Development of EN 338(2003) Strength Classes of Doka (*Isoberlinia doka),* Madaci (*Khaya senegalensis*) Gawo (*Acacia albida*) and Rimi (*Ceiba pentandra*) Timber Species of Nigerian Origin

By

Ismaila RABIU
M.Sc/Eng/10150/2007-2008

A thesis submitted to the Postgraduate School
Ahmadu Bello University Zaria, Nigeria
In partial fulfillment of the requirements for the award of degree of
Master of Science in Civil Engineering

Department of Civil Engineering
Faculty of Engineering
Ahmadu Bello University, Zaria
Nigeria

December, 2012

DECLARATION

I hereby declare that this project titled "Development of EN 338 Strength Classes of Doka (*Isoberlinia doka),* Madaci (*Khaya senegalensis*) Gawo (*Acacia albida*) and Rimi (*Ceiba pentandra*) Timber Species of Nigerian Origin" is solely my work in the Department of Civil Engineering under the supervision of Engr.(Dr). Idris Abubakar. It has not been used for any degree outside this department.

_____ _____

Ismaila Rabiu Date

CERTIFICATION

This thesis titled "Development of EN 338 (2003) Strength Classes of Doka (Isoberlinia doka), Madaci (Khaya senegalensis) Gawo (Acacia albida) and Rimi (Ceiba pentandra) Timber Specie of Nigerian Origin" by Ismaila Rabiu meets the regulations governing the award of the Master degree in Ahmadu Bello University, Zaria and is approved for its contribution to knowledge and literary presentation.

_____ _____

Dr. I. Abubakar Date

Chairman Supervisory Committee

_____ _____

Prof. S.P. Ejeh Date

Member, Supervisory Committee

_____ _____

Dr. I. Abubakar Date

Head of Department

_____ _____

Prof. A.A. Joshua Date

Dean, Postgraduate School

DEDICATION

This thesis is dedicated to my aged mother and deceased father, as their success also mine, without Allah's blessing and their support and assistance I would not have accomplished this program. I pray to Almighty Allah to make Al-Janna Firdausi their final abode.

ACKNOWLEDGEMENTS

First and foremost, all praise and gratitude goes to Allah Subhanahu wa Ta'ala, the most Gracious, the Merciful, and peace be upon his Prophet for giving me the strength, health, patience, and courage to finish my master degree programme.

My immeasurable and sincere appreciations goes to my supervisor Engr. (Dr.) Idris Abubakar, for his valuable guidance, support and encouragement through all this work, more especially the time he spared to read through my research work, thanks for his inspirational and encouragement talk for embarking on the work as he never doubted the relevance of the study and my ability to complete. Special thanks to my second supervisor Prof. S.P. Ejeh for his assistance, much helpful insight and valuable suggestion throughout the work, my sincere appreciation goes to the following for their immense contribution for the accomplishment of this thesis.

My parent for proper upbringing, educational love and care, who I dedicated this work to, and may Allah grant them paradise. Ameen.

Arc.(Mrs.) Uwani I. Sulaiman for her unwavering support, patience and believe in me , she taught me the importance of commitment and accomplishment, I am truly blessed with a wonderful Director, she named me her ***Baby Engineer,*** the name I am always fraud up, the name that came out of hope and sympathy of a mother to her only child; this name, whenever inspirationally call by her , it empower, build confidence and create hope in my heart, may Allah accept her did and that of her beloved parent, continue to give her what she want in this life and the hereafter and make *Lailaha illallahu* her final statement. Ameen.

Here comes one of the committed servant of Allah, Alhaji Hassan Buba for his financial and moral support may Allah increase him in knowledge and more tolerance to accommodate our childish mistakes and behaviors. Amen.

My entire family especially my wives Rukayya Ahmad and Halima Salisu for being supportive, even when my mind seemed to be so attracted to my thesis while they were by my side. May Allah forgive us and bless our offspring. Ameen.

Other colleagues, Malam Sani Mudi and Abdulkarim Ibrahim for their brotherly advice and assistance .may Allah reward them abundantly.

Finally, special thanks to the members of the academic and non -academic staff of Civil Engineering Department ABU Zaria and Federal College of Education, Zaria for permission and sponsorship May Allah bless the college with good leaders. Ameen

TABLE OF CONTENTS

		Page
Title Page		i
Declaration		ii
Approval Page		iii
Dedication		iv
Acknowledgments		v
Tables of Contents		vii
Abstract		xvi
	CHAPTER ONE: INTRODUCTION	
1.1	Preamble	1
1.2	Problem Statement and Justification of the Research-	2
1.3	Aim and Objectives	3
	CHAPTER TWO: LITERATURE REVIEW	
2.1	General	5
2.2	The Tested Tree Spices	5
2.3	Moisture Content of Timber	8
2.4	Density of Sold Timber	10
2.5	Modulus of Elasticity	11
2.6	Derived Material Properties	13

CHAPTER THREE: MATERIALS AND METHODS

3.1 Materials 14

3.2 Methods 15

3.2.1 Bending Strength Test 16

3.2.2 Global Modulus of Elasticity 18

3.2.3 Moisture Content 19

3.2.4 Density 20

3.2.5 Bending strength 20

CHAPTER FOUR; RESULTS AND DISCUSSION

4.2 Moisture Content 25

4.3 Density 26

4.4 Modulus of Elasticity E_m and Bending Strength F_m 27

4.5 Derived Material Properties 30

4.6 Theoretical Distribution Models 34

4.7 Analysis of variance on Laboratory Data 55

4.8 Strength Grading to EN 338 (2003) 62

4.9 Summary 63

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

5.1 Conclusion 65

5.2 Recommendations 66

5.3 References 67

LIST OF FIGURES

Figure **Page**

4.1 Probability Density Function Plot or *Isoberlinia doka*, Considering Density as Normal Distribution 35

4.2 Probability Density Function Plot for *Isoberlinia doka* considering Density as Lognormal Distribution 35

4.3 Probability Density Function Plot for *Isoberlinia doka* considering Density as Gumbel Distribution 36

4.4 Probability Density Function Plot for *Khaya senegalensis* considering Density as Normal Distribution 36

4.5 Probability Density Function Plot for *Khaya senegalensis,* Considering Density as Lognormal Distribution 37

4.6 Probability Density Function Plot for *Khaya senegalensis,* Considering Density as Gumbel Distribution 37

4.7 Probability Density Function Plot for *Acacia albida,* Considering Density as Normal Distribution 38

4.8 Probability Density Function Plot for *Acacia albida* considering Density as Lognormal Distribution 38

4.9 Probability Density Function Plot for *Acacia albida* considering Density as Gumbel Distribution 39

4.10 Probability Density Function Plot for *Ceiba pentandra,* Considering Density as Normal Distribution 39

4.11 Probability Density Function Plot for *Ceiba pentandra,* Considering Density

as Lognormal Distribution 40

4.12 Probability Density Function Plot for *Ceiba pentandra,* Considering Density as Gumbel Distribution 40

4.13 Probability Density Function Plot for *Isoberlinia doka*, Considering Bending Strength as Normal Distribution 41

4.14 Probability Density Function Plot for *Isoberlinia doka*, Considering Bending Strength as Lognormal Distribution 41

4.15 Probability Density Function Plot for *Isoberlinia doka*, Considering Bending Strength as Gumbel Distribution 42

4.16 Probability Density Function Plot for *Khaya senegalensis*, Considering Bending Strength as Normal Distribution 42

4.17 Probability Density Function Plot for *Khaya senegalensis*, Considering Bending Strength as Lognormal Distribution 43

4.18 Probability Density Function Plot for *Khaya senegalensis*, Considering Bending Strength as Gumbel Distribution 43

4.19 Probability Density Function Plot for *Acacia albida*, Considering Bending Strength as Normal Distribution 44

4.20 Probability Density Function Plot for *Acacia albida*, Considering Bending Strength as Lognormal Distribution 44

4.21 Probability Density Function Plot for *Acacia albida*, Considering Bending Strengt as Gumbel Distribution 45

4.22 Probability Density Function Plot for *Ceiba pentandra*, considering Bending Strength as Normal Distribution 45

4.23 Probability Density Function Plot *Ceiba pentandra*, Considering Bending Strength as Lognormal Distribution 46

4.24 Probability Density Function Plot for *Ceiba pentandra,* Considering Bending Strength as Gumbel Distribution 46

4.25 Probability Density Function Plot for *Isoberlinia doka*, Considering Modulus of Elasticity as Normal Distribution 47

4.26 Probability Density Function Plot for *Isoberlinia doka*,, Considering Modulus of Elasticity as Lognormal Distribution 47

4.27 Probability Density Function Plot for *Isoberlinia doka*, Considering Modulus of Elasticity as Gumbel Distribution 48

4.28 Probability Density Function Plot for *Khaya senegalensis*, Considering Modulus of Elasticity as Normal Distribution 48

4.29 Probability Density Function Plot for *Khaya senegalensis*, Considering Modulus of Elasticity as Lognormal Distribution 49

4.30 Probability Density Function Plot for *Khaya senegalensis* i, Considering Modulus of Elasticity as Gumbel Distribution 49

4.31 Probability Density Function Plot for *Acacia albida,* considering Modulus of Elasticity as Normal Distribution 50

4.32 Probability Density Function Plot for *Acacia albida,* Considering Modulus of Elasticity as Lognormal Distribution 50

4.33 Probability Density Function Plot for *Acacia albida,* Considering Modulus of Elasticity as Gumbel Distribution 51

4.34 Probability Density Function Plot for *Ceiba pentandra* considering

Modulus of Elasticity as Normal Distribution 51

4.35 Probability Density Function Plot for *Ceiba pentandra* considering Modulus of Elasticity as Lognormal Distribution 52

4.36 Probability Density Function Plot for *Ceiba pentandra* considering Modulus of Elasticity as Gumbel Distribution 52

LIST OF TABLES

Table		Page
4.1	Statistics of Moisture Content	26
4.2	Statistics of Density	27
4.3	Statistics of Bending Strength and Modulus of Elasticity of *Isoberlinia Doka*	28
4.4	Statistics of Bending Strength and Modulus of Elasticity of *Khaya senegalensis*	28
4.5	Statistics of Bending Strength and Modulus of Elasticity of *Acacia albida*	29
4.6	Statistics of Bending Strength and Modulus of Elasticity of *Ceiba pentandra*	29
4.7	Derived Material Properties for *Isoberlinia doka*	32
4.8	Derived Material Properties For *Khaya senegalensis*	32
4.9	Derived Materials Properties for *Acacia albida*	33
4.10	Derived Materials Properties for *Ceiba pentandra*	33
4.11	Goodness of Fit *Kolmogorove smirnov* Test Result for Density	54
4.12	Goodness of Fit *Kolmogorove smirnov* Test Result for Bending Strength	55
4.13	Goodness of Fit *Kolmogorove smirnov* Test Result for Modulus of Elasticity	55
4.14	Two-way analysis of variance (ANOVA) for Density between timber species	56
4.15	ANOVA for Density between timber species	57
4.16	Two-way analysis of variance (ANOVA) for Bending strength	58
4.17	ANOVA for Bending Strength within timber species	59
4.18	Two-way analysis of variance (ANOVA) for Modulus of Elasticity	60
4.19	ANOVA for Modulus of Elasticity within timber species	61
4.20	Percentile Values of the References Material Properties	63
4.21	Strength Classes of the Tested Species	64

LIST OF PLATES

Plates		Page
Plate 3.1:	Prepared Material being arranged for conditioning in laboratory	15
Plate 3.2:	The prepared Marked Timber specie for bending Test (Rimi and Doka)	15
Plate 3.3:	Timber specie Marked for four points Test	16
Plate 3.4:	Density and moisture content test specimens of some specie	16
Plate 3.5:	Bending Test in Setup for four point test	18
Plate 3.6:	Bending Test in progress	18
Plate 3.7	Typical Failure Mode of bending test specimen	19

LIST OF APPENDICES

Appendix	Page
Appendix A: Density Test Data	72
Appendix B: Moisture Content	75
Appendix C: Density	79
Appendix D: Bending Test	83
Appendix E: Bending Strength	87
Appendix F: Modulus of Elasticity Test	91
Appendix G: Regression analysis	95

ABSTRACT

In this research work, laboratory experiments were conducted to generate bending strengths, modulii of elasticity, moisture contents and densities of four common timber species: [Doka (*Isoberlinia doka*), Madaci (*Khaya senegal*ensis) Gawo (*Acacia albida*) and Rimi (*Ceiba pentandra*)]. These timber species which are common from Northern Nigeria. Extensive review of relevant literature was undertaken to provide background information on the specie under investigation. The experiments conducted were in accordance with the EN 408 (2003). The generated properties include bending strength, density, modulus of elasticity, other properties such as tension and compression strength parallel and perpendicular to the grain, shear strength and shear modulus were also computed. Two-way analysis of variance (ANOVA) was undertaken using analysis-it software, with the view to examine the equality of mean values of material properties within and between each of the tested species. The results indicated that, all the samples of particular specie considered come from the same population. Likewise, the difference between the mean values of the tested species are significant .The species were assigned to appropriate strength classes defined in the EN 338 (2009). Doka (*Isoberlinia doka),* was assigned to strength class D30*, Madaci (Khaya senegalensis)* to strength class D35*, Gawo (Acacia albida)* to strength class C16, *and* Rimi *(Ceiba pentandra)* to strength class C14. The data was analyzed with the Easy fit (2010) statistical package in accordance with the EN 384 (2004) The stochastic models (mean, coefficient of variation and distribution models) of each species were generated.

CHAPTER ONE

INTRODUCTION

1.1 Preamble

Timber have for ages remained among the major structural materials for building construction worldwide, this is due to their renewable nature, availability in various sizes, shapes and colours, affordability, relatively high fatigue resistance and specific strength, ease of joining, durability, and aesthetic appeal. In Europe, Timber, have been successfully utilized in both simple and complex structures. In Nigeria however, the only area were timber received wide acceptance is in roof framing. The utilization of the material in the engineering design of residential and commercial building receive little or no attention (Afolayan, 2005).

NCP 2 (1973), which is the timber design code in Nigeria, is based on permissible stress design philosophy. The code made reference to the CP112 (1967). The code had passed through several revisions since 1967, up to the current BS 5268 (2002). Eurocode 5 (2004) is a limit state design code for timber structures which currently co-exist with BS5268, which was fully replaced in 2010 (Tord, 2001; TRADA, 2009). BS 5268 (2002) is fully deterministic, while the Eurocode 5 (2004) is semi probabilistic (Chanakya, 2009). The use of limit state design, instead of permissible stresses, enables differentiation of partial safety factors for permanent and variable loads, and makes it possible to reach a more even nominal safety level in all structures (Alpo, 2004).

As a recently developed and formulated structural design standard, Eurocode 5 (2004) provides a wide range of consistent and up to date models and procedures that can be considered for the development of a local code. The options that are provided for and allowed clearly reveal the manner in which provision should be made for local environmental and regulatory conditions. Revision of the Eurocode 5 (2004) design requirements based on the data on the properties of Nigerian timber species will go a long way in providing a background for the adaptation of advances in technology in the developed countries of Europe to local design practice of timber structures in Nigeria, just as it is being done in other developing countries like South Africa (Holicky and Ratief, 2005).

1.2 Problem Statement and Justification of Research

The four timber species under investigation; Doka (*Isoberlinia doka),* Madaci (*Khaya senegalensis*) Gawo (*Acacia albida*) and Rimi (*Ceiba pentandra*) are widely available in the savannah region of Nigeria, The demand for alternative and cheaper source of timber had increased, due to the increase in the demand for timber, especially in the production of concrete formwork and timber roof truss fabrications, brought about by the increase in construction activities.

As the world engineering community is shifting from the outdated permissible stress design criteria in the design of timber structures to the limit state design method, there is the need to provide adequate properties of local timber species to the Nigerian Construction industry.

The development of strength classes for Nigerian timber is necessary in order to utilize them for structural design based on the latest British Standard Eurocode 5 (2004). The use of the Eurocode 5 is for the fact that, through ages, British standard had been the major reference document for both structural design and educational curriculum development. The species tested were never classified as required by EN 338 (2009) in conjunction with the Eurocode 5 (2004).

The outcome of this study will serve two important purposes as follows:

i. For any timber species to be used in the construction of timber structures designed based on the Eurocode 5 (2004) design criteria, the species must be classified in accordance with the requirement of EN 338 (2009).

ii. To carry out reliability analysis and design of timber structures based on the properties of a particular timber grade, the statistical properties of the timber in use must be available. The outcome of this research provides data for the application of reliability concept in the safety assessment for the structural design of timber structures

The need for the grading of the species was the motivation of the present research work, coupled with the need for stochastic models of the strength properties of the species required for reliability analysis. The research need is clearly justified.

1.3 Aim and Objectives

1.3.1 Aim

The aim of this research is to develop EN 338 (2009) strength classes of some selected Northern Nigerian timber species Doka (*Isoberlinia doka),* Madaci (*Khaya senegalensis*), Gawo (*Acacia albida*) and Rimi (*Ceiba Pentandra*).

1.3.2 Objectives

The specific objectives are to:

i. generate experimental data on the reference material properties (density, bending strength and modulus of elasticity) of the selected species in accordance with the requirements of EN 408 (2003) specifications.

ii. generate data on the derived material properties (tension and compression strengths parallel and perpendicular to grain, shear strength, and shear modulus) of the species based on EN 384 (2004) and JCSS (2006) requirements.

iii. determine the characteristic values of both the reference and the derived material of each species in accordance with EN 384 (2004) with the aid of a specialist statistical analysis distribution fitting packages Easyfit (2010).

iv. perform strength grading in order to assign appropriate strength class to each specie, based on EN 338 (2009) recommendations.

1.4 Scope and Limitation of the Study

This study is limited to the investigation into the statistics of material properties of Doka (*Isoberlinia doka),* Madaci (*Khaya senegalensis*), Gawo (*Acacia albida*) and Rimi (*Ceiba pentandra*), obtained from the Zaria timber shed, located at Sabon Gari main market in Zaria Local Government of Kaduna state Nigeria.

CHAPTER TWO

LITERATURE REVIEW

2.1 General

A system of strength class comprises a limited number of classes each with its own set of strength properties, to which species or grade combination of similar strength are allocated. This makes the entire process of timber specification much easier. The introduction of strength class system is advantageous to the designer and supplier of timber in that he does not need to acquaint himself with a multitude of different grades and related characteristics values no matter in which country his project is to be built. Instead, he can simply choose the strength class suitable for his project from a concise table, similar to that used for other structural materials (Baltrušaitis and Pranckevičienė, 2003) .

2.2 The Tested Species

2.2.1 DOKA (*Isoberlinia doka*)

Isoberlinia doka is a hardwood tree native of Africa tropical savannah and Guinean forest-savannah mosaic dry forest where it can form single specie stands (Baker, 2000). The tree is exploited for its economic value as a commercial timber. The leaves and shoots of the tree dominate the diet of the giant Eland in its range (Kingdom, 1984). The tree is a host plant for *Anaphe moloneyi* (superfamily Thaumetopoeidae) of the caterpillars that produces a wild silk, sayana, local to parts of Nigeria (Krigar,2006).

2.2.2 MADACI (*Khaya senegalensis*)

Khaya senegalensis commonly known as "African Mahogany", is a specie of plant in the Meliaceae family. It is found in Benin, Burkina Faso, Cameroun, Central African Republic, Chad, Ivory Coast, Gabon, Gambia, Ghana, Guinea-Bissau, Mali, Niger, Nigeria, Northern Australia, Senegal, Sierra Leone, Sudan, Togo, and Uganda. Other common names of the specie include Benin Mahogany, dry zone Mahogany, Senegal Mahogany, cailcedrat, acajou, djalla and bois rouge. In West Africa it naturally occurs in gallery forests but is most often found as a shade tree of the old colonial forests.

Khaya senegalensis is moderately heavy, with a density of 710-810kg/m^3 at 12% moisture content. It generally air dries rather slowly, once dried, the wood is fairly stable in service. At 12% moisture content, the modulus of rupture is 82-122N/mm^2, modulus of elasticity 9800-11650N/mm^2, compression parallel to grain 45-54N/mm^2. The wood holds nail and screws well,

it has good gluing properties. The heartwood is moderately durable, being resistant to termite but moderately susceptible to fungi.

2.2.3 GAWO (*Acacia albida*)

Acacia albida is a species of Faidherbia native to Africa and the Middle East. It is a thorny tree growing up to 6-30m tall and 2m in trunk diameter. Its deep-penetrating tap root makes it highly resistant to drought. The bark is grey, and fissured when old. The wood is used for canoes, mortars and pestles, and the bark is pounded in Nigeria and used as a packing material on park animals. Ashes of the wood are used in making soap. Unlike most other trees, it sheds its leaves in the rainy season. For this reason, it is highly valued in agro-forestry as it grow among field crops without shading them. It is popularly known in Hausa as "Iccen Gawo" (NEST, 1991). *Acacia albida* posses good mechanical properties. Moisture content is around 20.5%. Specific gravity 0.47. The modulus of elasticity and modulus of rupture are of the order of 6728MPa and 75.02MPa respectively.

2.2.4 RIMI (*Ceiba pentandra*)

The *Ceiba pentandra* species or kapok tree (also called 'RIMI' in Hausa language) is often described as 'the tree of life'. It has also been considered sacred by the indigenous people of America. The Mayans for instance believe that the tree's roots extend to the underworld and its branches hold up the heavens. The ancient Mayan word for kapok means "raised up sky". The Maya believed that a great kapok tree stood at the centre of the earth. Its magnificent canopy symbolised the heavens and its flowers symbolised the stars. Today, the kapok tree remains a true tree of life, supporting vital life to rainforest plants and animals. In Africa, the tree is also considered sacred. It is said that sleeping on pillow made of kapok cotton will bring good luck, purify and empower your material and spiritual energy and bring good dreams. Slaves brought to the Caribbean often slept on pillows stuffed with kapok. The sacred tree symbolises hope, help, and strength rising up from the house of water for constant life. They also believed that the souls of the dead would climb up into the branch which reached into the heavens(NEST, 1991).

The kapok tree is an emergent tree of the tropical rainforest, and is often described as 'Majestic'. It can grow to a height of about 150 feet (45.7m) or beyond, towering over other trees in the rainforest. Originally, a native to South America, it now has spread to the priming peninsula, and the Indonesian archipelago. The straight trunks are cylindrical, smooth and gray in colour, and can reach a diameter of 9 feet (2.74m). Large spines protrude from the trunk to discourage damage to the trunk. Thin, plank type buttresses stabilise the giant and can extend to 30 feet (9.14m). The wood is pinkish white to ashy brown in colour, with a straight grain. The branches grow in horizontal tiers, and spread widely. The crown has an open umbrella shape. Many plants and animals grow and live in the branches of the kapok tree. Kapok is drought

deciduous, i.e. the tree shed most or all of its leaves during the tropical dry season. The dry season occur during the northern hemisphere winter. The leaves are palmate and compound. Their odour is unpleasant, but probably meant to attract the bats that pollinate them.

The main part of kapok tree primarily used as the major source of structural timber is the trunk (major branches, sometimes). This in common with other parts of a tree composed of cells (which are longer, thinner, and aligned parallel to the direction of the trunk). The mechanical strength of the timber is derived mainly from the fibrous tissue which forms the wall of the cells together with deposits within the cells.

Ceiba pentandra is particularly weak and soft. At 12% moisture content, the modulus of rupture is 26-61 N/mm^2, modulus of elasticity 2300-5600 N/mm^2, compression parallel to grain 14-26N/mm^2, shear strength 2-4N/mm^2, cleavage 4-13N/mm. The wood is difficult to saw clearly and finish smoothly (Gibbs and Semir, 2003).

2.3 Moisture Content of Timber

One of the most important factors that affect the mechanical properties of timber is its moisture content. The strength of clear timber rises approximately linearly as moisture content decreases from the fibre saturation point, and may increase multiple-fold when the oven dry state is reached. However, toughness decreases with drying. The mechanism of the strength increase in timber is similar to that of shrinkage in concrete; the contraction results in decreased inter-fibre spacing and therefore, stronger bonding between fibres (Baradan, 2002; Taylor, 2002; Widehammer, 2004).The presence of defects such as cross grain, knots, pitch pockets, shakes, and warp causes a considerable reduction in the mechanical properties of the timber.Thus, the presence of defects should be considered in the design of structural members.

