

Statistical analysis of mechanical properties of wood



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ABSTRACT

It is a known fact that wood is a very good material for structural building components. This paper attempts to carry out a series of statistical analyses to show the relationship or correlation between different types of wood as relates to their different mechanical properties. An analytical method was used to calculate the values of the parameters, while some statistical concepts were adopted to find the relationship and correlation between them. Computer software– Maple, was used to draw the graphs. The results give some information useful for structural engineers in taking important decisions. Some of the striking results are that average stiffness of the American hardwoods, considered in this paper, is greater than average stiffness of the American softwoods, and there is a little positive correlation between the bending stiffness and the compressive stiffness of America hardwoods.

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1. Introduction

Wood as an anisotropic material, is extraordinary compared to other materials used to produce structural building components. Wood has several kinds of strength. For a rough, general gauge of quality, allude to the specific gravity or density of the wood. Both the compressive strength and the bending strength of a piece of wood can be measured, usually in 'psi', which stands for; pounds per square inch. Also the stiffness and hardness of a piece of wood can be discovered by Engineers by driving a metal ball into the wood's surface.

It is an organic material, a natural composite of cellulose fibres that are strong in tension and embedded in a matrix of lignin that resists compression. Wood has been used for many years for furniture mainly and for fuel, making tools and weapons, paper, feedstock, purified cellulose and for construction. Wood is quite unique when compared to other building materials given that its material makeup is a result of naturally grown biological tissue.

The directionally dependent property of wood is a result of the horizontal or vertical orientation of

the individual cells and the arrangements of growth layers in a tree (Dinwoodie, 2000). Architects, engineers and members of the timber industry considers wood complex material characteristics has often been characterized as deficiencies (Alcorn, 1996). Wood's ecological advantages makes it an appealing material. It is becoming increasingly recognized that very few building materials can rival wood's environmental benefits. Wood is a natural, renewable material that holds a very low level of embodied energy. It is known for its ability to reduce carbon dioxide emissions by storing CO₂ and also by substituting for materials with high carbon content (Alcorn, 1996). In this manner, the use of wood actually produces a positive carbon footprint (Kolb, 2008). Wood is also an extremely energy efficient building material in its production. For example, wood requires 50 times less energy in its manufacturing than steel to ensure a given structural stiffness as a whole (Gordon, 2009). As a result of wood's naturally-grown origin, its unique material composition accounts for most of its properties and characteristics (Jeronimidis and Barnett, 2003). On the microscopic scale, one can describe wood as a natural fibre composite (Ryan, 2010; Hoadley, 2000; Wagenführ, 1999).

There are basically two categories of wood, namely; the hardwood and the soft wood. The goal of statistical analysis is to identify trends (Mendoza, 2014; Rouse, 2014). The Statistical methods used include; Mean Correlation and regression analysis. The correlation between two entities is represented by r . The value of r is such that $-1 \leq r \leq +1$. The + and

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- signs are used for positive linear correlations and negative linear correlations, respectively. If x and y have a strong positive linear correlation, r is close to +1. An r value of exactly +1 indicates a perfect positive fit. Positive values indicate a relationship between x and y variables such that as values for x increase, values for y also increase. If x and y have a strong negative linear correlation, r is close to -1. An

r value of exactly -1 indicates a perfect negative fit. A study utilizing scientific data may require a stronger correlation than a study using social science data (Hoffman, 1992). In this paper, statistical analysis of some mechanical properties of selected species of wood, using a secondary data, from 'Workshop Companion', was carried out. Also, Tables 1, 2 and 3 are used for calculation.

Table 1: North American Hardwoods

Wood Species	Specific Gravity	Compressive Strength (psi)	Bending Strength (psi)	Stiffness (Mpsi)
Alder Red	0.41	5,820	9,800	1.38
Ash	0.60	7,410	15,000	1.74
Aspen	0.38	4,250	8,400	1.18
Basswood	0.37	4,730	8,700	1.46
Beech	0.64	7,300	14,900	1.72
Birch, Yellow	0.62	8,170	16,600	2.01
Butternut	0.38	5,110	8,100	1.18
Cherry	0.50	7,110	12,300	1.49
Chestnut	0.43	5,320	8,600	1.23
Elm	0.50	5,520	11,800	1.34
Hickory	0.72	9,210	20,200	2.16
Maple, Hard	0.63	7,830	15,800	1.83
Maple, Soft	0.54	6,540	13,400	1.64
Oak, Red	0.63	6,760	14,300	1.82
Oak, White	0.68	7,440	15,200	1.78
Poplar	0.42	5,540	10,100	1.58
Sassafras	0.46	4,760	9,000	1.12
Sweetgum	0.52	6,320	12,500	1.64
Sycamore	0.49	5,380	10,000	1.42
Walnut	0.55	7,580	14,600	1.68

