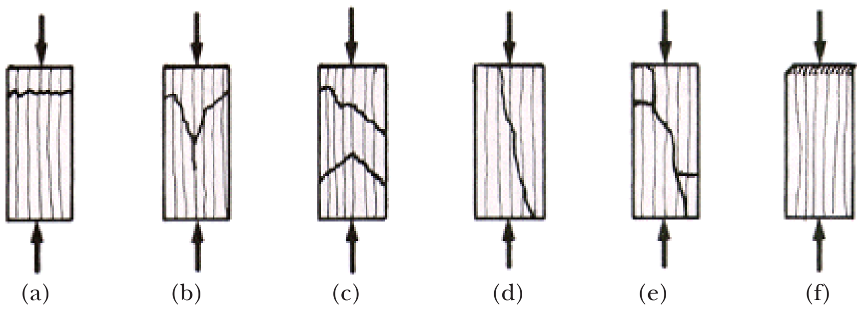


**Figure 8** Types of failure in compression test parallel to grain (a) crushing, (b) wedge splitting, (c) shearing, (d) splitting, (e) crushing and splitting, (f) brooming or end rolling (https://www.classes.mst.edu)

For compression parallel to grain test as shown in Figure 9, the

$$\text{Maximum compressive stress, } \delta_{Compressmax} = \frac{\text{maximum compressive load } (F)}{\text{Area of cross} - \text{section } (A)} \quad \text{N/mm}^2$$

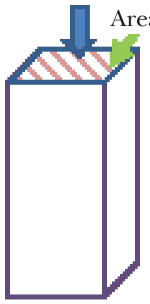


**Figure 9** Compression parallel to the grain

## Shear Parallel to Grain

Shear parallel to the grain happens when force acts upon an area of timber fibres that causes the fibres to slide in the same direction of the force. Shear strength is important during the design of connectors such as bolts and nuts whereby the force parallel to the fibres or grain can cause the area between the hole for the bolts and the end of the timber component to slide away or shear. Shear along the grain also happens during bending of a short beam (as shown in Figure 3 previously)

For shear parallel to the grain test as shown in Figure 10,

$$\text{Maximum compressive stress, } \delta_{Shearmax} = \frac{\text{maximum force } (F)}{\text{shear area } (A)} \quad \text{N/mm}^2$$

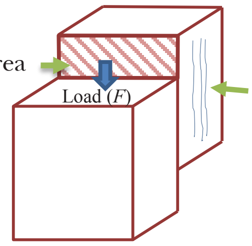


**Figure 10** Shear parallel to the grain

## Summary

The evaluation on the mechanical properties of timber is important before it can safely be used in engineering. The principle of testings does not differ much from the testings of other materials, but with a consideration on the anisotrophic characteristics of timber. Being a biological material, timber is variable in most of its mechanical properties such that an extensive amount of samples must be tested to produce statistically accurate values before they can safely be applied.

## Reference


HAYGREEN JG & BOWYER JL. 1989. *Forest Products and Wood Science*, Iowa State University Press, Ames, Iowa, U.S.A

## Appendix

### Derivation of Modulus of Elasticity in bending

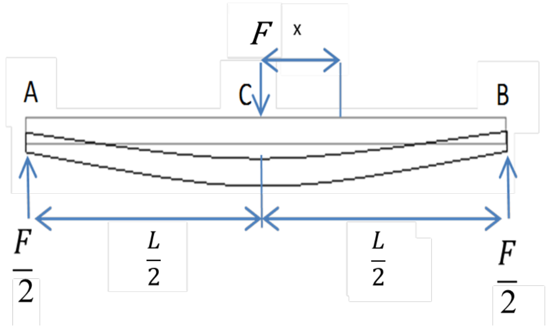


Figure (a)

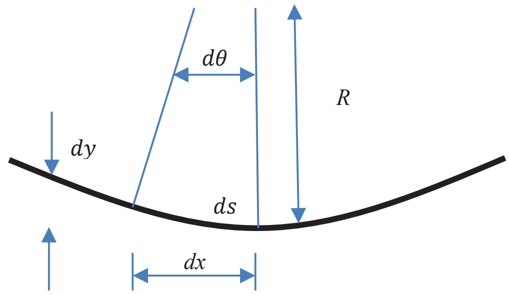


Figure (b)

For small angle, $\frac{dy}{dx} = \tan\theta \approx \theta$ ($\theta$ in radian)

$s = R\theta, \delta s = \delta x$ (for small angle)

$$\frac{1}{R} = \frac{d\theta}{ds} = \frac{d\theta}{dx} = \frac{d}{dx}\left(\frac{dy}{dx}\right) = \frac{d^2y}{dx^2}$$

From known relationship, $\frac{1}{R} = \frac{M}{EI} = \frac{d^2y}{dx^2}$

$$\text{Slope} = \theta = \frac{dy}{dx} = \int\left(\frac{d^2y}{dx^2}\right)dx = \int\frac{M}{EI}dx$$

Where, EI is the flexural stiffness.

Integrating between two limits and hence the deflection,

$$\text{Deflection} = y = \int \theta dx = \int\frac{dy}{dx}dx = \iint\frac{M}{EI}dx$$

$$\frac{d^2y}{dx^2} = \frac{1}{EI}\left[\frac{F}{2}\left(\frac{L}{2}+x\right) - Fx\right] = \frac{F}{2EI}\left(\frac{L}{2}-x\right)$$

$$\frac{dy}{dx} = \int\frac{F}{2EI}\left(\frac{L}{2}-x\right)dx = \frac{F}{2EI}\left(\frac{Lx}{2}-\frac{x^2}{2}\right) + c_1 \ldots$$

(Boundary condition: $c_1 = 0$ because $\frac{dy}{dx} = 0 \; at \; x = 0$)

$$y = \int\frac{F}{2EI}\left(\frac{Lx}{2}-\frac{x^2}{2}\right)dx = \frac{F}{2EI}\left(\frac{Lx^2}{4}-\frac{x^3}{6}\right) + c_2$$

(Boundary condition: $y = 0$)

When $x = \frac{L}{2}$, therefore $\frac{F}{EI}\left(\frac{L^3}{8}-\frac{L^3}{12}\right) + c_2 = 0$

And, thus $c_2 = -\frac{FL^3}{48EI}$.

At the end, $B\left(\frac{dy}{dx}\right)_b = -\frac{F}{2EI}\left(\frac{L^2}{4}-\frac{L^2}{8}\right) = \frac{FL^2}{16EI}$ , and

$$y_B = \frac{F}{EI}\left(\frac{L^3}{8} - \frac{L^3}{12}\right) - \frac{FL^3}{48EI} = 0 \,.$$

At the centre $C, x = 0$

$$y_c = -\frac{FL^3}{48EI} \qquad \left(slope\ \frac{dy}{dx} = 0 \ \text{ by symmetry}\right)$$

in several methods, the deflection at centre $y_c$ is designated as the letter Δ (delta).

Where,

$R$ = radius of arbitrary circle
$E$ = modulus of elasticity
$I$ = moment of inertia
$L$ = span length between supports
$\theta$ = angle of segment
$x$ = horizontal axis of beam
$y$ =vertical axis of beam
$s$ = arc length
$F$ = point load at centre
$M$ = moment at distance $x$
*c1,c2* = constants of integrals



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