The moisture content of a specimen of timber is defined as the ratio of the weight of water (which it contains) to its dry weight. It is usually expressed as a percentage. After the tree is cut down, most of the water evaporates and the timber eventually reaches 'equilibrium moisture content' whose exact value depends on the species and on the conditions of the environment in which it is placed. It depends principally on temperature and relative humidity (Macdonald, 1998). When timber dries out following the cutting down of a tree, moisture is lost initially from the interior of the cells and the only physical change which this causes is a reduction in density. At a moisture content of around 30% (exact figure depend on the specie), all of the moisture content in the cell interior walls will remain, a condition referred to as 'fibre saturation point' of the timber. Further reduction in the moisture content causes water to be lost from the cell walls and this gives rise to shrinkage and weight loss.

However, shrinkage is greater in the across-grain direction than in the along-grain direction (Macdonald, 1998). The moisture in a board is not always distributed uniformly, and when the moisture content varies along the length, across the width, or through the thickness of the board,

a phenomenon known as ‘moisture gradient‘, may be present. It usually occurs during the drying of timber by the outer layers losing more moisture rapidly than the core. Surface wetting of an otherwise dry timber will produce a reversed moisture gradient where the external layers are wetter than the core (Melbourne, 1974).

The greatest amount of movement takes place during the initial drying process which must be regulated carefully because differential shrinkage, due to variations in the rates at which moisture is lost from different parts, could cause damage in the form of cracks and warping. The controlled drying out of timber after felling is termed ‘seasoning’. It involves the adoption of measures to restrict the rate at which moisture is lost from the timber and to restrain the latter physically so as to prevent excessive deformation from occurring. Various techniques for seasoning have been developed but most timber used for building is either air seasoned or kiln seasoned.

During air seasoning, the timber is stacked in well ventilated sheds and allowed to dry out under atmospheric conditions. Similarly, in kiln seasoning, timber is allowed to dry more quickly under condition of close environmental control. In both processes, the stacking arrangement adopted is designed to allow air circulate freely between timbers so as to promote drying and to restrain the timber from warping. A certain amount of deterioration in the quality of timber due to formation of cracks and warping is inevitable during seasoning, however because differences in the rates at which moisture is lost from different part of each timber cannot be entirely eliminated.

2.4 Density of Solid Timber

Wood density is often considered to be the single most important wood property because of its strong influence on the quality of a wide range of solid wood and fiber products and has as such, received the most attention (Cown et al., 2002). Bunn (1981) states that “density is probably the most important intrinsic wood property for most wood products”, while Bamber and Burley (1983) point out, “of all the wood properties, density is the most significant in determining end use”. Similarly, Zobel and van Buijtenen (1989) states that “density largely determines the value and utility of wood and overshadows the importance of other wood properties”. However, the importance of density as an indicator of wood quality alone is debatable because variability is due to many intrinsic factors, defects and variations inherent in basic wood structures.

2.4 Density of Solid Timber

Wood density is often considered to be the single most important wood property because of its strong influence on the quality of a wide range of solid wood and fibre products and has as such, received the most attention Bunn (1981). The author states that “density is probably the most important intrinsic wood property for most wood products”, while Bamber and Burley

(1983) point out, “of all the wood properties, density is the most significant in determining end use”.

Similarly, Zobel and van Buijtenen (1989) states that “density largely determines the value and utility of wood and overshadows the importance of other wood properties”. However, the importance of density as an indicator of wood quality alone is debatable because variability is due to many intrinsic factors, defects and variations inherent in basic wood structures.

2.5 Modulus of Elasticity

An important element of wood quality is that of “stiffness” or its modulus of elasticity (E_m). The end-use of wood material, especially for structural timber is strongly related to MOE (Piter and Zerbino, 2003). Modulus of elasticity defines the relationship between stress and strain within the elastic region. Timber is considered to be an isotropic material with three mutually perpendicular axes in the longitudinal, radial and tangential directions. The longitudinal modulus of elasticity is a quantitative measure of the stiffness of the wood along the grain. It is the most commonly measured elastic property and the most important elastic constant. Elasticity implies that deformations produced by the low stress are completely recoverable after loads are removed, and this is the accepted criterion of stiffness. The values of MOE is of great importance for estimating deformation in timber structures (Thelanderson, 1995), and for calculating timber columns (Blab, 1995).

The modulus of elasticity and bending strength are determined in the laboratory by testing timber beams in bending. In the bending test of structural members, two forms of loading are employed, the choice depending upon the type specified in codes of practice for the particular material. In the first, a simply supported beam is subjected to a four-point loading system. Two concentrated loads are symmetrically applied to the test piece (beam) producing zero shear force and constant bending moment in the central span of the beam. The condition of pure bending is therefore achieved in the central span.

The second form of loading system consists of a single concentrated load at mid-span. The loads are usually applied by a testing machine. Deflection is measured by a dial gauge placed underneath the beam, and load-deflection diagrams were plotted.

ASTM D 143 (2006) set out method for measurement of MOE of small clear timber specimen based on the three point bending. The European Standard EN 408 (2003) establishes a third point loading test for calculating the local MOE, free of shear (clause 9), in the central third, but the standard additionally allows obtaining the global MOE, over the whole span (clause 10). Global MOE is due to both bending and shear deformation. Shear correction is recommended in ASTM D 143 (2006). However, Piter and Zerbino (2003) pointed out the following benefits of using the global MOE in assigning strength class to a particular timber specie without shear correction:

i. Global MOE increase safety for wood species.

ii. The structural design according to both ultimate and serviceability limit states is situated on the safe side if Modulus of Elasticity without shear correction is employed instead of the local ones

2.6 Derived Material Properties

The following material properties of solid timber, which are known as the other material properties depends of the reference material properties (Piter and Zerbino, 2003; Baltrusaitis and Pranckavicene, 2003; Rovenshort, 2004; JCSS, 2006). EN 384 (2004) and JCSS (2006) established clear procedure for obtaining these properties from the reference properties.

The relationship between the reference properties of timber (bending strength, bending modulus of elasticity and density) and other timber properties (tension parallel and perpendicular to grain, compression parallel and perpendicular to grain etc) was given as EN 384, 2004; JCSS, 2006):

$$R_{t,0} = 0.6R_m \quad (2.1)$$

$$R_{t,90} = 0.015\rho_{den} \quad (2.2)$$

$$E_{t,0} = R_m \quad (2.3)$$

$$E_{t,90} = E_m/90 \quad (2.4)$$

$$R_{c,0} = 5(R_m)^{0.45} \quad (2.5)$$

$$R_{c,90} = 0.08\rho_{den} \quad (2.6)$$

$$G_v = E_m/16 \quad (2.7)$$

$$R_v = 0.2(R_m)^{0.8} \quad (2.8)$$

In equations (2.1) to (2.8) where $R_{t,0}$ is the tensile strength parallel to the grain. $R_{t,90}$ is the tensile strength perpendicular to the grain. $E_{t,0}$ is the tension modulus of elasticity parallel to the grain. $E_{t,90}$ is the tension modulus of elasticity perpendicular to the grain. $R_{c,0}$ is the compressive strength parallel to the grain. $R_{c,90}$ is the compressive strength perpendicular to the grain. G_v is the shear modulus. R_v is the shear strength. ρ_{den} mean density of the species and E_m mean modulus of elasticity.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Materials

The materials used in this study are four timber species of Nigerian Origin, namely ,Madaci (*Khaya senegalensis)*, Gawo *(Acacia albida),* Rimi (*Ceiba pentandra)* and Doka (*Isoberlinia doka)*. All the four species were obtained from the Zaria, timber shed and kept for two months in the Concrete and strength of materials laboratory of Ahmadu Bello University, Zaria, in order to attain equilibrium moisture content.

The materials were prepared for the tests using the methods presented in EN 408 (2003). The prepared materials are as shown in Plates 3.1 to 3.4.



Plate 3.1 Prepared Material being arranged for conditioning in the laboratory (Madaci)



Plate 3.2 The prepared Marked Timber species for bending tests (Rimi and Doka)



Plate 3.3: Timber species marked for four points test



Plate 3.4 Density and moisture content test specimens some Timber species

3.2 Methods

Any result achieved in the assessment of mechanical properties depends on the testing method adopted. Moreover, with the adoption of limit state design and with the development of both visual and machine stress grading, attention will be increasingly focused on the determination and monitoring of the strength properties and variability of structural grades of timber. The European Standard (EN 408:2003) specifies laboratory test methods for the determination of some physical and mechanical properties in structural sizes.

This standard presents test methods for determining the modulus of elasticity, the bending strength and the compression strength in both parallel and perpendicular direction to the grain orientation in a structural timber. In addition, the determination of moisture content, density ,

bending and compression tests procedures specified by EN408 (2003). 40 pieces for each of the four species of 50mm×75mm×1500mm were used.

3.2.1 Bending strength test

The bending strength test considered a simply supported piece of timber with two point loads placed on 1/3 of the span. Small steel plate of length not greater than one-half of the depth of the test piece was inserted between the loading heads and test piece to minimize local indentation.

The bending strength was obtained with the continuation of the test until point of failure was reached, and applying the load with a constant loading-head movement so adjusted that the maximum load is reached within 300±120 seconds. Therefore, the bending strength, *fm* was achieved based on the following equation:

$$f_m = \frac{aF_{max}}{2W} \qquad (3.1)$$

Where F_{max} Maximum load at point of rupture in N, a is the distance between one load and the nearest support in mm, W is the section modulus of the beam in mm^3.

The bending tests are as shown in plates 3.5 to 3.7

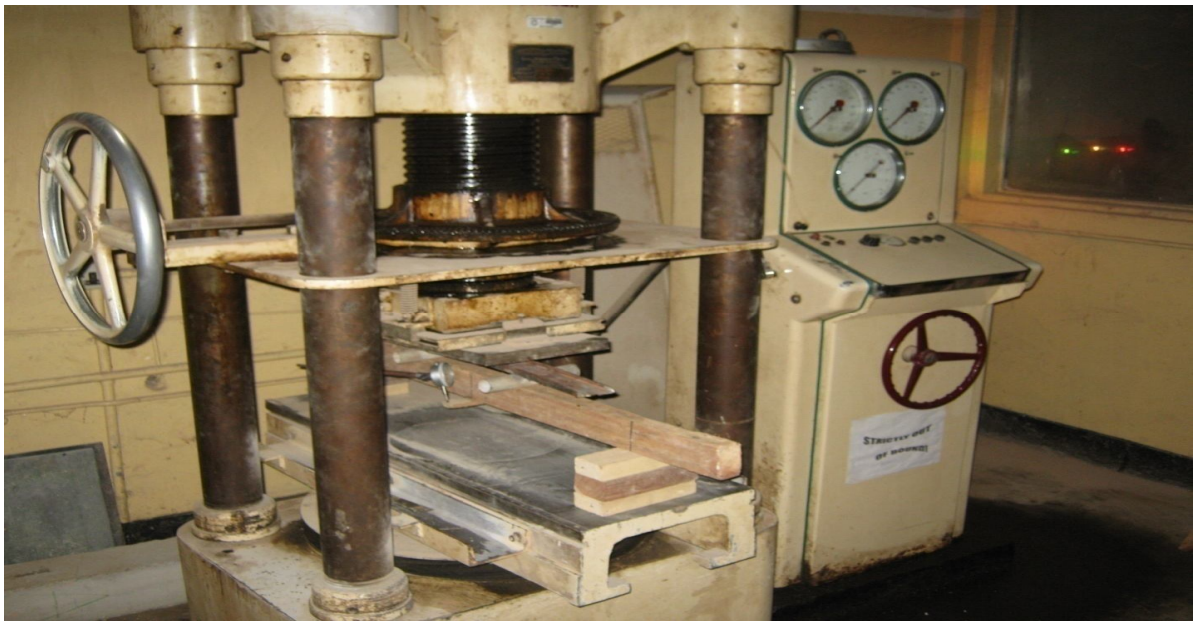


Plate 3.5: Bending Test Setup for four point test



Plate 3.6: Bending Test in progress



plate 3.7: Typical Failure Mode of bending test specimen

3.2.2 Global Modulus of Elasticity

The evaluation of the global modulus of elasticity in bending was based on the deformations measured at the centre of a central gauge length of 5 times the depth of the section. This deformation was taken as the average of measurements on both faces at the neural axis. Using the deformation values measured at the centre of the span and that at the compression or tension edge, the global modulus of elasticity in bending (*Em,g*) could be obtained from

$$E_{m,g} = \frac{l^3(F_2 - F_1)}{bh^3(w_2 - w_1)}\left[\left(\frac{3a}{4l}\right) - \left(\frac{a}{l}\right)^3\right] \qquad (3.2)$$

Where $\frac{(F_2-F_1)}{(w_2-w_1)}$ is the slope of the least square regression line, L the span between the beam supports in mm , F_1 is the load on straight line at point one , F_2 is the load on straight line at point two ,(F_2-F_1) the increment of load on the straight line of the Load-deformation least square regression line in N, (w_2-w_1)the increment of deformation corresponding to (F_2-F_1) in mm b = width of test piece (mm) and h the depth of test piece (mm) w_2 deformation corresponding to load F_2 .

3.2.3 Moisture Content

Whatever means are adopted for determining the moisture content of timber, it is necessary to have a standard basis for expressing the result of the tests. The formula for calculating the moisture content on the basis of percentage of oven dry weight is expressed by equation (3.3)

$$\text{Moisture content, M.C} = \frac{\text{weight of moisture}}{\text{oven dry weight}} \text{ x } 100$$

$$= \left(\frac{\text{totalweight of wood and moisture}}{\text{oven dry weight}} - 1\right) \text{ x } 100 \qquad (3.3)$$

3.2.3.1 Adjustment of Moisture Adjustment

The European strength class system EN, 338 is based on material properties with a reference moisture content equal to 12%. Likewise, the reference moisture content in Nigeria as specified in NCP2 (1973) is 18%. For easy comparison, the modulus of elasticity, bending strength and density values were adjusted to 12% and 18% reference moisture content using equations (3.4) to (3.6). (Bostron, 1994; Heikkila and Hijarvi, 2008). The 12% moisture content adjustment equation for bending strength is given by equation (3.4) .

$$f_{m,12\%} = \frac{f_{measured}}{1+0.0295(12-u)} \qquad (3.4)$$

where $f_{m,12\%}$ is the bending strength at 12% moisture content, $f_{measured}$ is the bending strength at the measured moisture content, and u is the measured moisture content in %

The 12% moisture content adjustment equation for modulus of elasticity is given by equation (3.5) (Bostrom, 1994).

$$E_{12}=\frac{E_{measred}}{1+0.0143*(12-u)} \quad (3.5)$$

Likewise, Heikkila and Herajarvi (2008) gave moisture adjustment factor for density as:

$$\rho_{12} = \rho_w \left(1-\frac{(w-12)}{200}\right) \quad (3.6)$$

Where $\bar{\rho}$ and s are the mean and standard deviations for densities of specimens (in kg/m^3) respectively computed from easy fit (2010).

3.2.4 Density

Density which is simply defined as mass per unit volume, denoted by ρ (rho) is an intrinsic property of timber, and can be described mathematically as:

$$\text{Density, } \rho = \frac{\text{Mass}}{\text{volume}} \ (\text{kg/m}^3) \quad (3.7)$$

3.2.5 Bending Strength

The bending strength test was carried out in accordance with EN408 (2003) clause 13 (determination of bending strength). The test pieces used had an average depth and span of 85mm and 2629mm respectively. The test pieces were simply supported and symmetrically loaded in bending over a span of 846mm. the distance between the inner loads was 283mm. Two point loads were inserted between the test piece and the loading heads. The loading equipment (compression test machine) was capable of measuring the load to an accuracy of 1% of the load applied to the test piece. The load was applied at a constant loading head movement so adjusted that the maximum load was reached within 300 ± 120 seconds. The bending strength, f_m (in N/mm^2) is expressed by equation (3.1).

The bending stiffness in structural member is a function of both shear and bending deflection. When measuring the Local Modulus of Elasticity E_{local}, as prescribed in EN 408 (2003), the mid-span deflection (deflection relative to the point load in the four-point bending test set-up) represent a pure bending deflection, that is no effect from shear deflection. The biggest source of error will be linked to initial twist of the timber pieces. Since the local (mid-

span) deflection is just a tenth of the global (that is deflection relative to the end support), any effect from twist will be more vital Solli (2000). Likewise since the mid-span deflection if with respect to the central span, the value of the Local Modulus of Elasticity (MOE_{local}) is not necessarily representative for the whole piece. The moduli of elasticity were obtained using four-point (two point load) bending test, loading are applied at the central third of the test piece. The testing arrangement is shown in Figure 3.1 (EN 408, 2003).

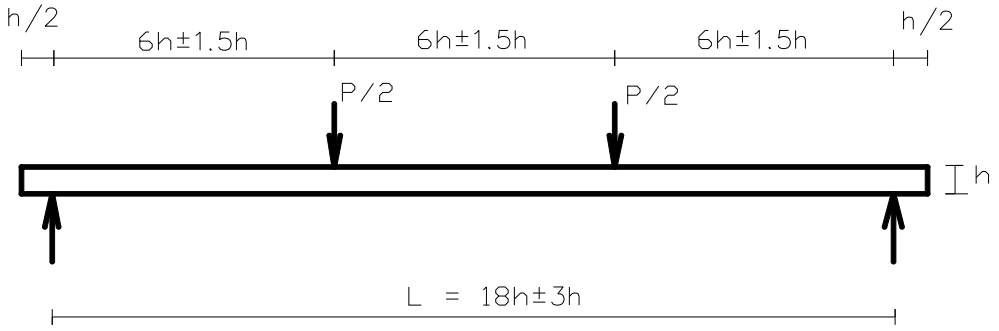


Figure 3.1 Four Point Bending Test Setup (EN 408, 2003)

The four-point bending test based on the recommendation of EN 408 for the measurement of the Global Modulus of Elasticity, was used to establish the Strength and stiffness of the tested species based on the recommendation of EN 384. The Global Modulus of Elasticity and the Bending Strength were obtained from equations 3.8 and 3.9 as follows:

$$E_m = \frac{L^3(F_2-F_1)}{4.7bh^3(w_2-w_1)} \qquad (3.8)$$

where (F_2-F_1), L, b, h. and (w_2-w_1) are as defined earlier. **a** is the distance between one load and the nearest support in mm. **W** is the section modulus of the beam in mm^3.and F_{max} is Maximum load at piece rupture in N

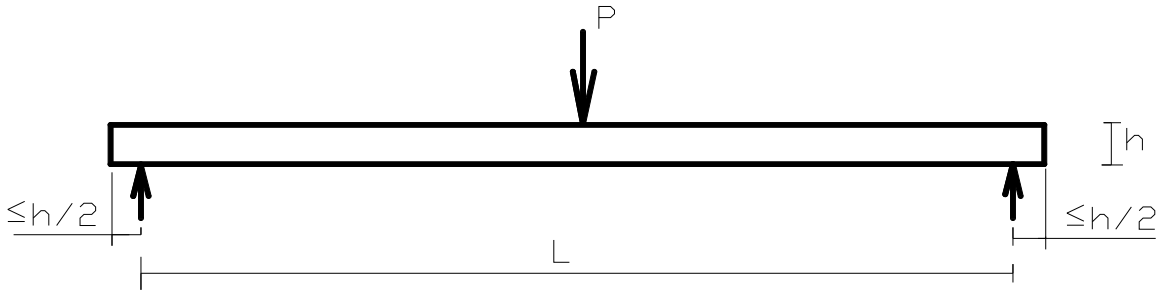


Figure 3.2: Three point bending test set up (ASTM D143-94, 2000)

Three-point bending test is based on central deflection of tested timber specie and the relative position of supports as specified by ASTM D 143-94 (2002).

The bending strength f_m is computed using equation (10).

$$f_m(N/mm^2)=\frac{3F_{max}L}{2bh^2} \quad (3.9)$$

where : L is span between the beam supports in mm, F_{max} is Maximum load at piece rupture in N, b is width of test piece (mm) and h is depth of test piece (mm)

Density of the test pieces used was based on oven dry mass, when a constant mass was considered to be attained after successive weighing.

Moisture content, (M.C) is one of the essential properties of any timber with almost a direct relationship with its strength capacity. Therefore, every structural timber is expected to undergo the process of seasoning (drying) as much as the mean value of the moisture content it is expected to attain in service before it can safely be put to use. This is particularly true when considering strength properties which has direct relationship with moisture content below the fibre saturation point (moisture content at which all free water is expelled while the cell wall still remain saturated (Siau, 1984), as well as the effect of moisture exchange between the timber and surrounding environmental humidity, due to its hygroscopic nature. Similarly, some level of control scheme should ensure that the effects associated with dimensional changes which could result into shrinkage or swelling is well minimized.

The amount of moisture in a timber is ordinarily expressed as the percentage of wood mass when oven dried. The oven drying method has the advantage of being the most universally accepted method, and requires cutting the wood into smaller pieces or fragments, weighting it, and subsequently drying it in an electrical oven until all the moisture is evaporated. Reweighting it and then calculating its moisture content. The equipment used was simple, and in good working order. For weighting the sections, a balance having a capacity of 500g was used.

To obtain an average moisture content of a test piece, each section was marked out and labelled with an identifying number on the sample. This process was followed by recording the weight corresponding to the identified numbers. Furthermore, the specimens were placed in an electrical oven for drying. After 24 hours, the specimens were removed from the oven, and their weight was recorded. The specimens were again replaced into the oven, and reweighted at interval of 4 hours, until there was no further loss in weight. Each weighting was recorded.

Since moisture content is a function of relative humidity and temperature of the surrounding air, then the equilibrium moisture content is expected to occur when the timber has

reached a water content equivalent to its environment. The mathematical equation behind this phenomenon is given thus:

$$M = \frac{1800}{W}\left[\frac{KH}{(1-KH)} + \frac{(K_1KH + 2K_1K_2K^2H^2)}{(1+K_1KH+K_1K_2K^2H^2)}\right] \quad (3.10)$$

Where M is the moisture content (%), T is the surrounding temperature in ^{0}C. H is the relative humidity. $W = 300 + 0.452T + 0.00415T^2$ (3.11)

$K = 0.791 + 0.000463T - 0.000000844T^2$. (3.12)

$K_1 = 6.34 + 0.000775T - 0.0000935T^2$. (3.13)

$K_2 = 1.09 + 0.0284T - 0.0000935T^2$ (3.14)

It is clear from equation 3.10, that the moisture content of any timber specie is a function of temperature and relative humidity of its surrounding environment. Other factors (K_1, K_2, K_3, and W) are clearly related to temperature effect. Hence, the importance and significance of moisture content in timber cannot be overemphasised.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

The results experiments for moisture contents, density and bending tests for the four timber species tested, namely Doka (*Isoberlinia doka),* Madaci (*Khaya senegalensis)*, Gawo (*Acacia albida)* and Rimi (*Ceiba pentandra)*. as conducted in structures laboratories of Civil Engineering Department Ahmadu Bello University, Zaria are presented in the following sections:

4.2 Moisture Content

The mean, standard deviation and the coefficient of variation of the moisture content of each species are presented in Table 4.1. The mean values of the moisture contents for the Doka (*Isoberlinia doka),* Madaci (*Khaya senegalensis)*, Gawo (*Acacia albida)* and Rimi (*Ceiba pentandra)* are 21.5%, 19.3%, 17.8% and 23.5% respectively with the corresponding coefficients of variation of 0.17, 0.23, 0.19 and 0.22.

Moisture content is a very important property that greatly influences the properties of timber. Moisture variation results in variation in the material properties, such as bending strength, modulus of elasticity and density. Timber normally stabilises to arrive at the equilibrium moisture content, which is based on the environment where the timber is located. Moisture content of timber is therefore adjusted appropriately in design in accordance with the location of use. The material properties of timber presented in the EN 338 (2009), are based on the reference moisture content of 12%. The reference moisture content in the Nigerian Code of Practice NCP2 (1973) is based on the reference moisture content of 18%.