Table 2: North American Softwoods

Wood Species	Specific Gravity	Compressive Strength (psi)	Bending Strength (psi)	Stiffness (Mpsi)
Cedar, Aromatic Red	0.47	6,020	8,800	0.88
Cedar, Western Red	0.32	4,560	7,500	1.11
Cedar, White	0.32	3,960	6,500	0.80
Cypress	0.46	6,360	10,600	1.44
Fir, Douglas	0.49	7,230	12,400	1.95
Hemlock	0.45	7,200	11,300	1.63
Pine, Ponderosa	0.40	5,320	9,400	1.29
Pine, Sugar	0.36	4,460	8,200	1.19
Pine, White	0.35	4,800	8,600	1.24
Pine, Yellow	0.59	8,470	14,500	1.98
Redwood	0.35	5,220	7,900	1.10
Spruce, Sitka	0.40	5,610	10,200	1.57

Table 3: World wood (other than North America)

Wood Species	Specific Gravity	Compressive Strength (psi)	Bending Strength (psi)	Stiffness (Mpsi)
Bubinga	0.71	10,500	22,600	2.48
Jelutong	0.36	3,920	7,300	1.18
Lauan	0.40	7,360	12,700	1.77
Mahogany, African	0.42	6,460	10,700	1.40
Mahogany, Honduras	0.45	6,780	11,500	1.50
Purpleheart	0.67	10,320	19,200	2.27
Rosewood, Brazilian	0.80	9,600	19,000	1.88
Rosewood, Indian	0.75	9,220	16,900	1.78
Teak	0.55	8,410	14,600	1.55

2. Statistical analysis

The above data is a secondary data collected in order to discover underlying patterns and trends of mechanical properties of wood generally. The statistical problem, in this paper, includes estimation of the relationship between the mechanical properties of the wood species. Also, the average of the mechanical properties values of different wood species have to be determined. The following Statistical methods were used for the statistical analysis: Mean Regression and Correlation.

• *Specific Gravity Mean (SGM)*

$$\frac{\sum_1^n x}{n} = \frac{\sum_1^{20} x}{20} = \frac{10.47}{20} = 0.5235 \tag{1}$$

$$\frac{\sum_1^n x}{n} = \frac{\sum_1^{12} x}{12} = \frac{4.96}{12} = 0.41333 \tag{2}$$

$$\frac{\sum_1^n x}{n} = \frac{\sum_1^9 x}{9} = \frac{5.11}{9} = 0.56778 \tag{3}$$

• *Compressive Strength Mean (CSM)*

$$\frac{\sum_1^n x}{n} = \frac{\sum_1^{20} x}{20} = \frac{110620}{20} = 5531 \tag{4}$$

$$\frac{\sum_1^n x}{n} = \frac{\sum_1^{12} x}{12} = \frac{69210}{12} = 5767.5 \tag{5}$$

$$\frac{\sum_1^n x}{n} = \frac{\sum_1^9 x}{9} = \frac{72570}{9} = 8063.33 \tag{6}$$

• *Bending Strength Mean (BSM)*

$$\frac{\sum_1^n x}{n} = \frac{\sum_1^{20} x}{20} = \frac{249300}{20} = 12465 \tag{7}$$

$$\frac{\sum_1^n x^2}{n} = \frac{\sum_1^{12} x^2}{12} = \frac{115900}{12} = 9658.33 \tag{8}$$

$$\frac{\sum_1^n x}{n} = \frac{\sum_1^9 x}{9} = \frac{134500}{9} = 14944.44 \tag{9}$$

• *D. Stiffness Mean (SM)*

$$\frac{\sum_1^n x}{n} = \frac{\sum_1^{20} x}{20} = \frac{31.4}{20} = 1.57 \tag{10}$$

$$\frac{\sum_1^n x}{n} = \frac{\sum_1^{12} x}{12} = \frac{16.18}{12} = 1.3483 \tag{11}$$

$$\frac{\sum_1^n x}{n} = \frac{\sum_1^9 x}{9} = \frac{15.81}{9} = 1.7567 \tag{12}$$

3. Regression

A scatterplot can be a helpful tool in determining the strength of the relationship between the compressive strength and the bending strength of the wood species considered in this paper. A linear regression line has an equation of the form:

$$Y = a + b X \tag{13}$$

where *X* is the explanatory variable and *Y* is the dependent variable.

The slope of the line is *b*, and *a* is the intercept (the value of *y* when *x* = 0).