Table 4.1 Statistics of Moisture Content

Timber Specie	Moisture Content		
	Mean (%)	Coefficient of Variation	Standard Deviation (%)
Isoberlinia doka	21.5	0.17	3.66
Khaya senegalensis	19.3	0.23	4.44
Acacia albida	17.8	0.19	3.38
Ceiba pentandra	23.5	0.22	5.17

4.3 Density

Table 4.2 contains the mean values of the density of Doka (*Isoberlinia doka),* Madaci (*Khaya senegalensis)*, Gawo (*Acacia albida)* and Rimi (*Ceiba pentandra).* These densities are 983.67kg/m^3, 869.94kg/m^3, 581.49kg/m^3 and 340.01kg/m^3. From this table, it is observed that the coefficients of variation of density for the Doka (*Isoberlinia doka),* Madaci (*Khaya senegalensis)*, Gawo (*Acacia albida)* and Rimi (*Ceiba pentandra)* are 23%, 16%, 26%, 20% respectively.

Table 4.2 Density Results

Specie	Moisture Content	Density		
		Mean (kg/m^3)	Standard Deviation (kg/m^3)	Coefficient Of Variation
Isoberlinia doka	Measured	983.67	229.43	0.23
	12%	936.95	215.50	
	18%	968.10	222.66	
Khaya senegalensis	Measured	869.94	139.08	0.16
	12%	838.19	134.11	
	18%	864.29	138.29	
Acacia albida	Measured	581.49	153.86	0.26
	12%	564.62	146.80	
	18%	580.93	151.04	
Ceiba pentandra	Measured	340.01	88.40	0.20
	12%	320.45	83.32	
	18%	330.84	86.02	

4.4 Modulus of Elasticity (E_m) and Bending Strength (f_m)

In the four point bending tests carried out, the central deflection of each test piece was measured relative to the end supports by means of a dial gauge graduated at 1/100th of a millimetre. The measurement was made at interval of 1000 N up to the failure load. Load-deflection scatter plot were made for each test piece. The modulus of elasticity were obtained from the least square lines of the load deflection plots developed for each specimen in MS Excel, 2007. The corresponding bending strengths were obtained using the failure load. The values of other material properties (Tension strength parallel and perpendicular to grain, Compression strength parallel and perpendicular to grain and shear strength) were generated based on the procedure reported in literature (JCSS, 2006; EN 338, 2008). The test data have

been analysed statistically, to generate the average values, and coefficient of variation of the strength and stiffness properties of each of the four species.

The statistics of Bending Strength and Modulus of Elasticity obtained from four point bending test and adjusted to 12% and 18% moisture content were presented in Tables 4.3 to 4.6.

Table 4.3: Statistics of Bending Strength and Modulus of Elasticity of *Isoberlinia doka*

S/No	Property	Unit	MC	Mean	Standard Deviation	Coefficient of Variation
1	Bending Strength	(N/mm^2)	Measured	47.93	7.81	0.16
			12%	66.59	10.65	
			18%	54.15	8.66	
2	Modulus of Elasticity	(N/mm^2)	Measured	10145	1489.9	0.15
			12%	11740	1761.0	
			18%	10677	1602	

Table 4.4: Statistics of Bending Strength and Modulus of Elasticity of *Khaya senegalensis*

S/No	Property	Unit	MC	Mean	Standard Deviation	Coefficient of Variation
1	Bending Strength	(N/mm^2)	Measured	49.78	7.29	0.15
			12%	63.44	9.52	
			18%	52.21	7.83	
2	Modulus of Elasticity	(N/mm^2)	Measured	12090	2131	0.18
			12%	13499	2430	
			18%	12341	2221	

Table 4.5: Statistics of Bending Strength and Modulus of Elasticity of *Acacia albida*

S/No	Property	Unit	MC	Mean	Standard Deviation	Coefficient of Variation
1	Bending Strength	(N/mm^2)	Measured	34.85	8.21	0.24
			12%	42.04	10.09	
			18%	34.85	8.21	
2	Modulus of Elasticity	(N/mm^2)	Measured	7845	1686	0.21
			12%	8555	1797	
			18%	782	1686	

TABLE 4.6: Statistics of Bending Strength and Modulus of Elasticity of *Ceiba pentandra*

S/No	Property	Unit	MC	Mean	Standard Deviation	Coefficient of Variation
1	Bending Strength	(N/mm^2)	Measured	34.45	6.82	0.20
			12%	52.14	10.43	
			18%	42.75	8.55	
2	Modulus of Elasticity	(N/mm^2)	Measured	4855	1360	0.28
			12%	5811	1627	
			18%	5303	1485	

In Table 4.3, the mean values, standard deviation and coefficients of variation of the grade determining properties (density, modulus of elasticity and bending) for *Isoberlinia doka* are

presented. The Moduli of elasticity and the bending strengths were generated from the four point bending tests. These values were adjusted to 12% moisture content and 18% moisture content as required by EN 338 (2009) and NCP2 (1973) respectively. In Tables 4.3 The coefficient of variation for modulus of elasticity and bending strength for *Isoberlinia doka* are 15% and 16% respectively. The coefficients of variation for the tension and compression strengths parallel and perpendicular to grain as well as shear strengths were also generated based on the criteria outlined in JCSS (2006).

In Tables 4.2 and 4.4, the mean values, standard deviation and coefficients of variation of the grade determining properties (density, modulus of elasticity and bending) for *Khaya senegalensis* are presented. The coefficient of variation for modulus of elasticity and bending strength are 18% and 15% respectively.

In Table 4.5, the mean values, standard deviation and coefficients of variation for modulus of elasticity and bending strength for *Acacia albida* are 21% and 24% respectively.

In Tables 4.2 and 4.6, the mean values, standard deviation and coefficients of variation of the grade determining properties (density, modulus of elasticity and bending) for *Ceiba pentandra* are 20%, 28% and 20% respectively.

The general observation is that, high variability exist not only between timber specie, but also within the species. This is not the case with other construction materials like concrete and steel, which properties could be controlled through manufacturing process. There is great implication of these variability on the issue of acceptability of the European strength classification system (EN 338, 2003), which is used in conjunction with the Eurocode 5. In this classification system, solid timber species that have minimum values of the grade determining properties (density, modulus of elasticity and bending strength) of a particular strength class are assigned to that strength class.

4.5 Derived Material Properties

As mentioned earlier, the reference material properties of each of the four timber species tested in this study (*Isoberlinia Doka, Khaya senegalensis, Acacia Albida and Ceiba pentandra*) were generated from the laboratory test results conducted in accordance with the provision of EN 408 (2003) and EN 384 (2004). The derived material properties of the species (JCSS, 2006; EN 384 (2004) are as follows:

1. Tension Strength Parallel to Grain, $f_{t,0}$
2. Tension Strength Perpendicular to Grain $f_{t,90}$
3. Compression Strength Parallel to Grain $f_{c,0}$
4. Compression Strength Perpendicular to Grain $f_{c,90}$
5. Shear Strength f_v
6. Shear Modulus G_v

The derived properties were generated based on the equations recommended in the JCSS (2006) and EN 384 (2003) as follows:

$$f_{t,0} = 0.6 f_m \quad (4.4)$$

$$f_{t,90} = 0.0015\rho \quad (4.5)$$

$$f_{c,0} = 5 f_m^{0.45} \quad (4.6)$$

$$f_{c,90} = 0.008\rho \quad (4.7)$$

$$f_v = 0.5 f_m^{0.8} \quad (4.8)$$

$$G_v = \frac{E_{mean}}{16} \quad (4.9)$$

Where E_{mean} is the mean value of modulus of elasticity

The derived material properties are presented in Tables 4.7 to 4.10.

Table 4.7 Derived Material Properties for *Isoberlinia doka*

Derived Material Property	Mean (N/mm^2)	Coefficient of Variation	Standard Deviation
Tension Strength Parallel to Grain ($f_{t,0}$)	28.76	0.19	5.46
Tension Strength Perpendicular to Grain ($f_{t,90}$)	14.76	0.58	8.56
Compression Strength Parallel to Grain ($f_{c,0}$)	28.53	0.13	3.71
Compression Strength Perpendicular to Grain ($f_{c,90}$)	7.87	0.23	1.81
Shear Strength (f_v)	11.05	0.16	2.54
Shear Modulus (G_v)	634.06	0.15	95.11

Table 4.8 Derived Material Properties for *Khaya senegalensis*

Derived Material Properties	Mean (N/mm^2)	Coefficient of Variation	Standard Deviation
Tension Strength Parallel to Grain ($f_{t,0}$)	29.87	0.18	5.38
Tension Strength Perpendicular to Grain ($f_{t,90}$)	13.05	0.40	5.22
Compression Strength Parallel to Grain ($f_{c,0}$)	29.02	0.12	3.48
Compression Strength Perpendicular to Grain ($f_{c,90}$)	6.96	0.16	1.11
Shear Strength (f_v)	11.39	0.15	1.71
Shear Modulus (G_v)	755.63	0.18	136.01

Table 4.9 Derived Material Properties for Gawo (*Acacia albida)*

Derived Material Properties	Mean (N/mm^2)	Coefficient of Variation	Standard Deviation
Tension Strength Parallel to Grain ($f_{t,0}$)	20.91	0.29	6.06
Tension Strength Perpendicular to Grain ($f_{t,90}$)	8.72	0.65	5.67
Compression Strength Parallel to Grain ($f_{c,0}$)	24.72	0.19	4.70
Compression Strength Perpendicular to Grain ($f_{c,90}$)	4.65	0.26	1.21
Shear Strength (f_v)	8.57	0.24	2.06
Shear Modulus (G_v)	490.31	0.21	102.97

Table 4.10 Derived Material Properties for Rimi (*Ceiba pentandra)*

Derived Material Properties	Mean (N/mm^2)	Coefficient of Variation	Standard Deviation
Tension Strength Parallel to Grain ($f_{t,0}$)	20.67	0.24	4.96
Tension Strength Perpendicular to Grain ($f_{t,90}$)	5.10	0.50	2.55
Compression Strength Parallel to Grain ($f_{c,0}$)	24.59	0.16	3.93
Compression Strength Perpendicular to Grain ($f_{c,90}$)	2.72	0.20	0.54
Shear Strength (f_v)	8.49	0.20	1.70
Shear Modulus (G_v)	303.44	0.28	84.96

4.6 Theoretical Distribution Models

The properties of a physical process may suggest the form of its required distribution. For example, if a process is composed of the sum of many individual effects, the Normal or Lognormal distribution may be appropriate on the basis of central limit theorem (Ang and Tang, 1975). Whereas, if the extreme conditions of a physical process are of interest, an extreme value distribution such as Gumbel or Weibull distribution may be a suitable model. Density, stiffness and strength properties of timber have been modelled with normal, lognormal and extreme value distributions (JCSS, 2006). The sample data plots of histograms together with the probability density functions of the fitted distributions for the Density, bending strength and Modulus of Elasticity are presented in the figures below.

4.6.1 Result and discussion

In this study, Normal, lognormal, and Gumbel, distribution were fitted to the grade determining properties (Modulus of Elasticity, Bending Strength and Density) using the **EASYFIT** statistical package**.** The plots of probability density functions superimposed of the histogram for the density, bending strength and modulus of elasticity data are presented in Figs 4.1 to 4.12, 4.13-4.24 and 4.25 -4.36 respectively. The necessary data used in plotting the graphs are as shown in the appendix A B and C. The probability density function (PDF) is the probability that the considered variant has the value x:

$$f(x) = (X = x) \tag{4.10}$$

The empirical PDF is displayed as a histogram consisting of equal-width vertical bars (bins), each representing the number of sample data values (falling into the corresponding interval), divided by the total number of data points. The theoretical PDF is displayed as a continuous curve properly scaled depending on the number of intervals. Theoretical PDF plot for normal distribution has a bell shape. The PDF plots shown in Figs 3.1 to 3.36 displayed results for normal, lognormal and Gumbel distribution for each reference material property. A material property is best assigned to normal distribution if its PDF plot is close to that of normal distribution.

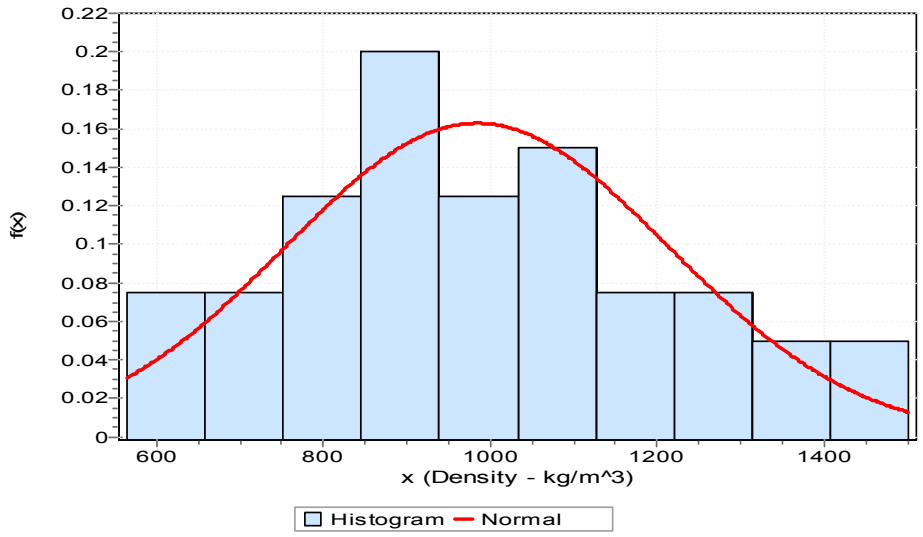


Fig. 4.1 Probability Density Function Plot for *Isoberlinia doka,* considering Density as Normal Distribution

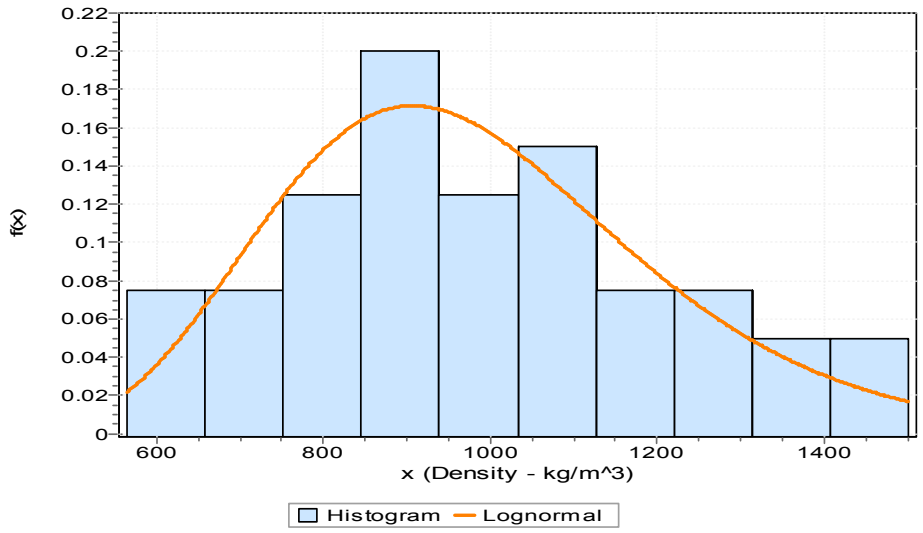


Fig. 4.2 Probability Density Function Plot for *Isoberlinia doka,* considering Density as Lognormal Distribution

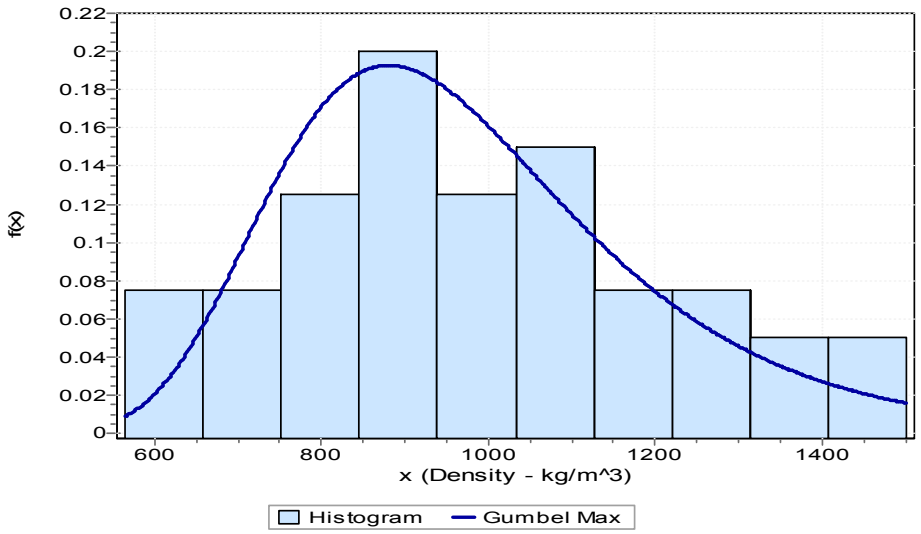


Fig. 4.3 Probability Density Function Plot for *Isoberlinia doka,* considering Density as Gumbel Distribution

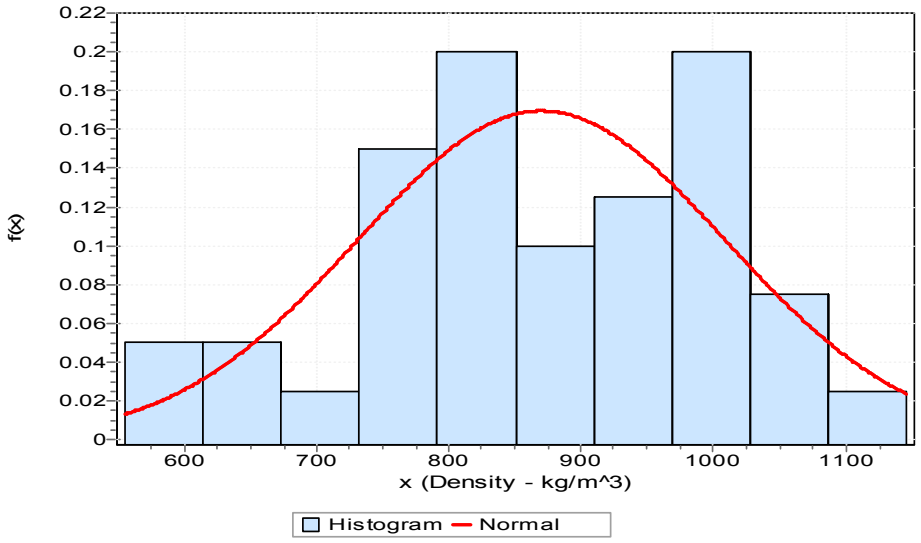


Fig 4.4 Probability Density Function Plot for *Khaya senengalansis*,, considering Density as Normal Distribution

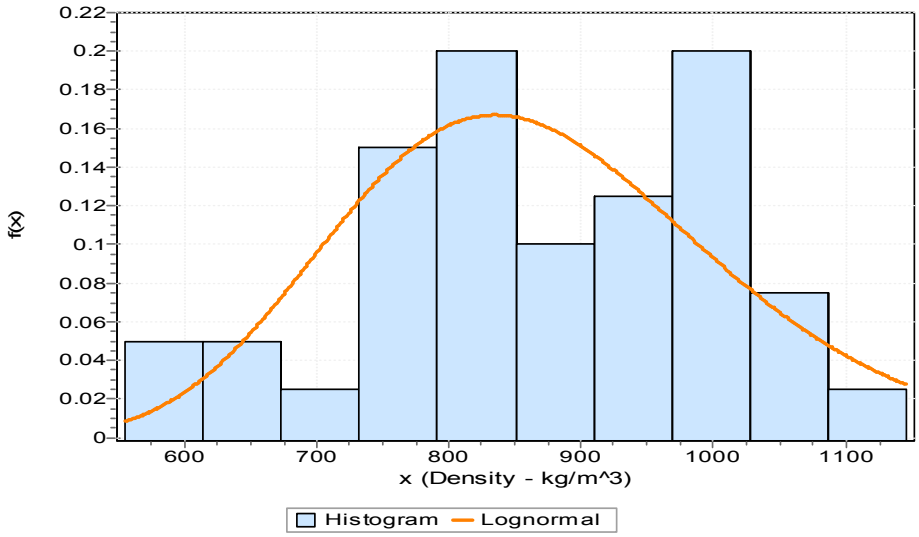


Fig. 4.5 Probability Density Function Plot for *Khaya senengalensis*, considering Density as Lognormal Distribution

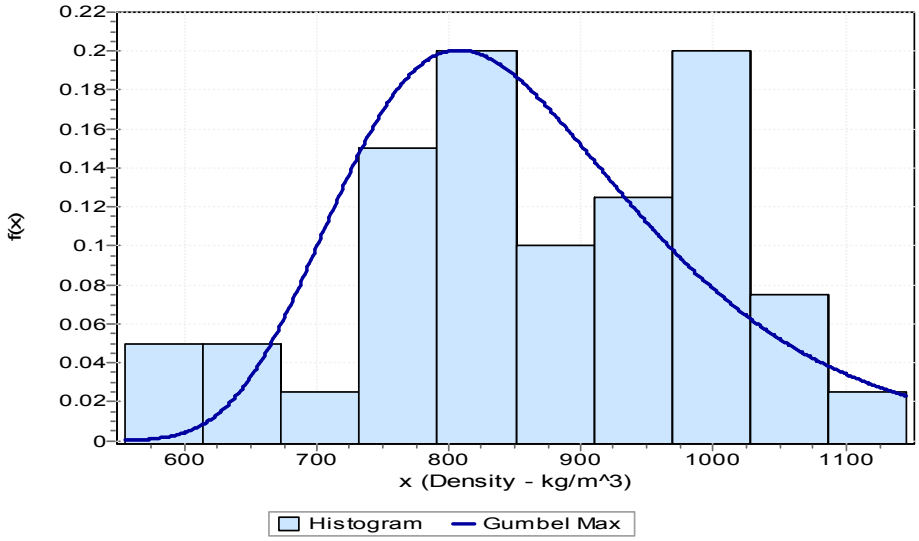


Fig. 4.6 Probability Density Function Plot for *Khaya senengalensis*, considering Density as Gumbel Distribution

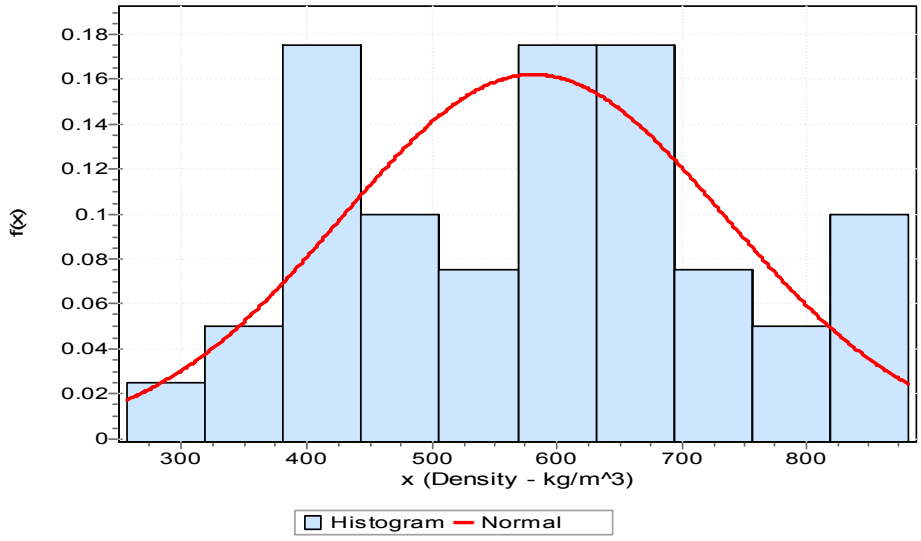


Fig 4.7 Probability Density Function Plot for *Acacia albida*, considering Density as Normal Distribution

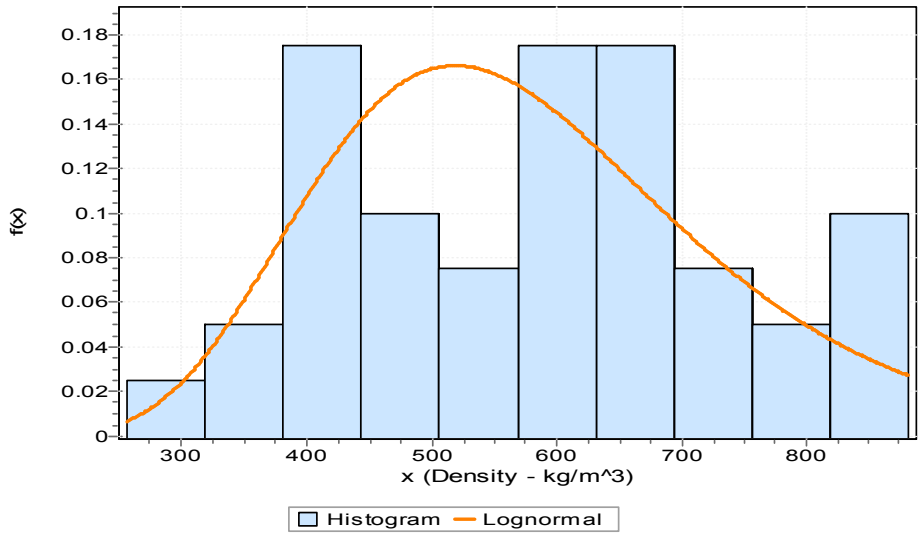


Fig. 4.8 Probability Density Function Plot for *Acacia albida*, considering Density as Lognormal Distribution.

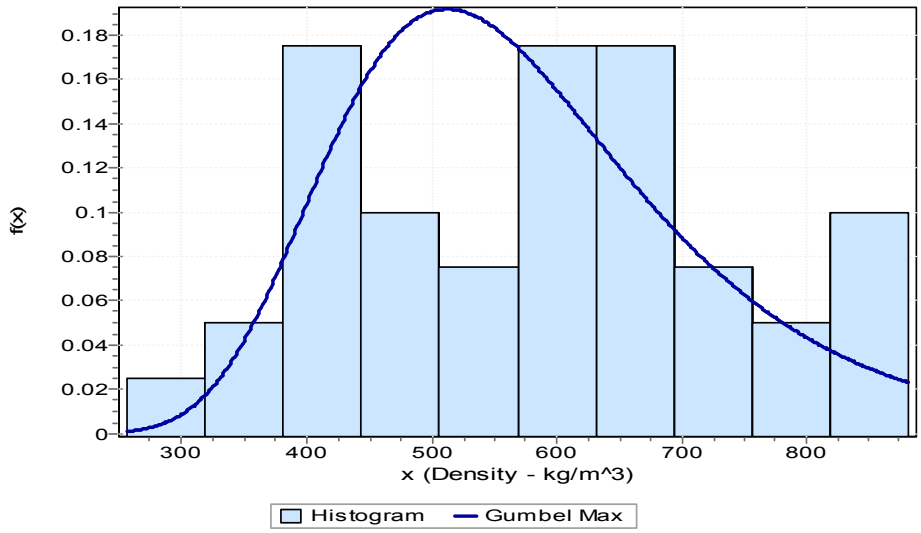


Fig. 4.9 Probability Density Function Plot for *Acacia albida*, considering Density as Gumbel Distribution

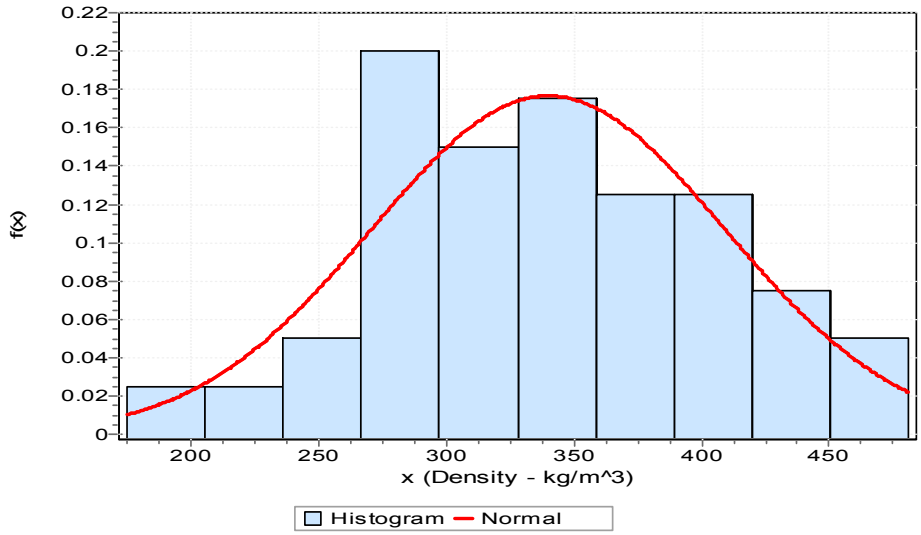


Fig. 4.10 Probability Density Function Plot for *Ceiba pentandra* considering Density as Normal Distribution.

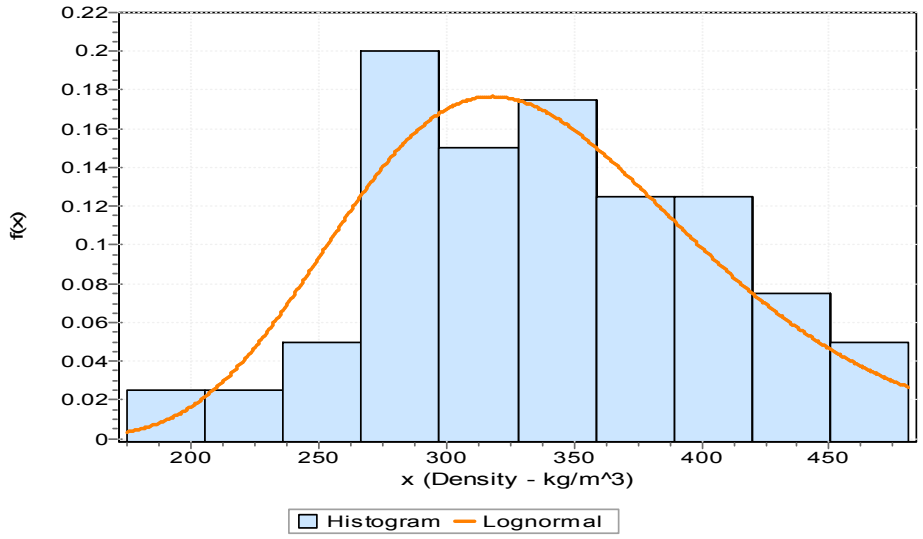


Fig. 4.11 Probability Density Function Plot for *Ceiba pentandra* considering Density as Lognormal Distribution

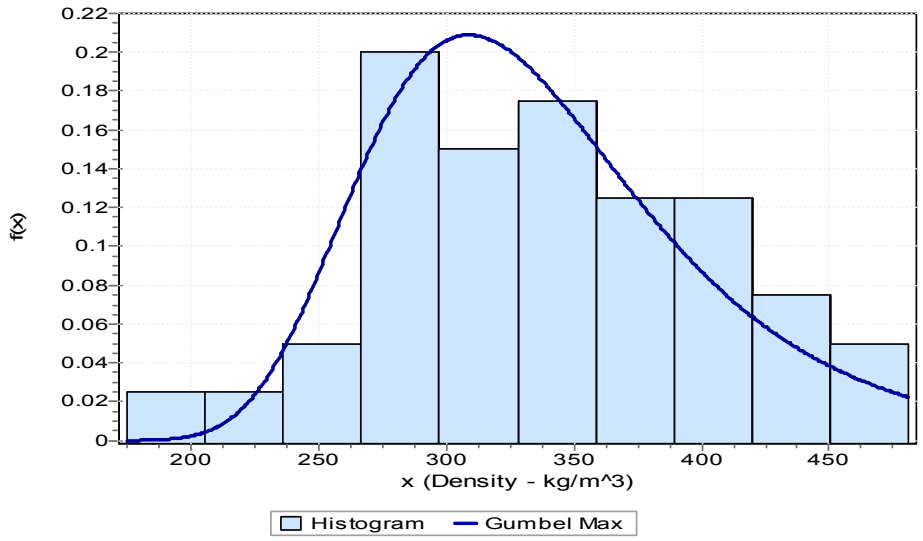


Fig 4.12 Probability Density Function Plot for *Ceiba pentandra*, considering Density as Gumbel Distribution

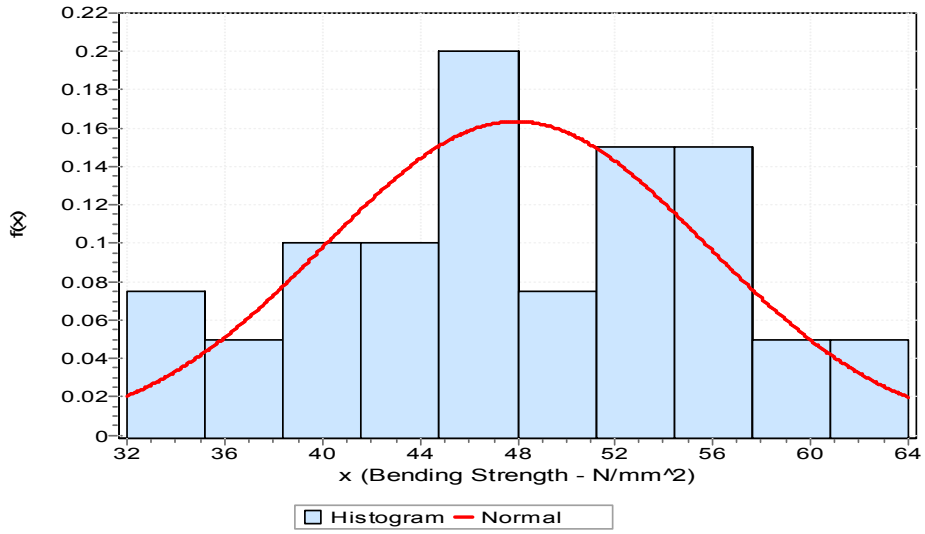


Fig. 4.13 Probability Density Function Plot for *Isoberlinia doka,* considering Bending Strength as Normal Distribution

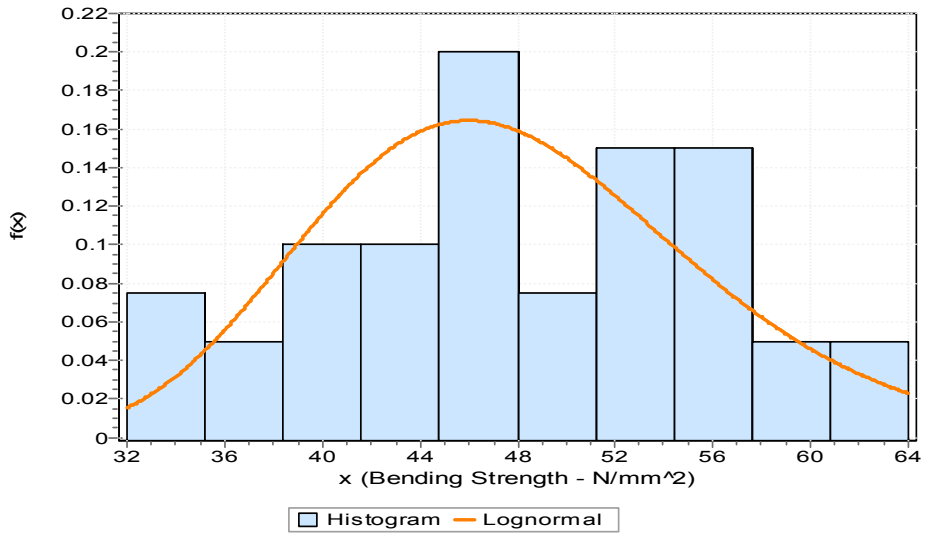


Fig. 4.14 Probability Density Function Plot for *Isoberlinia doka,* considering Bending Strength as Lognormal Distribution

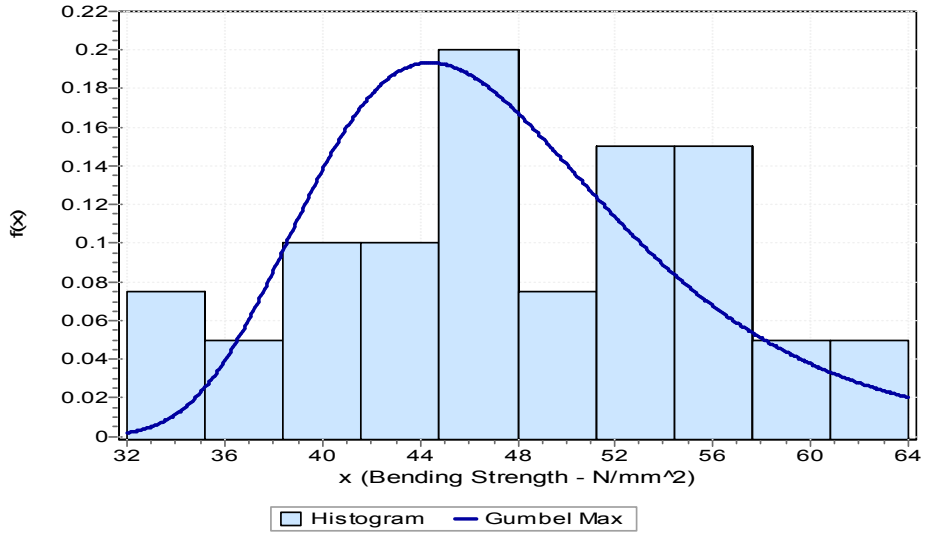


Fig. 4.15 Probability Density Function Plot for *Isoberlinia doka,* considering Bending Strength as Gumbel Distribution

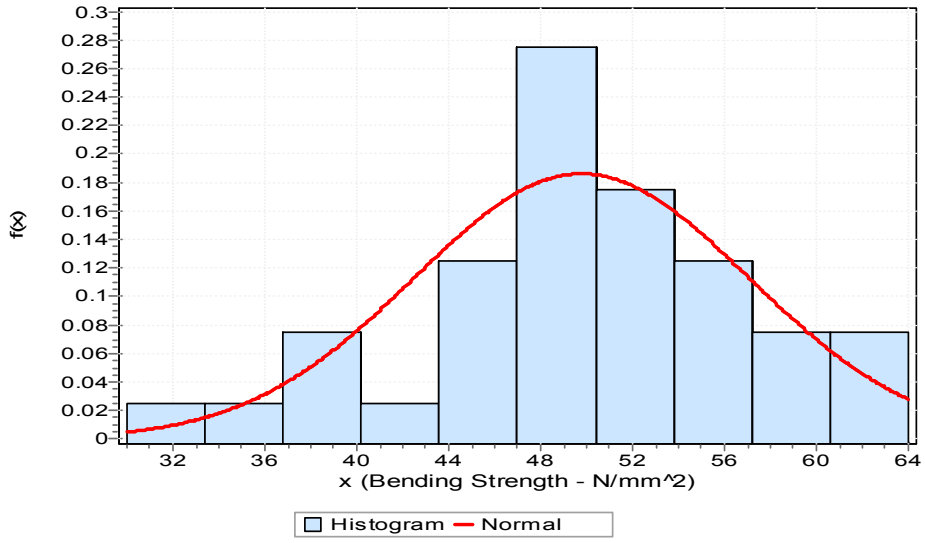


Fig 4.16 Probability Density Function Plot for *Khaya senengalensis,* considering Bending Strength as Normal Distribution

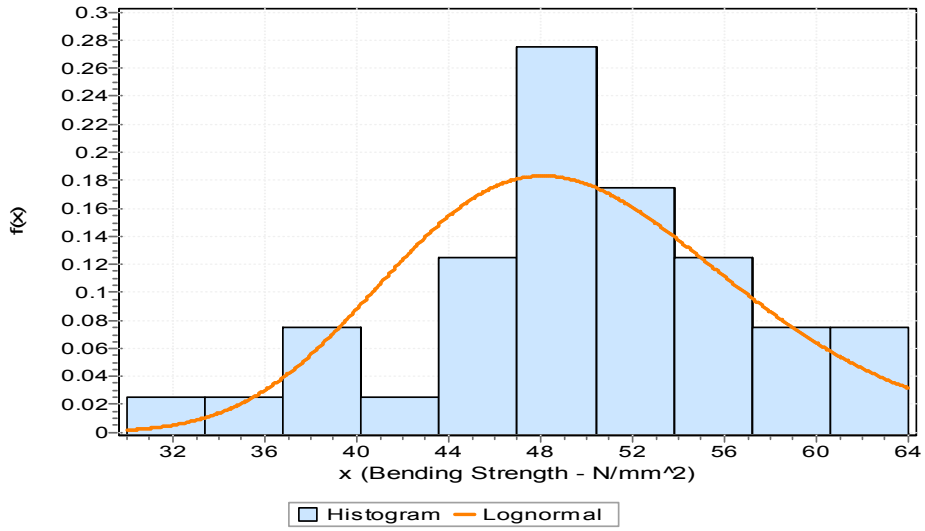


Fig. 4.17 Probability Density Function Plot for *Khaya senengalensis,* considering Bending Strength as Lognormal Distribution

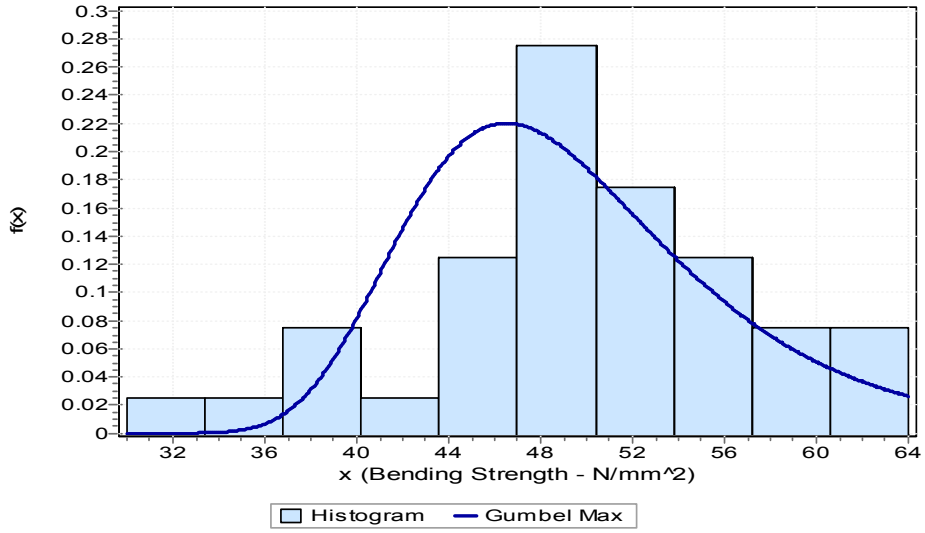


Fig. 4.18 Probability Density Function Plot for *Khaya senengalensis,* considering Bending Strength as Gumbel Distribution

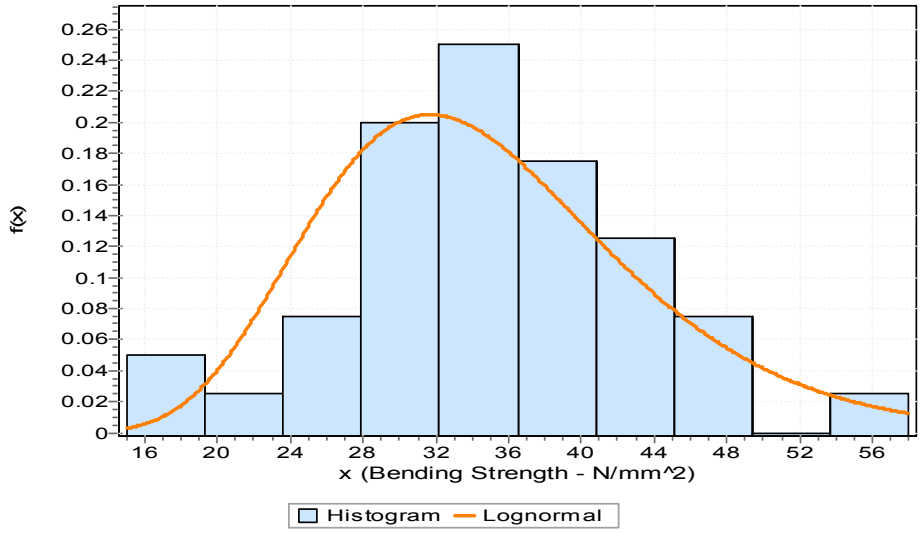


Fig. 4.19 Probability Density Function Plot for *Acacia albida,* considering Bending Strength as Normal Distribution

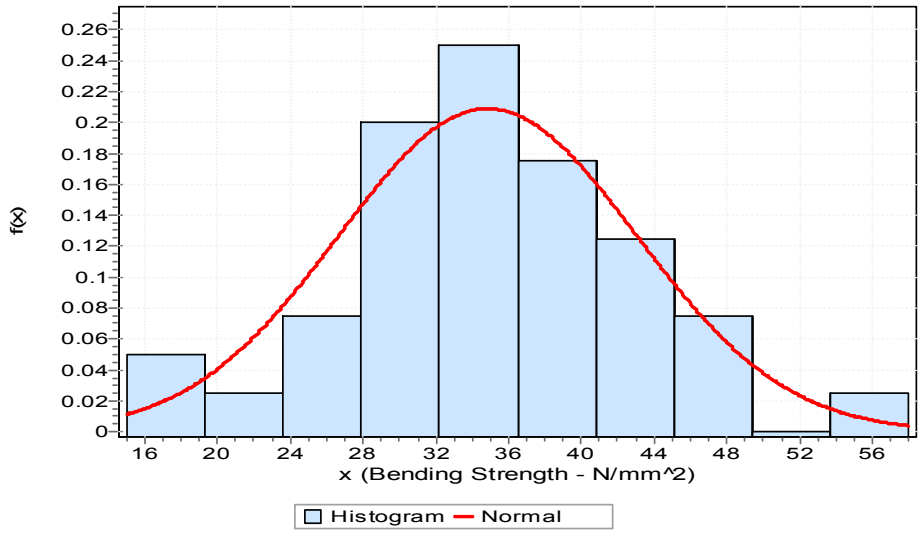


Fig. 4.20 Probability Density Function Plot for *Acacia albida,* considering Bending Strength as Lognormal Distribution

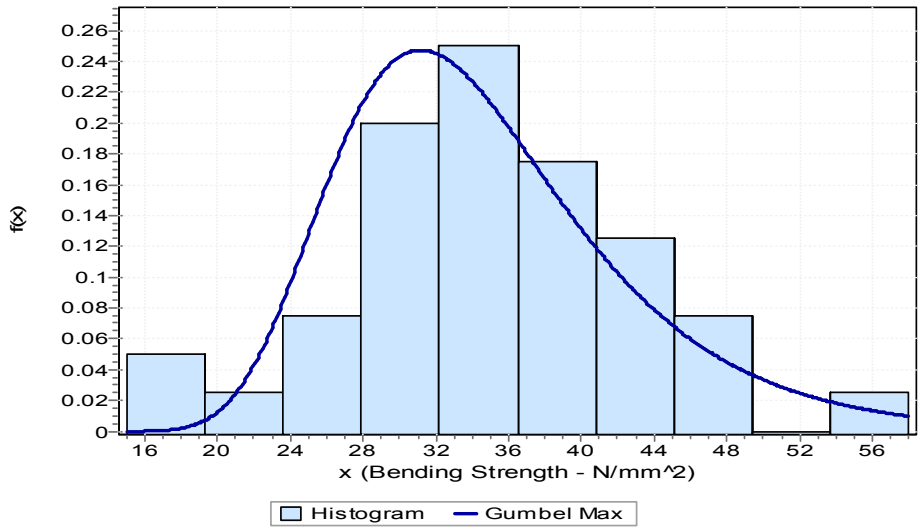


Fig. 4.21 Probability Density Function Plot for *Acacia albida,*, considering Bending Strength as Gumbel Distribution

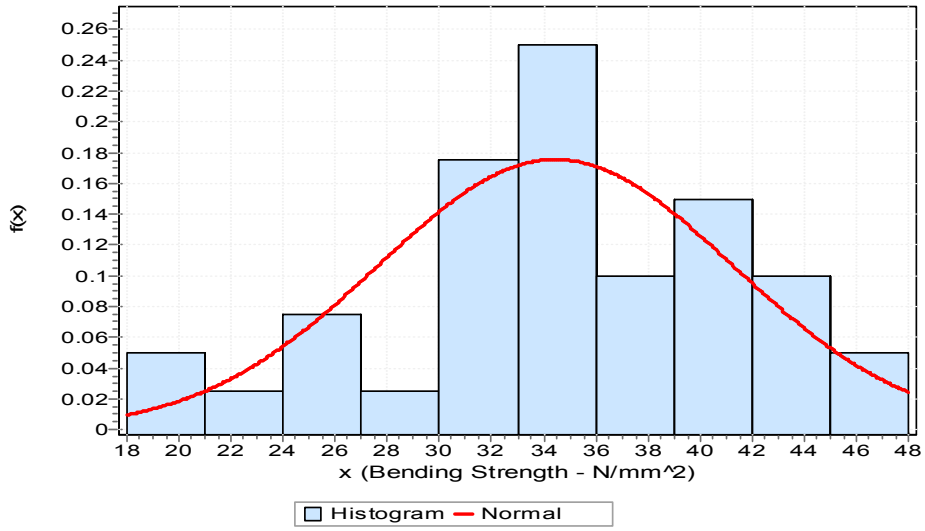


Fig. 4.22 Probability Density Function Plot for *Ceiba pentandra*, considering Bending Strength as Normal Distribution.