Now applying this to the relationship between the species in American hardwoods data (Table 4):

Table 4: Compressive and bending strengths of American hardwoods

Wood Species	Compressive Strength (X)	Bending Strength (Y)
Alder, Red	5,820	9,800
Ash	7,410	15,000
Aspen	4,250	8,400
Basswood	4,730	8,700
Beech	7,300	14,900
Birch, Yellow	8,170	16,600
Butternut	5,110	8,100
Cherry	7,110	12,300
Chestnut	5,320	8,600
Elm	5,520	11,800
Hickory	9,210	20,200
Maple, Hard	7,830	15,800
Maple, Soft	6,540	13,400
Oak, Red	6,760	14,300
Oak, White	7,440	15,200
Poplar	5,540	10,100
Sassafras	4,760	9,000
Sweetgum	6,320	12,500
Sycamore	5,380	10,000
Walnut	7,580	14,600

$$Y = a + b X$$

$$b = \frac{n \sum(xy) - (\sum x)(\sum y)}{n \sum x^2 - (\sum x)^2}$$

$$= \frac{20(1678571000) - (104060)(249300)}{20(818391800) - (104060)^2}$$

$$= \frac{7629262000}{5539352400} = 1.38 \tag{14}$$

$$a = \frac{\sum Y - b \sum X}{n}$$

$$= \frac{(249300) - 1.38(104060)}{20}$$

$$= 5284.86 \tag{15}$$

$$\therefore Y = 5284.86 - 1.38 X \tag{16}$$

4. Correlation

A measure that determines the degree to which two variable's movements is associated. The *correlation coefficient (r)* is used. The mathematical formula for computing *r* is:

$$\therefore r = \frac{n \sum xy - (\sum x)(\sum y)}{\sqrt{n(\sum x^2) - (\sum x)^2} \sqrt{n(\sum y^2) - (\sum y)^2}} \tag{17}$$

where *n* is the number of pairs of data.

$$r = \frac{20(167857100) - (104060)(249300)}{\sqrt{20(818391800) - (104060)^2} \sqrt{20(3112214000) - (249300)^2}}$$

$$r = \frac{762926200}{(7442682581)(93790000)}$$

$$r = 0.0011 \tag{18}$$

Similar regression and correlation analyses can be carried out on American softwood data and world wood (other than North America), but for brevity only that of American hardwoods was considered in this paper.

5. Results and discussion

The mean value of the specific gravity, compressive strength, bending strength and stiffness, for the wood specie were computed for the three categories considered: American hardwoods, American softwoods, and world woods not in North America. It was observed that the average of specific gravity of world wood is greater than that of American hardwoods, which in turn is greater than that of American softwoods. The compressive strength of American softwoods is the lowest, followed by the American hardwoods. The world wood has the highest compressive strength average. This implies that world woods can resist external force that causes reduction in size, than the American woods.

The bending strength mean for world wood is the highest, followed by that of American hardwoods. The American softwoods, however, has the least

average value. This implies that the average resistance of world woods, not in North America, to the bending force is more than both the American hardwoods and softwoods. The American softwoods have least resistance to the bending force. The stiffness average of the American softwoods is the least, followed by that of American hardwoods. The world woods have the highest value. This means that American woods have the least resistance to external loading, while the world woods resist the external forces more.

The regression graph in Fig. 1, shows that a negative relationship between the compressive strength and bending strength, for the American hardwoods category of wood species. The meaning of this is that the higher the bending strength the lower the compressive strength of the American hardwoods. In other words, the resistant the American hardwood species are to external forces to deformation, the less resistance they will show to external forces that lead to reduction in size. There is a little positive correlation between the bending stiffness and the compressive stiffness of America hardwoods. This implies that the strength and the direction of a linear relationship between them is very small.

6. Conclusion

This paper sets out to analyze, using statistical tools, some mechanical properties of selected wood species in order to know their strength and make comparisons. Secondary data of American hardwoods, American softwoods and world woods, not in North America, were used for the analysis. In particular, measure of central tendency, regression analysis and correlation analysis were carried out on the values of specific gravity, compressive strength, bending strength and stiffness of the wood species. With the results obtained, based on the data used, one can take an informed decision as regards the trend and relationship between the wood species; the mean of the mechanical properties is useful in determining the overall trend of the data used. It also provides a rapid snapshot of the data.

For instance, the average stiffness of America hardwood is greater than the average stiffness of America softwoods. Also, from the results obtained, it was obvious that the relationship between the compressive strength and bending strength of the wood species considered in this paper is very weak, though positive.

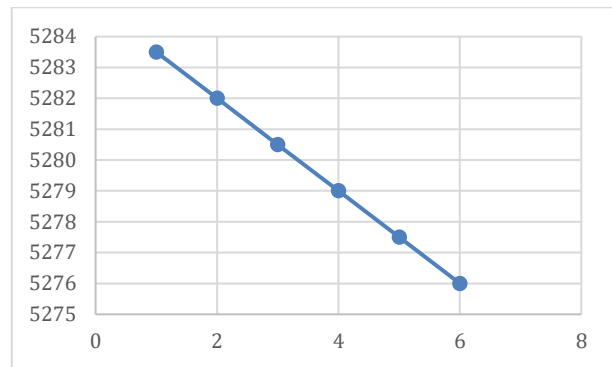


Fig. 1: Relationship between the compressive strength and bending strength of American hardwoods

Compliance with ethical standards

Conflict of interest

The authors declare that they have no conflict of interest.

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