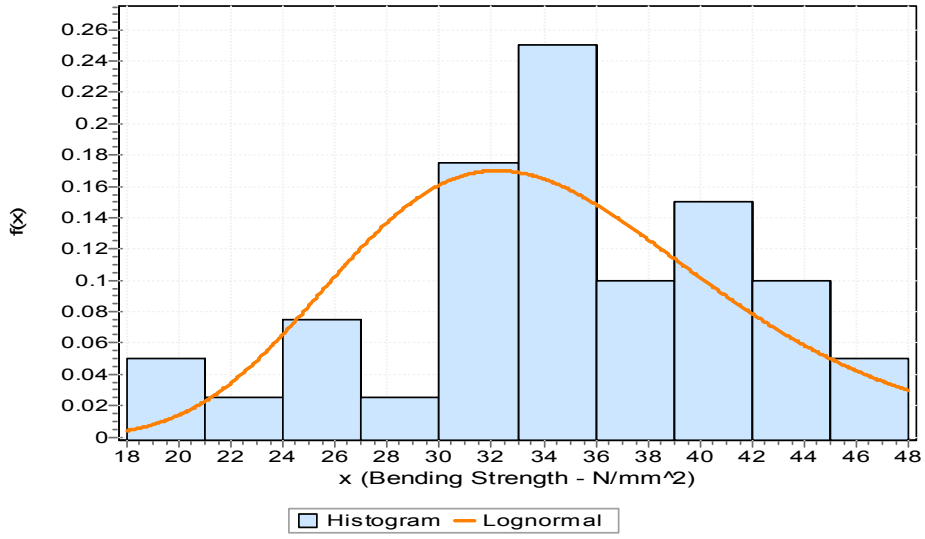


Fig. 4.23 Probability Density Function Plot for *Ceiba pentandra,* considering Bending Strength as Lognormal Distribution

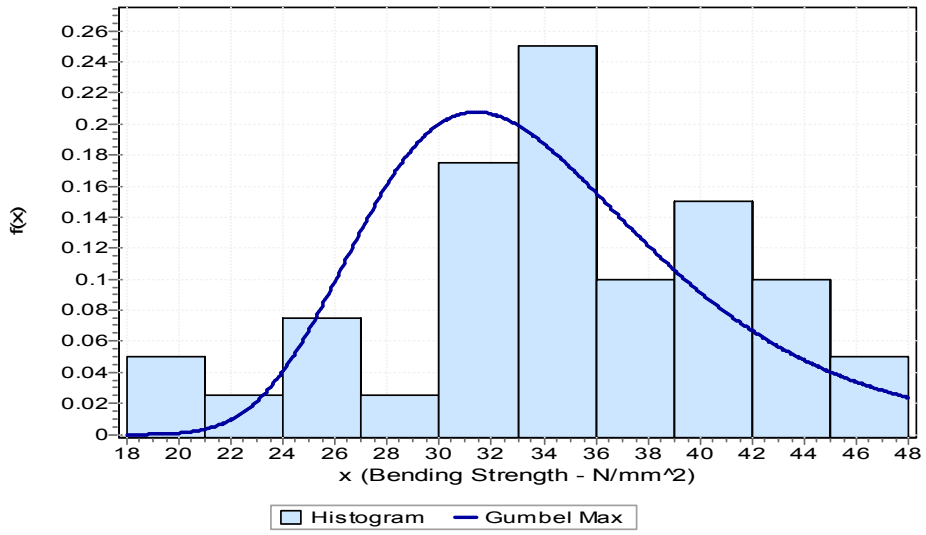


Fig. 4.24 Probability Density Function Plot for *Ceiba pentandra*, considering Bending Strength Gumbel Distribution

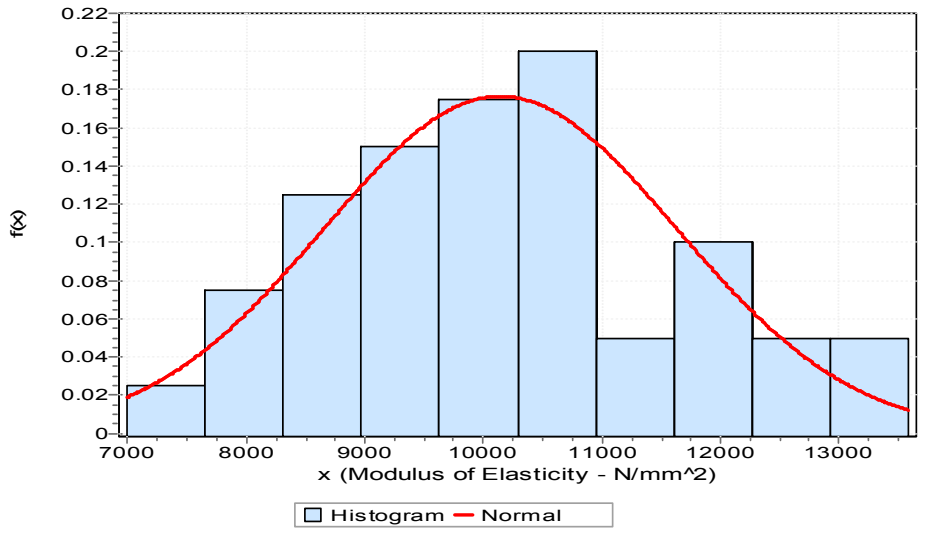


Fig. 4.25 Probability Density Function Plot *Isoberlinia dok*a, considering Modulus of Elasticity as Normal Distribution

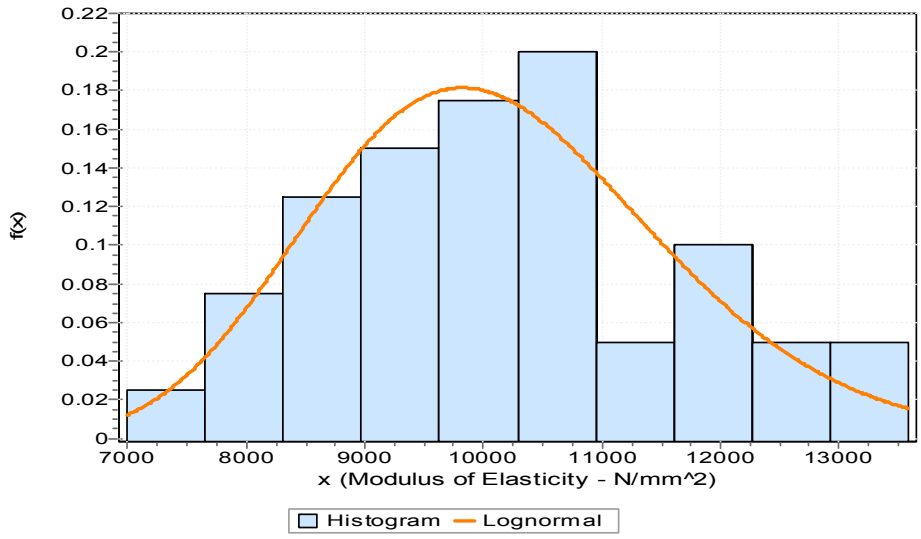


Fig 4.26 Probability Density Function Plot for *Isoberlinia doka*, considering Modulus of Elasticity as Lognormal Distribution

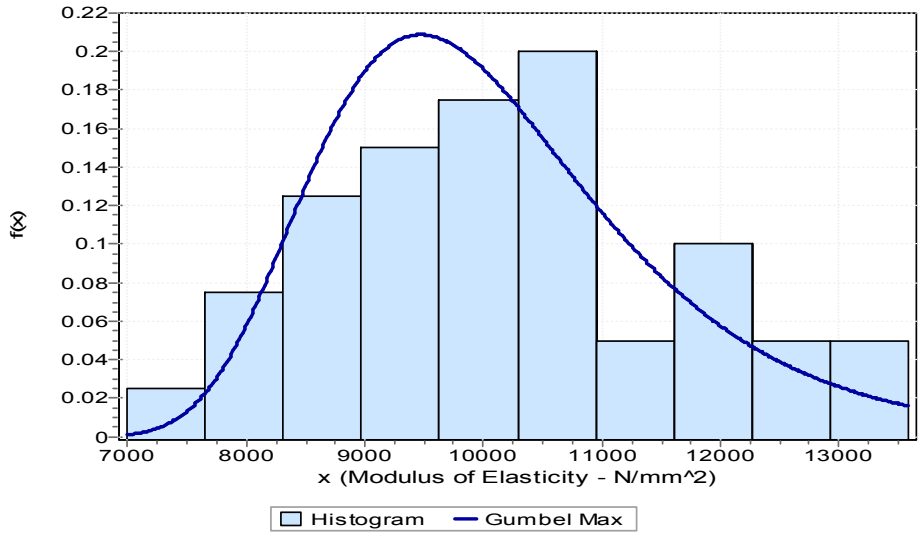


Fig. 4.27 Probability Density Function Plot for *Isoberlinia dok*a, considering Modulus of Elasticity as Gumbel Distribution

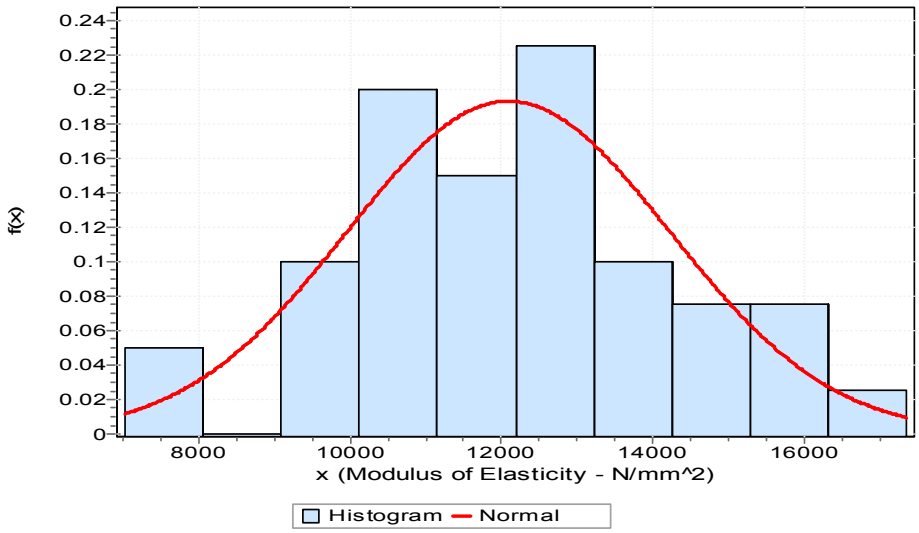


Fig. 4.28 Probability Density Function Plot for *Khaya senengalensis*, considering Modulus of Elasticity as Normal Distribution

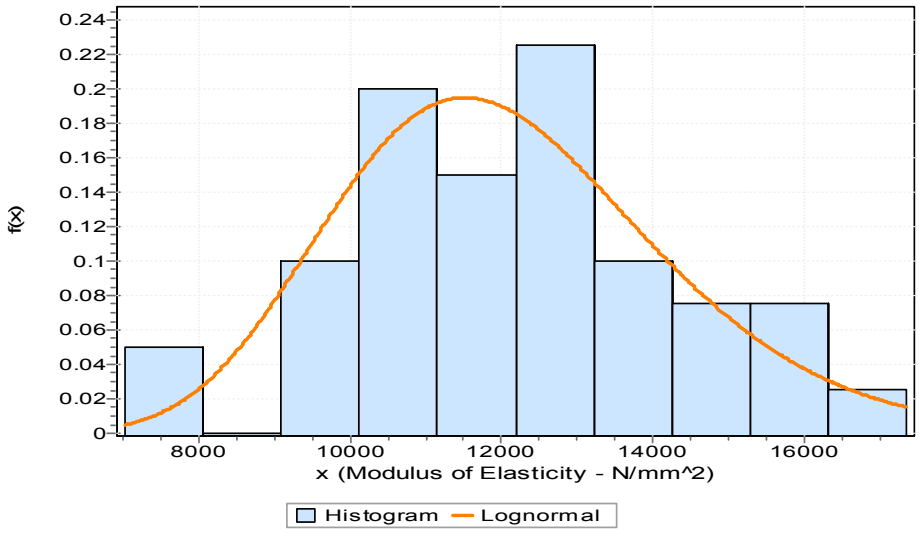


Fig. 4.29 Probability Density Function Plot for *Khaya senengalensis,* considering Modulus of Elasticity as Lognormal Distribution

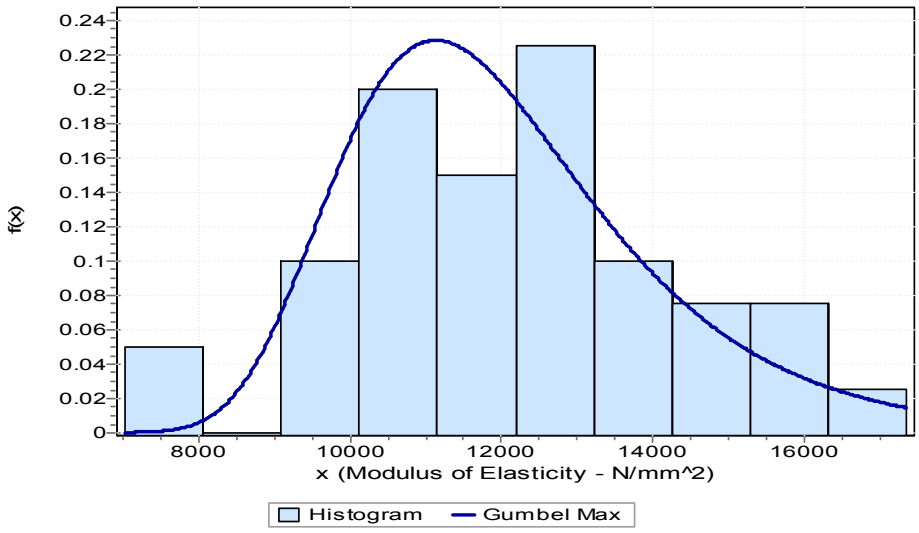


Fig. 4.30 Probability Density Function Plot for *Khaya senengalensis,* considering Modulus of Elasticity as Gumbel Distribution

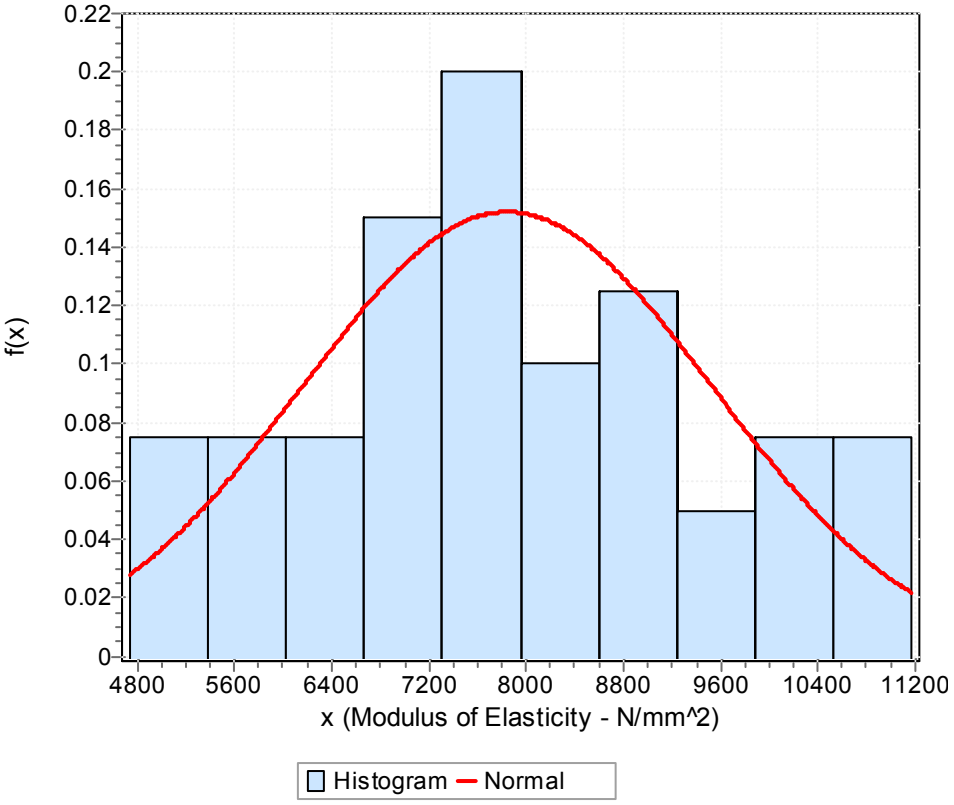


Fig. 4.31 Probability Density Function Plot for *Acacia albida* considering Modulus of Elasticity as Normal Distribution

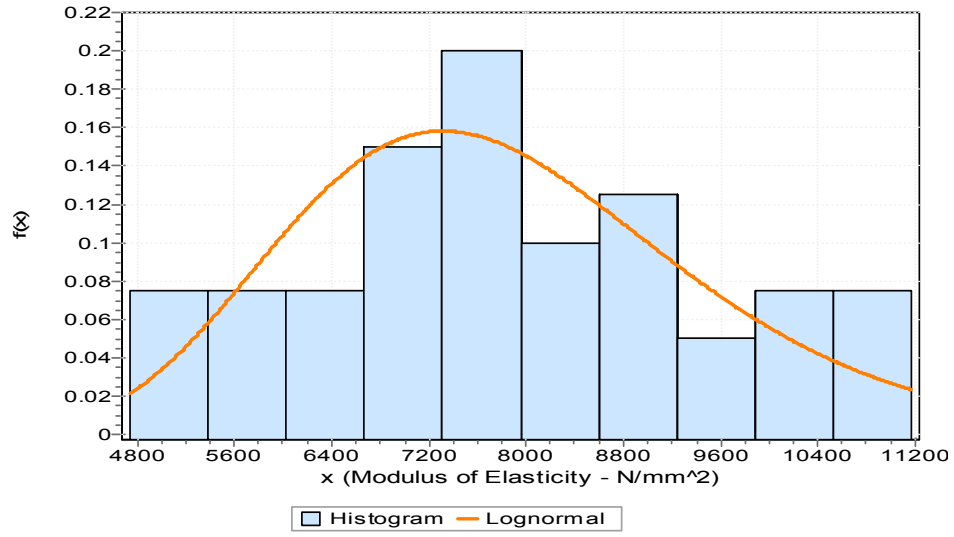


Fig. 4.32 Probability Density Function Plot for *Acacia albida,* considering Modulus of Elasticity as Lognormal Distribution

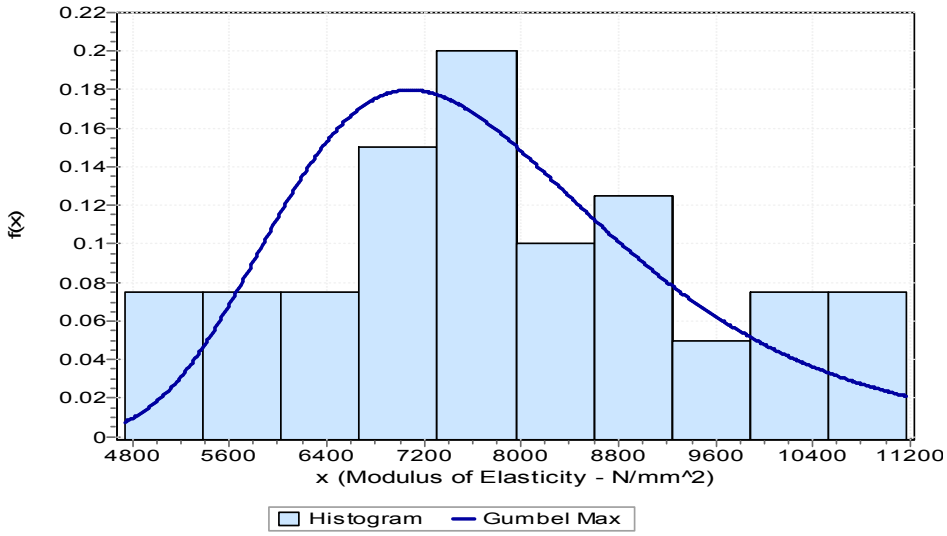


Fig. 4.33 Probability Density Function Plot for *Acacia albida* considering Modulus of Elasticity as Gumbel Distribution.

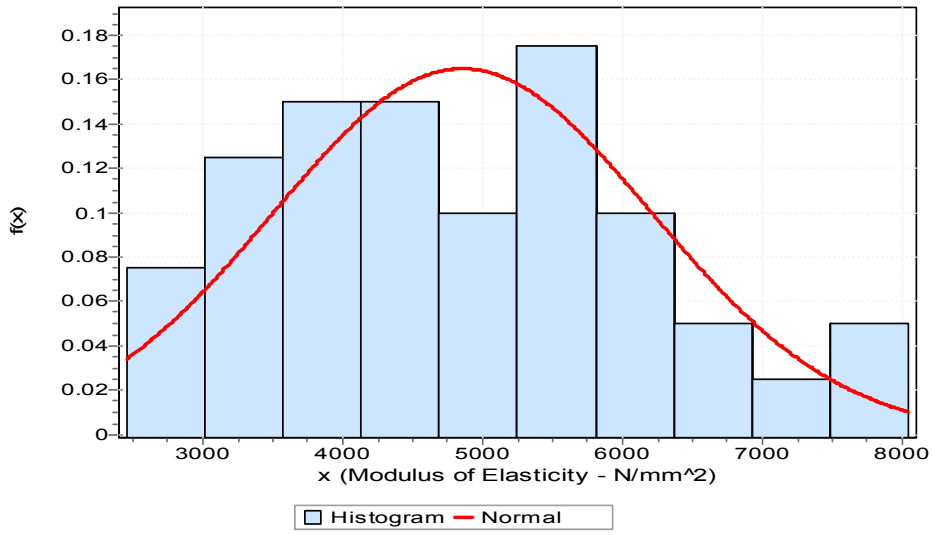


Fig. 4.34 Probability Density Function Plot for *Ceiba pentandra* considering Modulus of Elasticity as Normal Distribution.

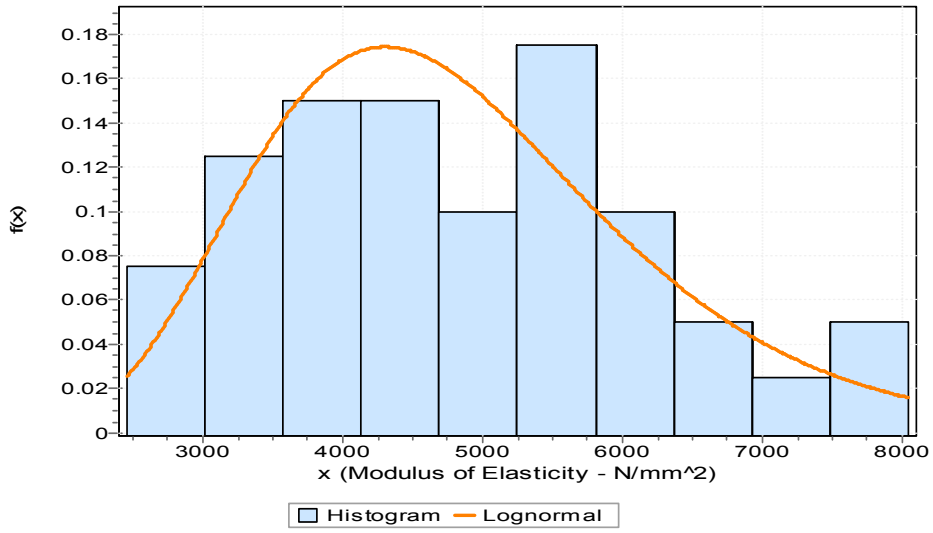


Fig. 4.35 Probability Density Function Plot for *Ceiba pentandra,* considering Modulus of Elasticity as Lognormal Distribution

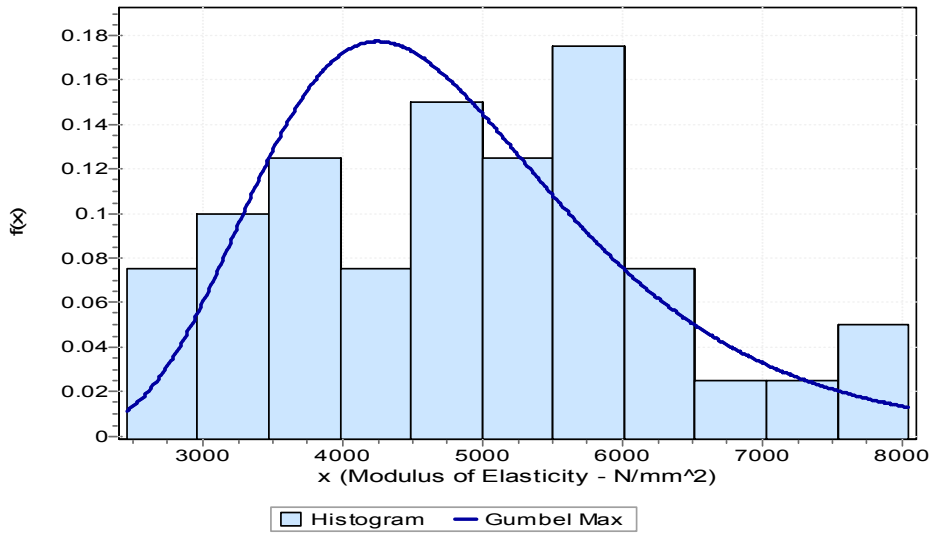


Fig. 4.36 Probability Density Function Plot for *Ceiba pentandra,* considering Modulus of Elasticity as Gumbel Distribution.

4.6.2 Test for goodness of fit

In the assignment of distribution models, two or more distribution may appear to be plausible probability distribution models. In that case, test of goodness of fit can be used to delineate the relative degree of validity of the different distribution (Ang and Tang, 1975). Kolmogorov Smirnov test was performed on the density, modulus of elasticity and bending strength, for each of the four species, in order to access if each data set comes from a population with a specific distribution. The basic procedure involves the comparison between the experimental cumulative frequency (Empirical Cumulative Distribution Function – ECDF) and the assigned theoretical distribution function. If the discrepancy is large with respect to what is normally expected from a given sample size, the theoretical model is rejected (Ang and Tang, 1975). The hypothesis is that "The data follow a specified distribution". Given N ordered data points Y_1, Y_2, . . . Y_N the Kolmogorov-Smirnov test statistics is defined as.

$$D = \max \left(F(Y_i) - \frac{i-1}{N}, \frac{i}{N} - F(Y_i) \right) \qquad (4.10)$$

Where, D is the statistics of the Kolmogorov Smirnov test. F is the theoretical cumulative distribution of the distribution being tested. The hypothesis regarding the distributional form is rejected if the test statistics, D, is greater than the critical value at 0.05 confidence level. In this

study, Kolmogorov-Smirnov test was implemented using **EASYFIT (2010)** software. The results are presented in Tables 4.7 to 4.9

4.6.3 Distribution model for density

From Table 4.11, the critical value for Kolmogorov Smirnov test at $\alpha = 0.05$, for density of all the four species is 0.29. This value is greater than the K-S statistics of the normal, lognormal, and gumbel distribution. It implied that, all the four distribution can be used to model the density of this specie. However, considering the ranking of the validity of the three distribution model, it can be concluded that, the density of Doka (*Isoberlinia doka)* can best be modelled using gumbel distribution. The density of Madaci (*Khaya senegalensis), Gawo (Acacia albida) and Rimi (Ceiba pentandra)* could best be modelled with normal distribution.

Table 4.11: Goodness of Fit (Kolmogorov smirnov) Test Result for Density

Distribution	*Isoberlinia doka*		*Khaya senegalensis*		*Acacia albida*		*Ceiba pentandra*	
	Statistics	Rank	Statistics	Rank	Statistics	Rank	Statistics	Rank
Normal	0.1139	3	0.0894	1	0.0945	1	0.0628	1
Lgnormal	0.0694	2	0.1072	2	0.1340	2	0.0899	2
Gumbel	0.0644	1	0.1470	3	0.1523	3	0.1238	3

4.6.4 Distribution model for bending strength

The critical value for Kolmogorov smirnov test at $\alpha = 0.05$, bending strengths for all the four species as presented in Table 4.12 is also 0.29. This value is greater than the corresponding K-S statistics of the normal, lognormal, and gumbel distribution. Each of the four distribution models can therefore be used to model the bending strength of timber. Considering the ranking of the validity of the four distribution model, it is observed that, the most fitted distribution model for bending strength of solid timber is the normal distribution.

Table 4.12: Goodness of Fit (Kolmogorov Smirnov) Test Result for Bending Strength

Distribution	*Isoberlinia doka*		*Khaya senegalensis*		*Acacia albida*		*Ceiba pentandra*	
	Statistics	Rank	Statistics	Rank	Statistics	Rank	Statistics	Rank
Normal	0.0992	1	0.1022	1	0.0892	1	0.1064	1
Lognormal	0.1161	2	0.1282	2	0.1397	2	0.1468	3
Gumbel	0.1502	3	0.1358	3	0.1517	3	0.1428	2

4.6.5 Distribution model for modulus of elasticity

The critical value for Kolmogorov Smirnov test at $\alpha = 0.05$, for all the species as presented in Table 4.13 is 0.29. This value is greater than the corresponding K-S statistics of the normal, lognormal and gumbel distribution. This is a clear indication that each of the four distribution models can be used to model the modulus of elasticity of timber. Considering the ranking of the validity of the four distribution model, it is observed that, the most fitted distribution model for modulus of elasticity of solid timber is lognormal distribution, with the least statistics of 0.0678.

Table 4.13: Goodness of Fit (Kolmogorov Smirnov) Test Result for Modulus of Elasticity

Distribution	*Isoberlinia doka*		*Khaya senegalensis*		*Acacia albida*		*Ceiba pentandra*	
	Statistics	Rank	Statistics	Rank	Statistics	Rank	Statistics	Rank
Normal	0.0926	3	0.0696	1	0.1047	3	0.0796	1
Lognormal	0.0678	1	0.0766	2	0.0680	1	0.0942	2
Gumbel	0.0921	2	0.1076	3	0.0934	2	0.1029	3

4.7 Analysis of Variance on Laboratory Data

Analysis of variance is a statistical technique whereby total variance present in a set of data is partitioned into several components. Associated with each of these components is specific source of variation, so that in the analysis, it is possible to ascertain the magnitude of the contribution of each of these source to the total variation.

F-tests are used to compare the between- and within- the timber specie variances to determine if they are different. A hypothesis test is shown which tests the hypothesis that the samples have different means. The *p*-value shows the probability of rejecting the null hypothesis, that the samples have the same mean, when it is in fact true. A significant p-value implies that at least two samples have different means. In this study two-way analysis of variance was conducted using Analyse-it software in order to ascertain the sample variance within and between timber species.

Table 4.14: Two-way Analysis of Variance (ANOVA) for Density (Between timber species)

n	160

Specimen No	n	Mean	SE	Pooled SE	SD
1	4	797.4	261.96	80.18	523.9
2	4	672.8	111.44	80.18	222.9
3	4	630.9	165.22	80.18	330.4
4	4	818.3	199.45	80.18	398.9
5	4	710.7	188.80	80.18	377.6
6	4	610.8	116.75	80.18	233.5
7	4	749.0	202.24	80.18	404.5
8	4	643.7	137.06	80.18	274.1
9	4	781.4	174.70	80.18	349.4
10	4	799.3	222.09	80.18	444.2
11	4	619.1	116.57	80.18	233.1
12	4	700.0	145.03	80.18	290.1
13	4	723.1	263.89	80.18	527.8

14	4	651.4	116.58	80.18	233.2
15	4	749.9	218.96	80.18	437.9
16	4	709.2	185.97	80.18	371.9
17	4	681.9	177.98	80.18	356.0
18	4	739.7	106.63	80.18	213.3
19	4	797.2	142.43	80.18	284.9
20	4	708.6	181.36	80.18	362.7
21	4	716.0	132.40	80.18	264.8
22	4	582.0	114.48	80.18	229.0
23	4	664.7	141.46	80.18	282.9
24	4	608.1	188.43	80.18	376.9
25	4	669.4	181.01	80.18	362.0
26	4	721.1	142.98	80.18	286.0
27	4	694.4	182.03	80.18	364.1
28	4	495.8	112.11	80.18	224.2
29	4	818.1	207.62	80.18	415.2
30	4	750.2	151.11	80.18	302.2
31	4	584.3	127.06	80.18	254.1
32	4	766.5	157.76	80.18	315.5
33	4	684.2	132.54	80.18	265.1
34	4	787.7	209.24	80.18	418.5
35	4	566.6	131.66	80.18	263.3
36	4	635.4	171.71	80.18	343.4
37	4	700.7	168.23	80.18	336.5
38	4	618.3	73.14	80.18	146.3
39	4	760.4	125.55	80.18	251.1
40	4	632.9	101.70	80.18	203.4

Table 4.15 ANOVA for Density within the timber species

Groups	n	Mean	SE	Pooled SE	SD
Isoberlinia doka	40	983.7	36.28	25.05	229.4
Kahaya senehalenses	40	869.9	21.99	25.05	139.1
Acacia albida	40	581.5	24.33	25.05	153.9
Ceiba pentandra	40	340	10.92	25.05	69.1
Source of variation	Sum squares	DF	Mean square	F statistic	p
Groups	10113316	3	3371105	134.27	<0.0001
Residual	3916567	156	25106.2		
Total	14029883	159			

The null hypotheses for the analysis of variance of timber density are as follows:

1. Analysis of variance within timber specie:

Null hypotheses H0: The samples have different mean density within timber specie

Ha: The samples have the same mean density within timber specie

2. Analysis of variance between timber species:

Null hypotheses H0: The samples have different mean density between timber species

Ha: The samples have the same mean density between timber species

In Table 4.15, the p-value for density within timber species is 0.6298. Since this value is greater than the critical value 0.05, the hypotheses are rejected and concluded that, the mean of the samples constituting the population of each of the four species are the same. Likewise, the p-value for density between timber species is <0.0001, the hypothesis is accepted, that the populations of the tested species have different means. Based on the measured density therefore, the species are from different strength, and the populations of each specie are truly representative.

Table 4.16: Two-way Analysis of Variance (ANOVA) for Bending Strength between the timber species.

n	160

Specimen No	n	Mean	SE	Pooled SE	SD
1	4	45.9	3.35	3.87	6.7
2	4	44.2	1.43	3.87	2.9
3	4	43.3	7.55	3.87	15.1
4	4	34.5	7.17	3.87	14.3
5	4	41.9	4.49	3.87	9.0
6	4	43.7	8.07	3.87	16.1
7	4	44.5	5.21	3.87	10.4
8	4	42.0	4.09	3.87	8.2
9	4	42.1	6.18	3.87	12.4
10	4	46.9	4.94	3.87	9.9
11	4	39.4	3.51	3.87	7.0
12	4	40.8	6.51	3.87	13.0
13	4	42.6	2.69	3.87	5.4
14	4	40.3	1.83	3.87	3.7
15	4	42.2	5.02	3.87	10.0
16	4	45.0	9.12	3.87	18.2
17	4	42.9	4.18	3.87	8.4
18	4	40.5	6.90	3.87	13.8
19	4	37.9	5.35	3.87	10.7
20	4	41.1	4.79	3.87	9.6
21	4	44.9	4.60	3.87	9.2
22	4	44.7	6.02	3.87	12.0
23	4	39.2	6.04	3.87	12.1
24	4	40.4	8.85	3.87	17.7

25	4	46.1	4.83	3.87	9.7
26	4	38.7	1.98	3.87	4.0
27	4	33.5	6.41	3.87	12.8
28	4	43.4	8.35	3.87	16.7
29	4	34.8	2.45	3.87	4.9
30	4	38.6	2.21	3.87	4.4
31	4	48.5	5.19	3.87	10.4
32	4	40.0	8.25	3.87	16.5
33	4	42.5	5.12	3.87	10.2
34	4	45.5	6.10	3.87	12.2
35	4	44.2	7.19	3.87	14.4
36	4	41.4	4.42	3.87	8.8
37	4	35.9	4.20	3.87	8.4
38	4	44.8	4.01	3.87	8.0
39	4	42.9	7.12	3.87	14.2
40	4	37.8	4.72	3.87	9.4

Table 4.17 ANOVA for Bending Strength within the species

Groups	n	Mean	SE	Pooled SE	SD
Isoberlinia doka	40	47.8	1.25	1.19	7.9
Kahaya senehalenses	40	49.8	1.14	1.19	7.2
Acacia albida	40	34.9	1.3	1.19	8.2
Ceiba pentandra	40	34.4	1.08	1.19	6.8
Source of variation	Sum squares	DF	Mean square	F statistic	p

Groups	8107.4	3	2702.5	47.38	<0.0001
Residual	8898	156	57		
Total	17005.4	159			

The null hypotheses for the analysis of variance of timber bending strength are as follows:

1. Analysis of variance within timber specie:

Null hypotheses H0: The samples have different mean bending strength within timber specie

Ha: The samples have the same mean bending strength within timber specie

2. Analysis of variance between timber species:

H0: The samples have different mean bending strength between timber species

Ha: The samples have the same mean bending strength between timber species

In Table 4.17, the p-value for bending strength within timber species is 0.7857. Since this value is greater than the critical value 0.05, the hypothesis is rejected and conclude that, the mean of the samples constituting the population of each of the four species are the same. Likewise, the p-value for bending strength between timber species is <0.0001, the hypothesis is accepted, that the populations of the tested species have different means. Based on the measured bending strength therefore, the species are from different strength, and the populations of each species are truly representative.

Table 4.18: Two-way Analysis of Variance (ANOVA) for Modulus of Elasticity between the species.

n	160

Specimen No.	n	Mean	SE	Pooled SE	SD
1	4	8492.7	1863.78	858.58	3727.6
2	4	9842.8	818.55	858.58	1637.1

3	4	9270.4	1594.16	858.58	3188.3
4	4	8789.0	1634.30	858.58	3268.6
5	4	9204.5	932.99	858.58	1866.0
6	4	7417.2	1294.45	858.58	2588.9
7	4	9206.6	1121.25	858.58	2242.5
8	4	8648.1	1608.10	858.58	3216.2
9	4	9114.4	2392.39	858.58	4784.8
10	4	10015.8	1766.53	858.58	3533.1
11	4	8370.6	1081.82	858.58	2163.6
12	4	7590.2	2027.10	858.58	4054.2
13	4	9554.3	2065.44	858.58	4130.9
14	4	8629.6	1432.50	858.58	2865.0
15	4	7874.4	1416.97	858.58	2833.9
16	4	7218.5	1402.78	858.58	2805.6
17	4	8843.4	1723.89	858.58	3447.8
18	4	8515.6	1932.93	858.58	3865.9
19	4	10545.3	2309.47	858.58	4618.9
20	4	7873.3	948.61	858.58	1897.2
21	4	8447.7	1728.56	858.58	3457.1
22	4	8219.1	1242.69	858.58	2485.4
23	4	8250.5	2185.83	858.58	4371.7
24	4	9690.4	1393.59	858.58	2787.2
25	4	10533.9	1518.29	858.58	3036.6
26	4	9228.6	1591.85	858.58	3183.7
27	4	8360.1	2211.59	858.58	4423.2
28	4	10093.5	2488.81	858.58	4977.6
29	4	7975.3	1603.96	858.58	3207.9
30	4	9211.2	2139.67	858.58	4279.3
31	4	7757.7	1765.26	858.58	3530.5
32	4	9060.7	2037.54	858.58	4075.1
33	4	8478.2	2542.88	858.58	5085.8

34	4	8421.0	1767.42	858.58	3534.8
35	4	8755.8	1678.47	858.58	3356.9
36	4	8708.3	2374.71	858.58	4749.4
37	4	8671.6	1651.48	858.58	3303.0
38	4	8568.6	1905.75	858.58	3811.5
39	4	8217.1	1947.22	858.58	3894.4
40	4	7683.9	1673.91	858.58	3347.8

Table 4.19: ANOVA for Modulus of Elasticity within the species

Groups	n	Mean	SE	Pooled SE	SD
Isoberlinia doka	40	10144.9	235.58	267.27	1490
Kahaya senehalenses	40	12089.6	336.87	267.27	2130.6
Acacia albida	40	7845.1	266.65	267.27	1686.4
Ceiba pentandra	40	4855.4	213.67	267.27	1351.3
Source of variation	Sum squares	DF	Mean square	F statistic	p
Groups	1.16E+09	3	3.88E+08	135.72	<0.0001
Residual	4.46E+08	156	2857390		
Total	1.61E+09	159			

The null hypotheses for the analysis of variance of timber modulus of elasticity are as follows:

1. Analysis of variance within timber specie:

H0: The samples have different mean modulus of elasticity within timber specie

Ha: The samples have the same mean modulus of elasticity within timber specie

2. Analysis of variance between timber species:

H0: The samples have different mean modulus of elasticity between timber species

Ha: The samples have the same mean modulus of elasticity between timber species

In Table 4.19, the p-value for modulus of elasticity within timber species is 0.6752. Since this value is greater than the critical value 0.05, the hypothesis is rejected and conclude that, the

mean of the samples constituting the population of each of the four species are the same. Likewise, the p-value for modulus of elasticity between timber species is <0.0001, the hypothesis is accepted, that the populations of the tested species have different means. Based on the measured modulus of elasticity therefore, the species are from different strength classes, and the populations of each species is truly representative.

4.8 Strength Grading to EN 338

The Eurocode 5 (2004) is used in conjunction with the European strength classification system presented in the EN annex EN 338 (2009). To use a particular species in design, the specie must be graded in accordance with this standard. The species under investigation in this study, are assigned into the appropriate strength classes based on their 5 percentile (characteristic) values of their bending strength. The 5 percentile values for the modulus of elasticity, bending strength and the density were generated for each of the four species (*Isoberlinia doka, Khaya senengalensis, Acacia albida and Ceiba pentandra*). This is presented in table 4.17.

Table 4.20 Percentile Values of the Reference Material Properties

Species	Density (Kg/m^3)	Bending Strength (N/mm^2)	Modulus of Elasticity (N/mm^2)
Isoberlinia doka	613.59	34.05	7875.00
Khaya senengalensis	567.15	36.15	8010.00
Acacia albida	343.84	17.3	5204.80
Ceiba pentandra	213.71	20.18	2679.80

To assign a timber species to a particular strength class, the 5 percentile value of the bending strength of that specie must be greater than or equal to the characteristic bending strength of the species under that class, another timber class determining factor considered is density The assigned strength classes of the tested species are presented in Table 4.18. *Isoberlinia doka* was assigned to D30 strength class, *Khaya senegalensis* was assigned to D35 strength class, *Acacia albida* was assigned to strength class C16 and *Ceiba pentandra* to strength class of C14.

4.21: Strength Classes of the Tested Species

Species	Strength Class
Isoberlinia doka	D30
Khaya senengalensis	D35
Acacia albida	C16
Ceiba pentandra	C14

4.9 Summary

In this research work, stochastic models of the material properties of four common timber species (*Isoberlinia Doka, Khaya senegalensis, Acacia albida and Ceiba pentandra*) were generated. Also the species were assigned to appropriate strength classes defined in the EN 338 (2008). *Isoberlinia doka,* was assigned to strength class D30*, Khaya senegalensis* to strength class D35*, Acacia Albida* to strength class C16, *and Ceiba pentandra* to strength class C14. Of the tested species, *Ceiba pentandra* was found to have the least elastic modulus. This might have been the reason why this species results to serious bowing when used as formwork, because of its very low stiffness. Two-way analysis of variance (ANOVA) was undertaken using analysis-it software, with the view to examine the equality of mean values of material properties within and between each of the tested species. The results indicated that, all the sample of particular species considered come from the same population. Likewise, the difference between the mean values of the tested species is significant.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Stochastic models for the material properties of four common timber species Doka (*Isoberlinia doka), Madaci (Khaya senegalensis) ,Gawo (Acacia albida) and Rimi (Ceiba pentandra*) were generated. Also the species were assigned to appropriate strength classes defined in the EN 338 (2008). Doka (*Isoberlinia doka),* was assigned to strength class D30*, Madaci (Khaya senegalensis)* to strength class D35*, Gawo (Acacia albida)* to strength class C16, *and* Rimi *(Ceiba Pentandra)* to strength class C14. Of the tested species, Rimi (*Ceiba pentandra*) was found to have the least elastic modulus. This might have been the reason why this specie results to serious bowing when used as formwork, because of its very low stiffness. Comparing the four tested species, Madaci (*Khaya senegalensis)* has the highest density and also highest modulus of elasticity and bending strength. The material properties were adjusted to 12% and 18% moisture content in order for the data to be relevant to the European and Nigerian Environmental conditions. The derived properties obtained from three reference property were based on the recommendations of EN384 (2004) and JCSS (2006). The entire statistical analysis was perfumed in accordance with EN384 (2004) using Easyfit (2010) statistical package**,** it was used to plots and analyse all the probability density functions superimposed on the histogram for the density, bending strength and modulus of elasticity data. Two-way analysis of variance (ANOVA) was undertaken using analysis-it software, with the view to examine the equality of mean values of material properties within and between each of the tested species. The results indicated that, all the samples of particular specie considered come from the same population. Likewise, the difference between the mean values of the tested species are significant

5.2 Recommendations

Based on the investigation conducted in this study, the following recommendations were made.

i. The data generated in this study are necessary input for structural reliability analysis. The use of this data is therefore recommended, as this will address the issues of uncertainties in timber structural design.

ii. The tested species were graded based on the recommendation of EN 338 (2009). The assignment of strength classes to timber species is necessary, if the species are to be employed in the construction of timber structures designed using the Eurocode 5. The

modification of the NCP2 (1973) and the adoption of the Eurocode 5 (2004) is therefore recommended.

References

Afolayan, J. O. (2005). Probability-based design of glued thin-webbed timber beams.

Asian Journal of Civil Engineering (Building and Housing) Vol. 4 (1-2) pp. 75-84.

ASTM D-143 (2006). "Standard Method of Testing Small Clear Specimens of Timber,"

American Society for Testing and Materials, USA.

Antti, H. Ranta-Maunus, A. and Goran, T. (2006) "Potential of Strength Grading of Timber with Combined Measurement Technique. Report of the Cambridge Project – phase 1, UK

Ang A. H. S. and Tang W. S. (1975) Probability Concepts in Engineering Design. Vol. 1: Basic Principles. Wiley, New York. Project – phase 1.

Akindele, S. O. (2003). Volume Prediction from Stump Diameters of Ginelina Arboria (Rocb)

trees in Akure Forest Reserve. Nigeria. Niger J. Forestry Vol. 33 No. 2, pp. 116-123.

Alpo. R. (2004). Theoretical and Practical Aspects of the Reliability Analysis of Timber

Structures. WCTE 2004 conference in Lahti, Finland

Baker, B.F. (2000). Properties of imported tropical woods. Res. Pap. FPL–RP–125. Madison,

WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 67 p.

Bostrom. L. (1994) Machine Strength Grading . "Comparison of For Different Systems"

Swedish National Testing and Research Institute Building Technology special Report 1994, pp. 49-57.

Bostrom, L. and Ormassn, S. (1999) .Measurement of Modulus of Elasticity in Bending of

Structural Timber-Determination of Some Physical and Mechanical Properties.

Baltrusaitis, A and Pranckevicene, V. (2003). "Strength Grading of the Structural Timber

Material Science Journal, Vol 9, No 3. pp 284-287

Baradan, E.A. (2002). Wood identification:a review. IAWA Journal. Vol. 19 No. Pp 241–264.

Baltrušaitis A. Pranckevičienė V. (2003) Strength Grading of the Structural Timber material science (MEDŽIAGOTYRA). Vol. 9, No. 3.

BS 5268: Part 2 (2002). Code of Practice for Permissible Stress Design, Material and Workmanship, British Standard Institute, BSI, London.

Bamber, R. K. and Burley, J. (1983) The Wood Properties of Radiata Pine. Commonwealth Agricultural Bureu. England.

Burkill, H. M. (1994) Useful Plants of West Tropical Africa. Vol. 2. Families E-I. Royal Botanical Gardens, Kew.

Burley J, and Styles B. T. (1976) Tropical Trees: Variation, Breeding and Conservation. Linnean Society Symposium Series No. 2. Academic Press.

Bunn, E. H. (1981). The nature of the Resource. New Zealand Journal of Forestry. Vol. 26 No. 2 pp 162-199.

Blab F.F. (1995). Resistance of wood to chemical degradation. Forest Products Journal. Vol. 16. No. 2. Pp 53-64

Chanakya A. (2009). Design of Structural Elements. Concrete, Steelwork, Masonry and Timber Design to British Standards and Eurocodes. 3rd Ed. Taylor and Francis, USA.

Cown J. L. And Burkill, H. M. (2002) Useful Plants of West Tropical Africa. Vol. 2. Families E- I. Royal Botanical Gardens, Kew.

Eurocode 5 (2004). "Design of Timber Structures; Part 1-1: General – Common rules and rules for Buildings" European Committee for Standardisation, CEN, Brussels, Belgium, 2004.

EN 338 (2009). Structural Timber – Strength Classes. European Committee for Standardisation, CEN, Brussels, Belgium.

EN 408 (2003). Timber Structures- Structural timber and Glued-laminated Timber: Determination of some Physical and Mechanical Properties", European Committee for Standardisation, CEN, Brussels, Belgium.

EN 384 (2004) “Structural Timber- Determination of Characteristic values of Mechanical Properties and Density”, European Committee for Standardisation, CEN, Brussels, Belgium

EN 350-2 (1994) Durability of Two Wood-Based Products. Guide to Natural Durability and Treatability of Selected Wood Species of Importance in Europe.

EN 13153-1 (2002) Moisture Content of a Piece of Sawn Timber-Part 1. Determination by Oven Dry Method.

Easyfit (2010) “Data Analysis and Simulation Software”, Version 5.5, Professional Evaluation Version, A Special Statistical Analysis and Probability Distribution Package, Published by Mathwave Technologies, Ukraine

Gibbs P. S and Semir I (2003). A Taxonomic Revision of the Genus Ceiba Mill. (Bombacacene). Anales del JardenBotanico de Madrid Vol. 60. No. 1.. 259-300.

Holicky, M., and Retief, V. (2005). Reliability assessment of alternative Eurocode and South African load combination schemes for structural design. Journal of the South African Institution of Civil Engineering. Vol. 47. No. pp 15-21.

Heikkila, K. and Herajarvi, H. (2008). Stiffness and Strength of 45X95mm beams Glued from Norway Spruce Using 8 Different Structural Models. Conference COST E53 29-30. Delft, the Netherlands ,Institute. Agricultural University of Norway. 104 p.

JCSS (2006). ”Probabilistic Model Code: Material Properties for Timber” Joint Committee on Structural Safety .

Jorascav, H., and Pavel, K. (2010) Analysis of selected Mechanical Properties of Construction Wood KVH and Paraliam 2.0 E. DRVNA INDUSTRIJA 61(1) pp15-25.

Krigar, F.F.P. (2006). Principles of wood science and technology I—solid wood. New York: Springer Verlag. 592 p.

Kingdom.K.S. (1980).Textbook of wood technology. New York: McGraw-Hill. Vol. 1,4th ed.

Kumar, R.F.S. (2004). The elasticity of wood and plywood. Special Rep. 7. London, England:

Department of Scientific and Industrial Research, Forest Products Research.

Kohler, J. (2004). Probabilistic Modeling of Duration of Load Effects in Timber Structures.

35, CIB W18 Meeting, Kyoto, September, 2002

Lucas, E. Olorunmisola, A. and Adewole, N. (2006) Preliminary Evaluation of

Guava (*Psidium guajava* L.) Tree Branches for Truss Fabrication in Nigeria.

Agricultural Engineering International: CIGR Ejournal vol VIII.

McDonald, K.A.(1998) Measuring localized slope of grain by electrical capacitance. Forest

Products Journal. Vol. 36. No. 10. Pp. 75–78.

Melbourne, C.C. (1974) Effect of moisture content and temperature on the

mechanical properties of wood: an analysis of immediate effects. Wood and Fiber.

Vol. No. 14. No. 1. Pp. 4–36.

NEST (1991). Nigeria's Threatened Environment: An national Profile Ibadan. Nigerian Environmental Study/Action Team.

NCP 2 (1973). "Timber Design Manual" Nigerian Industrial Standard, 1973."The Use of Timber for Construction". Nigerian Standard Code of Practice, Nigerian Standard Organisation, Federal Ministry of Industries, Lagos, Nigeria

Piter, J. C. Zerbino, R. L. Blab, H. J. (2003) Relationship Between Local and

Global Modulus of Elasticity in Beams of Argentinian Eucalyptus Grandis.

Maderas Cienciay Technologia Vol. 5; No. 2. pp. 107-116.

Ranta-Maurus, A., Forselius, M., Kurkela, J. and Toratti, T (2001) "Reliability

Analysis of Timber Structures". Nordic Industrial Fund. Technical Research

Centre of Finland.

Ravenshorst, G.van der Linden, M., Vrouwenveider, T., and Kuilien, W. (2004) An Economic Method to Determine the Strength Class of Wood Species. HERO Vol, No 4. Pp 34-36.

Raw Materials and Development Council, RMRDC (1998). Local Building and Construction Materials. Report of the Multi-Disciplinary Task Force on the Survey and Update of The Report on Local Sourcing of Raw Materials for Building and Construction Industry in Nigeria, pp 27-39

Retief, V. And Holicky, M., (2005) Reliability assessment of alternative Eurocode and South African load combination schemes for structural design. Journal of the South African Institution of Civil Engineering. Vol. 47. 1. pp 15-21.

Schoome, D (2003) A Step Towards a More Precise Prediction of the Bending Strength of Spruce. Report of a Short Term Scientific Mission to CNR-IVALSA.

Siau, F.F.P. (1984). Principles of wood science and technology. New York: Springer–Verlag 245p.

Solli, K. H. (1996). "Determination of Modulus of Elasticity in Bending According to EN 408.

Thelandersson, S (1995). "Serviceability Limit States-Deformation. In Timber Engineering STEP 1 pp. A17/8. Centrum Hout, The Netherlands.

Taylor M. (2002). Annual growth rings, rainfall-dependent growth and long-term growth patterns of tropical trees in the Capar Forest Reserve in Venezuela. Journal of Ecology. Vol. 87. No, 2. Pp. 391–403.

Tord. I. (2001) System Effect. Nordic Wood-Reliability of Timber Structures.

TRADA (2009). Design to Eurocode 5-Introductory workshop. TRADA and BM Group Ltd, 22nd , May, 2009.

Widehammer, W.T. (2004). Specific gravity, moisture content, and density relationships for wood. Gen. Tech. Rep. FPL–GTR–76. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. Vo. 2. No. 3. Pp. 23-45

Xu, W.W. (2000). Review of literature on the effects of early stages of decay on wood strength. Wood and Fiber Science. Vol, 9. No 1. pp 252–257.

Zobel, B. J. and Buijtenen, J. P. (1989) Wood Variation-Its Cause and Control. Springer Series in Wood Science. Springer-verlag. Berlin, Germany.

APPENDIX A: Test results from calculations

Table A1: Results of Density Test

S/N0 (Test Piece)	Density (kg/m^3)			
	Isoberlinia doka	*Khaya senengalensis*	*Acacia albida*	*Ceiba pentandra*
1	1501	807	635	247
2	840	814	683	355
3	1048	744	371	360
4	1223	940	837	272
5	1078	988	454	323
6	927	555	596	365
7	1199	960	529	308
8	924	826	468	356
9	1013	1051	769	292
10	1347	975	437	438
11	760	828	584	305
12	613	1086	709	391
13	1461	563	656	212
14	903	736	617	349
15	1343	808	492	357
16	1036	1027	386	389
17	1118	823	432	354
18	739	900	881	438
19	1054	972	745	417
20	1153	856	430	395
21	929	929	622	383
22	697	840	457	334

23	811	929	640	279
24	944	903	410	175
25	947	1013	410	308
26	1081	788	607	408
27	1149	764	588	276
28	624	744	342	273
29	1290	995	657	331
30	906	1008	765	322
31	888	643	529	277
32	678	1146	849	393
33	808	942	662	325
34	1277	790	828	255
35	864	701	417	285
36	1001	838	256	447
37	863	1055	608	277
38	802	667	523	481
39	945	989	648	460
40	564	855	727	386

Table A2: Results of Bending Strength Test

S/No (Test piece)	Bending Strength (N/mm^2)			
	Isoberlinia doka	*Khaya senengalensis*	*Acacia albida*	*Ceiba pentandra*
1	55	47	39	42
2	46	47	41	43

3	58	53	37	25
4	35	49	15	40
5	52	46	36	33
6	51	63	27	35
7	50	57	36	35
8	39	49	48	32
9	45	58	29	37
10	55	54	34	45
11	49	40	32	37
12	55	46	37	25
13	46	48	36	41
14	44	40	41	35
15	46	47	27	48
16	64	57	28	31
17	47	52	39	33
18	41	58	24	39
19	44	47	37	23
20	52	46	32	35
21	53	52	41	34
22	53	55	28	43
23	43	55	29	31
24	43	64	23	31
25	55	52	33	44
26	38	43	34	40
27	34	48	17	36
28	47	60	46	20
29	36	30	32	41
30	41	44	35	35

31	57	39	58	40
32	53	53	36	18
33	58	36	39	37
34	57	52	43	30
35	61	48	42	26
36	45	52	36	32
37	32	47	38	27
38	53	45	47	34
39	45	62	34	31
40	39	50	28	34

Table A3: Results of Modulus of Elasticity Test

S/No (Test Piece)	Modulus of Elasticity (N/mm2)			
	Isoberlinia doka	*Khaya senegalensis*	*Acacia albida*	*Ceiba pentandra*
1	12243	11011	6260	4456
2	9797	11138	10889	7548
3	12270	11755	6906	6151
4	10494	12494	5456	6712
5	10626	9510	10191	6492
6	8656	10394	5951	4667
7	10246	10569	10158	5853
8	10292	12288	6756	5257
9	10382	14593	8414	3068
10	9864	14172	10477	5551

11	10595	7936	9387	5564
12	10551	11561	4741	3508
13	8954	15396	8153	5714
14	8475	10469	10934	4641
15	7970	10758	8765	4004
16	7870	10485	6816	3703
17	12089	11496	6483	5305
18	7998	13268	8948	3847
19	13588	15295	7607	5692
20	8507	9609	8202	5176
21	9809	12515	6901	4566
22	8564	11460	7288	5565
23	10942	12942	5202	3916
24	9459	13603	8613	7087
25	11240	14538	8316	8042
26	9975	12366	9784	4790
27	11047	12362	7575	2457
28	9247	17339	7458	6330
29	9859	11519	5407	5117
30	11731	12833	9023	3258
31	12538	7032	7432	4029
32	9190	12569	11171	3313
33	6995	15648	7613	3657
34	9572	12900	5253	5959
35	12964	9564	7442	5053
36	9726	14337	7922	2848
37	10649	11968	7457	4613
38	9603	13401	6624	4647

39	11668	11066	6746	3389
40	9551	9429	9084	2671

APPENDIX B: MOISTURE CONTENT

Table B1; Isoberlinia doka

TEST PIECE MARK	BULK MASS, m1 (g)	OVEN-DRY MASS, m2 (g)	DECREASE IN MASS, m1 – m2 (g)	MOISTURE CONTENT (%)
1	82.7	68.0	14.7	21.6
2	100.7	79.4	21.3	26.8
3	120.2	100.6	19.6	19.5
4	83.1	66.4	16.7	25.1
5	126.3	106.6	19.7	18.5
6	119.7	98.2	21.4	21.8
7	119.9	94.9	25.0	26.4
8	85.7	72.7	13.0	17.9
9	111.9	92.9	19.0	20.5
10	125.8	102.4	23.4	22.8
11	79.8	64.1	15.7	24.5
12	79.6	69.9	9.7	13.8
13	96.3	81.4	14.9	18.3
14	71.9	57.9	14.0	24.1
15	103.2	81.4	21.8	26.7
16	67.7	56.6	11.1	19.5

17	104.8	87.8	17.0	19.3
18	112.4	88.2	24.2	27.5
19	100.4	81.6	18.8	23.1
20	95.2	80.7	14.5	18.0
21	113.1	94.3	18.8	19.9
22	100.9	81.7	19.3	23.6
23	119.6	102.1	17.5	17.1
24	83.5	66.3	17.2	25.9
25	96.7	78.0	18.6	23.9
26	95.3	77.2	18.2	23.5
27	82.7	72.1	10.7	14.8
28	96.2	81.5	14.7	18.0
29	97.1	78.0	19.1	24.5
30	123.5	107.1	16.4	15.3
31	130.4	108.1	22.3	20.6
32	95.7	78.7	17.0	21.6
33	98.6	81.8	16.7	20.5
34	95.1	80.2	14.9	18.5
35	97.1	78.0	19.1	24.5
36	89.4	74.3	15.1	20.4
37	100.5	82.5	18.0	21.8
38	115.6	97.5	18.1	18.6
39	89.7	73.8	15.9	21.6
40	99.7	79.9	19.8	24.8

Table B2 : Khaya senegalenses

TEST PIECE MARK	BULK MASS, m_1 (g)	OVEN-DRY MASS, m_2 (g)	DECREASE IN MASS, $m_1 - m_2$ (g)	MOISTURE CONTENT (%)
1	82.3	73.6	8.7	11.8
2	67.9	56.1	11.8	21.0
3	82.2	67.0	15.2	22.7
4	134.1	107.3	26.8	25.0
5	89.7	81.9	7.8	9.5
6	82.8	68.5	14.4	21.0
7	100.8	82.7	18.0	21.8
8	123.4	104.4	19.0	18.2
9	88.9	73.0	15.9	21.8
10	81.2	70.2	11.0	15.7
11	104.3	83.0	21.2	25.6
12	114.8	91.0	23.8	26.2
13	61.1	50.5	10.7	21.1
14	106.0	87.0	19.0	21.8
15	61.9	50.6	11.4	22.5
16	72.0	60.9	11.1	18.1
17	94.7	80.6	14.2	17.6
18	101.7	82.0	19.7	24.1
19	70.2	63.3	6.9	10.9
20	101.0	78.3	22.7	29.0
21	60.9	51.3	9.6	18.7
22	115.4	92.3	23.1	25.0
23	77.9	65.8	12.1	18.4
24	45.2	35.1	10.1	28.7
25	102.8	86.1	16.8	19.5

26	95.2	82.5	12.7	15.4
27	101.3	84.5	16.8	19.9
28	76.6	63.2	13.4	21.3
29	124.6	111.5	13.1	11.8
30	100.0	84.9	15.2	17.9
31	103.5	84.9	18.6	21.9
32	83.3	69.9	13.4	19.1
33	69.0	58.0	11.1	19.1
34	75.7	62.4	13.3	21.3
35	125.0	107.4	17.6	16.4
36	96.1	83.7	12.4	14.8
37	96.6	82.9	13.7	16.5
38	84.9	69.5	15.4	22.1
39	80.0	70.2	9.7	13.8
40	101.3	87.3	14.0	16.0

Table B3 : ***Acacia albida***

TEST PIECE MARK	BULK MASS, m_1 (g)	OVEN-DRY MASS, m_2 (g)	DECREASE IN MASS, $m_1 - m_2$ (g)	MOISTURE CONTENT (%)
1	101.8	84.1	17.8	21.1
2	79.3	64.8	14.5	22.5
3	114.2	100.4	13.9	13.8

4	109.5	91.0	18.5	20.3
5	102.5	90.1	12.4	13.7
6	108.9	93.7	15.2	16.2
7	78.0	66.4	11.6	17.5
8	106.0	87.4	18.6	21.3
9	97.1	84.1	13.0	15.5
10	128.4	112.0	16.4	14.6
11	73.2	62.9	10.3	16.4
12	126.1	106.9	19.2	18.0
13	102.0	86.5	15.4	17.8
14	82.8	67.5	15.3	22.7
15	100.2	87.8	12.5	14.2
16	91.0	78.7	12.4	15.7
17	111.9	93.7	18.2	19.4
18	91.2	78.2	13.0	16.7
19	116.3	99.8	16.5	16.5
20	100.2	81.6	18.6	22.8
21	88.7	76.1	12.6	16.6
22	112.7	99.4	13.3	13.4
23	87.1	73.8	13.3	18.0
24	99.5	83.5	15.9	19.0
25	70.4	60.6	9.8	16.1
26	89.0	76.2	12.8	16.8
27	80.7	71.3	9.4	13.2
28	101.4	87.6	13.8	15.8
29	108.6	93.1	15.5	16.7
30	117.8	99.1	18.7	18.9
31	89.8	76.7	13.1	17.1

32	116.9	100.6	16.4	16.3
33	66.5	59.9	6.6	11.0
34	118.3	104.2	14.1	13.5
35	81.0	70.7	10.3	14.6
36	119.5	101.7	17.9	17.6
37	114.8	94.5	20.2	21.4
38	128.8	113.8	15.0	13.2
39	108.5	91.2	17.3	19.0
40	93.2	79.8	13.4	16.8

Table B4: ***Ceiba pentandra***

TEST PIECE MARK	BULK MASS, m_1 (g)	OVEN-DRY MASS, m_2 (g)	DECREASE IN MASS, $m_1 - m_2$ (g)	MOISTURE CONTENT (%)
1	61.7	51.5	10.2	19.8
2	88.2	71.5	16.7	23.3
3	65.5	52.3	13.2	25.2
4	81.4	62.2	19.2	30.8
5	88.7	69.2	19.4	28.0
6	63.7	50.8	12.9	25.5
7	80.0	60.0	20.0	33.4
8	46.9	36.3	10.6	29.2
9	79.6	62.5	17.1	27.4
10	24.9	18.5	6.4	34.5
11	98.4	75.4	23.0	30.5
12	105.9	79.1	26.8	33.9

13	92.2	68.8	23.4	34.0
14	58.7	49.0	9.6	19.7
15	95.1	68.8	26.3	38.3
16	67.3	52.5	14.8	28.2
17	43.7	36.0	7.6	21.1
18	91.1	66.7	24.5	36.7
19	98.7	75.0	23.8	31.7
20	86.8	61.0	25.8	42.3
21	63.8	50.0	13.8	27.6
22	68.8	56.3	12.5	22.2
23	75.8	57.8	18.0	31.2
24	53.8	40.6	13.1	32.3
25	86.0	60.8	25.2	41.4
26	75.4	59.6	15.9	26.6
27	92.3	68.1	24.2	35.5
28	93.8	73.5	20.3	27.6
29	62.6	45.8	16.8	36.6
30	74.7	58.5	16.2	27.6
31	58.7	46.3	12.4	26.9
32	98.1	72.4	25.7	35.5
33	67.0	51.1	15.9	31.0
34	59.9	46.1	13.8	30.0
35	83.9	68.6	15.2	22.2
36	88.6	73.0	15.6	21.3
37	117.5	92.5	25.0	27.0
38	80.4	64.8	15.6	24.0
39	45.5	33.4	12.2	36.6
40	61.5	48.4	13.1	27.0

APPENDIX C: DENSITY

Table C1:*Isoberlinia doka*

PIECE MARK	WIDTH (MM)	DEPTH (MM)	BREADTH (MM)	BULK VOLUME (MM3)	BULK MASS (G)	DENSITY (KG/M3)
1	41	70	19	55069	83	1501
2	39	70	44	119847	101	840
3	43	71	38	114675	120	1048
4	36	70	27	67977	83	1223
5	36	69	47	117183	126	1078
6	38	71	48	129103	120	927
7	36	71	39	100002	120	1199
8	42	72	31	92740	86	924
9	42	68	38	110451	112	1013
10	42	69	32	93408	126	1347
11	44	67	36	105003	80	760
12	40	70	47	129858	80	613
13	41	70	23	65924	96	1461
14	40	71	28	79642	72	903
15	39	71	28	76838	103	1343
16	43	69	22	65337	68	1036
17	36	72	36	93751	105	1118
18	41	69	54	152132	112	739
19	38	70	36	95302	100	1054
20	41	72	28	82581	95	1153
21	42	69	42	121712	113	929
22	42	68	51	144825	101	697
23	39	69	56	147491	120	811

24	38	73	32	88460	84	944
25	39	70	37	102091	97	947
26	42	69	30	88203	95	1081
27	42	68	25	72011	83	1149
28	41	72	53	154243	96	624
29	39	73	26	75285	97	1290
30	41	71	46	136271	123	906
31	45	70	47	146825	130	888
32	41	71	49	141208	96	678
33	43	70	41	121989	99	808
34	36	69	30	74469	95	1277
35	42	72	37	112382	97	864
36	37	71	34	89284	89	1001
37	37	69	45	116416	100	863
38	39	69	53	144149	116	802
39	40	70	34	94931	90	945
40	41	74	58	176769	100	564

Table C2:*Khaya senegalensis*

PIECE MARK	WIDTH (MM)	DEPTH (MM)	BREADTH (MM)	BULK VOLUME (MM^3)	BULK MASS(G)	DENSITY (KG/M^3)
1	40	75	34	101998	82	807
2	40	68	30	83406	68	814
3	39	71	40	110483	82	744
4	41	69	50	142666	134	940
5	40	73	31	90835	90	988

6	41	63	58	149226	83	555
7	39	69	40	104970	101	960
8	41	69	53	149445	123	826
9	40	66	32	84549	89	1051
10	42	68	29	83234	81	975
11	41	69	45	125945	104	828
12	41	63	41	105711	115	1086
13	41	62	42	108585	61	563
14	39	65	57	143985	106	736
15	40	66	29	76647	62	808
16	41	70	24	70066	72	1027
17	38	71	42	115110	95	823
18	39	70	41	112997	102	900
19	40	73	25	72214	70	972
20	41	70	41	117979	101	856
21	40	71	23	65512	61	929
22	41	70	48	137436	115	840
23	42	73	27	83804	78	929
24	42	69	17	50100	45	903
25	39	69	38	101523	103	1013
26	40	75	40	120842	95	788
27	39	69	49	132549	101	764
28	41	71	35	103001	77	744
29	39	63	51	125263	125	995
30	41	70	35	99229	100	1008
31	40	68	59	160910	103	643
32	42	70	25	72713	83	1146
33	41	73	25	73262	69	942

34	42	69	33	95835	76	790
35	40	71	63	178296	125	701
36	38	74	41	114709	96	838
37	40	70	32	91599	97	1055
38	39	66	49	127247	85	667
39	41	70	28	80839	80	989
40	39	71	42	118511	101	855

Table C3:*Acacia albida*

PIECE MARK	WIDTH (MM)	DEPTH (MM)	BREADTH (MM)	BULK VOLUME (MM^3)	BULK MASS(G)	DENSITY (KG/M^3)
1	41	74	53	160375	102	635
2	43	70	38	116166	79	683
3	36	77	110	307894	114	371
4	32	66	62	130816	109	837
5	33	73	95	225831	103	454
6	48	61	62	182801	109	596
7	33	75	60	147458	78	529
8	38	79	76	226573	106	468
9	37	66	52	126277	97	769
10	36	75	108	293879	128	437
11	42	67	45	125311	73	584
12	39	70	66	177919	126	709
13	43	77	47	155454	102	656

14	40	69	48	134151	83	617
15	36	72	78	203708	100	492
16	43	73	76	235770	91	386
17	43	77	79	259053	112	432
18	40	71	36	103573	91	881
19	37	72	59	156121	116	745
20	41	68	84	233082	100	430
21	42	68	51	142589	89	622
22	43	67	85	246693	113	457
23	42	70	47	136102	87	640
24	42	70	83	242563	99	410
25	41	68	61	171740	70	410
26	40	66	55	146545	89	607
27	46	74	40	137322	81	588
28	41	69	104	296484	101	342
29	41	71	57	165320	109	657
30	42	74	50	153943	118	765
31	35	66	74	169821	90	529
32	40	72	48	137727	117	849
33	43	68	34	100449	66	662
34	38	77	49	142838	118	828
35	42	64	72	194137	81	417
36	45	72	144	466963	120	256
37	34	69	80	188784	115	608
38	38	77	83	246247	129	523
39	38	66	68	167441	109	648
40	40	68	48	128183	93	727

Table C4:*Ceiba pentandra*

PIECE MARK	WIDTH (MM)	DEPTH (MM)	BREADTH (MM)	BULK VOLUME (MM^3)	BULK MASS(G)	DENSITY (KG/M^3)
1	44	71	81	249826	62	247
2	38	70	93	248361	88	355
3	40	70	65	181815	65	360
4	38	71	111	299163	81	272
5	39	70	100	274467	89	323
6	41	66	64	174591	64	365
7	41	70	89	259787	80	308
8	41	68	47	131606	47	356
9	45	71	85	272614	80	292
10	40	68	21	56889	25	438
11	40	72	113	322503	98	305
12	41	72	92	270844	106	391
13	41	68	156	435008	92	212
14	38	69	65	168070	59	349
15	46	71	83	266519	95	357
16	39	72	61	173124	67	389
17	40	70	44	123327	44	354
18	43	68	70	208009	91	438
19	41	75	78	236748	99	417
20	39	69	81	219631	87	395
21	40	69	61	166513	64	383
22	38	69	77	205918	69	334
23	42	74	88	271757	76	279
24	40	70	109	307193	54	175

25	42	70	95	279287	86	308
26	40	66	71	184844	75	408
27	39	72	121	334340	92	276
28	41	68	122	343441	94	273
29	42	70	65	188999	63	331
30	42	68	81	231932	75	322
31	41	74	69	212089	59	277
32	41	68	91	249642	98	393
33	39	70	75	206224	67	325
34	41	70	82	235002	60	255
35	39	71	106	294272	84	285
36	42	69	68	198221	89	447
37	38	74	151	424310	118	277
38	40	76	56	167133	80	481
39	40	73	34	99010	46	460
40	39	72	57	159242	61	386

APPENDIX D: BENDING TEST

Table D1*: Isoberlinia doka*

TEST PIECE	DIAL GAUGE READING (CONSTANT=0.01)			DEFLECTION (mm)			F_{MAX} (kN)
	1kN	2kN	3kN	1kN	2kN	3kN	
1	335.9	460.7	852.2	3.4	4.6	8.5	8.0
2	361.5	443.6	940.9	3.6	4.4	9.4	6.7
3	319.7	530.6	839.3	3.2	5.3	8.4	8.4

4	274.1	442.7	980.8	2.7	4.4	9.8	5.1
5	337.4	392.1	898.2	3.4	3.9	9.0	7.5
6	257.3	440.3	1000.6	2.6	4.4	10.0	7.4
7	279.5	440.2	865.8	2.8	4.4	8.7	7.3
8	255.3	557.7	881.3	2.6	5.6	8.8	5.7
9	330.5	442.2	979.6	3.3	4.4	9.8	6.5
10	319.9	363.0	930.1	3.2	3.6	9.3	8.0
11	276.0	431.6	1057.2	2.8	4.3	10.6	7.1
12	255.7	515.8	904.6	2.6	5.2	9.0	8.0
13	301.7	481.2	933.7	3.0	4.8	9.3	6.7
14	270.3	478.0	1030.5	2.7	4.8	10.3	6.4
15	352.5	467.4	898.6	3.5	4.7	9.0	6.7
16	322.4	500.3	974.0	3.2	5.0	9.7	9.3
17	313.6	407.5	1022.9	3.1	4.1	10.2	6.8
18	320.4	568.7	945.6	3.2	5.7	9.5	6.0
19	257.8	516.8	1002.3	2.6	5.2	10.0	6.4
20	310.1	467.8	905.3	3.1	4.7	9.1	7.5
21	353.2	492.1	892.0	3.5	4.9	8.9	7.7
22	258.5	487.4	880.3	2.6	4.9	8.8	7.7
23	286.7	456.7	839.6	2.9	4.6	8.4	6.2
24	342.7	462.0	1008.0	3.4	4.6	10.1	6.2
25	259.4	410.5	836.7	2.6	4.1	8.4	8.0
26	288.5	505.1	898.7	2.9	5.1	9.0	5.5
27	222.2	436.8	901.1	2.2	4.4	9.0	4.9
28	377.2	382.2	960.2	3.8	3.8	9.6	6.8
29	322.4	506.2	989.5	3.2	5.1	9.9	5.2
30	375.9	440.2	946.0	3.8	4.4	9.5	6.0

31	297.6	587.5	918.3	3.0	5.9	9.2	8.3
32	330.0	465.5	849.2	3.3	4.7	8.5	7.7
33	292.1	508.4	973.2	2.9	5.1	9.7	8.4
34	287.9	444.2	951.6	2.9	4.4	9.5	8.3
35	264.1	484.5	956.3	2.6	4.8	9.6	8.9
36	316.3	469.9	973.0	3.2	4.7	9.7	6.5
37	298.7	473.0	940.3	3.0	4.7	9.4	4.6
38	285.9	483.1	920.5	2.9	4.8	9.2	7.7
39	315.5	457.2	714.4	3.2	4.6	7.1	6.5
40	283.8	448.8	1045.3	2.8	4.5	10.5	5.7

Table D2:*Khaya senegalensis*

TEST PIECE	DIAL GAUGE READING (CONSTANT = 0.01)			DEFLECTION (mm)			F_{MAX} (kN)
	1kN	2kN	3kN	1kN	2kN	3kN	
1	240.6	483.4	1003.4	2.4	4.8	10.0	6.8
2	243.5	527.8	1008.6	2.4	5.3	10.1	6.8
3	231.4	505.2	1078.8	2.3	5.1	10.8	7.7
4	201.7	426.2	781.7	2.0	4.3	7.8	7.1
5	234.9	508.5	993.6	2.3	5.1	9.9	6.7
6	227.8	487.7	1052.0	2.3	4.9	10.5	9.1
7	210.0	403.7	971.4	2.1	4.0	9.7	8.3
8	210.1	447.9	956.4	2.1	4.5	9.6	7.1
9	234.7	467.3	1078.7	2.3	4.7	10.8	8.4
10	232.6	441.9	1062.9	2.3	4.4	10.6	7.8
11	258.7	423.4	901.2	2.6	4.2	9.0	5.8

12	256.6	463.2	1160.5	2.6	4.6	11.6	6.7
13	207.6	466.9	1161.3	2.1	4.7	11.6	7.0
14	249.0	466.1	999.4	2.5	4.7	10.0	5.8
15	214.5	505.0	865.0	2.1	5.0	8.7	6.8
16	219.1	465.3	1159.0	2.2	4.7	11.6	8.3
17	244.3	496.0	1006.1	2.4	5.0	10.1	7.5
18	263.2	361.6	877.6	2.6	3.6	8.8	8.4
19	202.7	416.0	966.6	2.0	4.2	9.7	6.8
20	228.5	428.7	893.7	2.3	4.3	8.9	6.7
21	232.9	401.3	1047.6	2.3	4.0	10.5	7.5
22	192.5	514.3	971.2	1.9	5.1	9.7	8.0
23	236.7	451.7	932.1	2.4	4.5	9.3	8.0
24	262.1	427.3	1086.0	2.6	4.3	10.9	9.3
25	275.5	474.0	986.7	2.8	4.7	9.9	7.5
26	233.7	406.2	916.3	2.3	4.1	9.2	6.2
27	249.0	360.5	915.0	2.5	3.6	9.1	7.0
28	208.0	499.5	932.4	2.1	5.0	9.3	8.7
29	258.3	378.1	875.9	2.6	3.8	8.8	4.4
30	238.1	426.0	980.3	2.4	4.3	9.8	6.4
31	224.8	405.5	1119.6	2.2	4.1	11.2	5.7
32	231.5	373.0	998.6	2.3	3.7	10.0	7.7
33	230.8	503.0	910.4	2.3	5.0	9.1	5.2
34	237.1	411.2	961.4	2.4	4.1	9.6	7.5
35	226.3	397.5	1005.3	2.3	4.0	10.1	7.0
36	244.0	410.9	998.8	2.4	4.1	10.0	7.5
37	229.8	377.7	1136.4	2.3	3.8	11.4	6.8
38	233.8	471.4	962.2	2.3	4.7	9.6	6.5

39	201.2	405.6	886.1	2.0	4.1	8.9	9.0
40	225.3	471.7	1104.9	2.3	4.7	11.0	7.3

Table D3:*Acacia albida*

TEST PIECE	DIAL GAUGE READING (CONSTANT=0.01)			DEFLECTION (mm)			F_{MAX}(kN)
	1kN	2kN	3kN	1kN	2kN	3kN	
1	452.9	669.7	1628.5	4.5	6.7	16.3	5.7
2	471.1	732.4	1538.7	4.7	7.3	15.4	6.0
3	455.0	702.1	1837.7	4.5	7.0	18.4	5.4
4	437.4	742.6	1440.8	4.4	7.4	14.4	2.2
5	393.5	659.0	1634.7	3.9	6.6	16.3	5.2
6	410.5	696.1	1566.3	4.1	7.0	15.7	3.9
7	449.0	698.6	1672.9	4.5	7.0	16.7	5.2
8	434.5	747.4	1590.7	4.3	7.5	15.9	7.0
9	392.9	737.0	1703.0	3.9	7.4	17.0	4.2
10	356.3	675.0	1766.4	3.6	6.7	17.7	4.9
11	358.8	691.9	1882.7	3.6	6.9	18.8	4.6
12	337.0	739.1	1701.7	3.4	7.4	17.0	5.4
13	531.3	700.2	1703.1	5.3	7.0	17.0	5.2
14	397.1	659.1	1748.7	4.0	6.6	17.5	6.0
15	414.1	688.5	1536.8	4.1	6.9	15.4	3.9
16	412.2	711.8	1566.0	4.1	7.1	15.7	4.1
17	399.2	728.5	1701.0	4.0	7.3	17.0	5.7
18	386.9	728.7	1790.3	3.9	7.3	17.9	3.5

19	450.1	693.1	1680.8	4.5	6.9	16.8	5.4
20	320.1	684.5	1705.0	3.2	6.8	17.1	4.6
21	470.2	694.8	1666.7	4.7	6.9	16.7	6.0
22	415.3	681.6	1652.0	4.2	6.8	16.5	4.1
23	490.5	742.8	1400.2	4.9	7.4	14.0	4.2
24	411.2	687.9	1642.4	4.1	6.9	16.4	3.3
25	495.6	634.3	1641.0	5.0	6.3	16.4	4.8
26	357.1	688.9	1443.2	3.6	6.9	14.4	4.9
27	413.7	723.8	1435.3	4.1	7.2	14.4	2.5
28	391.5	685.2	1600.9	3.9	6.9	16.0	6.7
29	393.6	638.3	1662.1	3.9	6.4	16.6	4.6
30	452.0	689.3	1471.7	4.5	6.9	14.7	5.1
31	382.5	689.6	1539.4	3.8	6.9	15.4	8.4
32	441.7	674.0	1654.0	4.4	6.7	16.5	5.2
33	414.1	727.6	1538.5	4.1	7.3	15.4	5.7
34	363.0	660.3	1885.9	3.6	6.6	18.9	6.2
35	409.2	694.5	1737.9	4.1	6.9	17.4	6.1
36	404.6	699.0	1945.5	4.0	7.0	19.5	5.2
37	420.9	719.6	1512.5	4.2	7.2	15.1	5.5
38	417.0	687.7	1607.3	4.2	6.9	16.1	6.8
39	348.3	779.6	1835.1	3.5	7.8	18.4	4.9
40	463.2	680.2	1683.1	4.6	6.8	16.8	4.1

Table D4:*Ceiba pentandra*

TEST PIECE	DIAL GAUGE READING (CONSTANT = 0.01)			DEFLECTION (mm)			F_{MAX}(kN)
	1kN	2kN	3kN	1kN	2kN	3kN	

1	490.7	849.6	2534.8	4.9	8.5	25.3	6.1
2	507.7	805.3	1839.2	5.1	8.1	18.4	6.2
3	549.6	814.6	2159.9	5.5	8.1	21.6	3.6
4	479.0	872.6	1952.9	4.8	8.7	19.5	5.8
5	483.1	711.0	2097.4	4.8	7.1	21.0	4.8
6	519.1	1007.1	2458.0	5.2	10.1	24.6	5.1
7	518.3	872.7	1899.6	5.2	8.7	19.0	5.1
8	481.7	814.8	2326.8	4.8	8.1	23.3	4.6
9	528.7	919.2	2668.4	5.3	9.2	26.7	5.4
10	551.9	856.3	2055.6	5.5	8.6	20.6	6.5
11	525.1	911.1	2310.5	5.3	9.1	23.1	5.4
12	490.0	865.7	2461.8	4.9	8.7	24.6	3.6
13	460.6	908.5	2466.7	4.6	9.1	24.7	6.0
14	471.8	881.6	2267.6	4.7	8.8	22.7	5.1
15	546.0	751.8	2492.9	5.5	7.5	24.9	7.0
16	488.3	850.4	1666.9	4.9	8.5	16.7	4.5
17	466.4	1038.9	1747.2	4.7	10.4	17.5	4.8
18	491.9	810.9	2078.5	4.9	8.1	20.8	5.7
19	484.5	736.5	1849.5	4.8	7.4	18.5	3.3
20	519.4	918.7	1737.1	5.2	9.2	17.4	5.1
21	474.5	821.5	2501.0	4.7	8.2	25.0	4.9
22	534.7	886.5	2137.1	5.3	8.9	21.4	6.2
23	514.7	805.3	2318.0	5.1	8.1	23.2	4.5
24	526.2	781.7	1958.2	5.3	7.8	19.6	4.5
25	466.7	803.2	1836.6	4.7	8.0	18.4	6.4
26	478.0	984.8	2306.0	4.8	9.8	23.1	5.8
27	518.2	864.4	1711.9	5.2	8.6	17.1	5.2

28	431.6	807.3	2078.1	4.3	8.1	20.8	2.9
29	496.4	939.5	2254.7	5.0	9.4	22.5	6.0
30	553.8	865.6	1941.7	5.5	8.7	19.4	5.1
31	553.4	947.2	2332.1	5.5	9.5	23.3	5.8
32	477.8	893.9	2364.1	4.8	8.9	23.6	2.6
33	534.4	883.0	1428.3	5.3	8.8	14.3	5.4
34	526.6	851.0	2593.2	5.3	8.5	25.9	4.4
35	516.7	822.3	1651.9	5.2	8.2	16.5	3.8
36	511.0	857.8	1958.7	5.1	8.6	19.6	4.6
37	556.8	821.0	2333.4	5.6	8.2	23.3	3.9
38	510.4	917.9	1829.6	5.1	9.2	18.3	4.9
39	561.5	911.8	2489.5	5.6	9.1	24.9	4.5
40	490.6	890.8	2825.7	4.9	8.9	28.3	4.9

APPENDIX E: BENDING STRENGTH

Table E1: *Isoberlinia doka*

Test Piece Mark	Distance Between Loads, a (mm)	Failure Load, F_{max} (kN)	Section Modulus, W(mm^3)	Bending Strength (N/mm^2)
1	450	8.0	37500	55
2	450	6.7	37500	46
3	450	8.4	37500	58
4	450	5.1	37500	35
5	450	7.5	37500	52
6	450	7.4	37500	51

7	450	7.3	37500	50
8	450	5.7	37500	39
9	450	6.5	37500	45
10	450	8.0	37500	55
11	450	7.1	37500	49
12	450	8.0	37500	55
13	450	6.7	37500	46
14	450	6.4	37500	44
15	450	6.7	37500	46
16	450	9.3	37500	64
17	450	6.8	37500	47
18	450	6.0	37500	41
19	450	6.4	37500	44
20	450	7.5	37500	52
21	450	7.7	37500	53
22	450	7.7	37500	53
23	450	6.2	37500	43
24	450	6.2	37500	43
25	450	8.0	37500	55
26	450	5.5	37500	38
27	450	4.9	37500	34
28	450	6.8	37500	47
29	450	5.2	37500	36
30	450	6.0	37500	41
31	450	8.3	37500	57
32	450	7.7	37500	53
33	450	8.4	37500	58
34	450	8.3	37500	57

35	450	8.9	37500	61
36	450	6.5	37500	45
37	450	4.6	37500	32
38	450	7.7	37500	53
39	450	6.5	37500	45
40	450	5.7	37500	39

Table E2*: Khaya senegalensis*

Test Piece Mark	Distance Between Loads, a (mm)	Failure Load, F_{max} (kN)	Section Modulus, W(mm^3)	Bending Strength (N/mm^2)
1	450	6.8	37500	47
2	450	6.8	37500	47
3	450	7.7	37500	53
4	450	7.1	37500	49
5	450	6.7	37500	46
6	450	9.1	37500	63
7	450	8.3	37500	57
8	450	7.1	37500	49
9	450	8.4	37500	58
10	450	7.8	37500	54
11	450	5.8	37500	40
12	450	6.7	37500	46
13	450	7.0	37500	48
14	450	5.8	37500	40
15	450	6.8	37500	47
16	450	8.3	37500	57

17	450	7.5	37500	52
18	450	8.4	37500	58
19	450	6.8	37500	47
20	450	6.7	37500	46
21	450	7.5	37500	52
22	450	8.0	37500	55
23	450	8.0	37500	55
24	450	9.3	37500	64
25	450	7.5	37500	52
26	450	6.2	37500	43
27	450	7.0	37500	48
28	450	8.7	37500	60
29	450	4.4	37500	30
30	450	6.4	37500	44
31	450	5.7	37500	39
32	450	7.7	37500	53
33	450	5.2	37500	36
34	450	7.5	37500	52
35	450	7.0	37500	48
36	450	7.5	37500	52
37	450	6.8	37500	47
38	450	6.5	37500	45
39	450	9.0	37500	62
40	450	7.3	37500	50

Table E3:*Acacia albida*

Test Piece Mark	Distance Between	Failure Load, F_{max}	Section Modulus,	Bending Strength

	Loads, a (mm)	(kN)	W(mm^3)	(N/mm^2)
1	450	5.7	37500	39
2	450	6.0	37500	41
3	450	5.4	37500	37
4	450	2.2	37500	15
5	450	5.2	37500	36
6	450	3.9	37500	27
7	450	5.2	37500	36
8	450	7.0	37500	48
9	450	4.2	37500	29
10	450	4.9	37500	34
11	450	4.6	37500	32
12	450	5.4	37500	37
13	450	5.2	37500	36
14	450	6.0	37500	41
15	450	3.9	37500	27
16	450	4.1	37500	28
17	450	5.7	37500	39
18	450	3.5	37500	24
19	450	5.4	37500	37
20	450	4.6	37500	32
21	450	6.0	37500	41
22	450	4.1	37500	28
23	450	4.2	37500	29
24	450	3.3	37500	23
25	450	4.8	37500	33
26	450	4.9	37500	34

27	450	2.5	37500	17
28	450	6.7	37500	46
29	450	4.6	37500	32
30	450	5.1	37500	35
31	450	8.4	37500	58
32	450	5.2	37500	36
33	450	5.7	37500	39
34	450	6.2	37500	43
35	450	6.1	37500	42
36	450	5.2	37500	36
37	450	5.5	37500	38
38	450	6.8	37500	47
39	450	4.9	37500	34
40	450	4.1	37500	28

Table E4:*Ceiba pentandra*

Test Piece Mark	Distance Between Loads, a (mm)	Failure Load, F_{max} (kN)	Section Modulus, W(mm^3)	Bending Strength (N/mm^2)
1	450	6.1	37500	42
2	450	6.2	37500	43
3	450	3.6	37500	25
4	450	5.8	37500	40
5	450	4.8	37500	33
6	450	5.1	37500	35
7	450	5.1	37500	35
8	450	4.6	37500	32

9	450	5.4	37500	37
10	450	6.5	37500	45
11	450	5.4	37500	37
12	450	3.6	37500	25
13	450	6.0	37500	41
14	450	5.1	37500	35
15	450	7.0	37500	48
16	450	4.5	37500	31
17	450	4.8	37500	33
18	450	5.7	37500	39
19	450	3.3	37500	23
20	450	5.1	37500	35
21	450	4.9	37500	34
22	450	6.2	37500	43
23	450	4.5	37500	31
24	450	4.5	37500	31
25	450	6.4	37500	44
26	450	5.8	37500	40
27	450	5.2	37500	36
28	450	2.9	37500	20
29	450	6.0	37500	41
30	450	5.1	37500	35
31	450	5.8	37500	40
32	450	2.6	37500	18
33	450	5.4	37500	37
34	450	4.4	37500	30
35	450	3.8	37500	26
36	450	4.6	37500	32

37	450	3.9	37500	27
38	450	4.9	37500	34
39	450	4.5	37500	31
40	450	4.9	37500	34

APPENDIX F: MODULUS OF ELASTICITY

Table F1: *Isoberlinia doka*

TEST PIECE MARK	SLOPE, $\frac{(F_2-F_1)}{(w_2-w_1)}$.	INTERCEPT	CORRELLATION R^2	MODULUS OF ELASTICITY (N/mm^2)
1	-57.35	-2188	0.99	12243
2	-59.86	-2284.1	0.95	9797
3	-60.51	-2308.9	0.97	12270
4	-62.96	-2402.2	0.98	10494
5	-60.45	-2306.3	0.98	10626
6	-62.64	-2390.1	0.96	8656
7	-60.13	-2294.3	0.97	10246
8	-62.36	-2379.3	0.95	10292
9	-64.92	-2477.1	0.98	10382
10	-60.40	-2304.7	0.99	9864
11	-58.63	-2236.9	0.97	10595
12	-60.25	-2298.8	0.97	10551
13	-55.44	-2115.1	0.97	8954
14	-57.26	-2184.6	0.97	8475
15	-60.29	-2300.3	0.98	7970
16	-59.88	-2284.7	0.96	7870
17	-59.39	-2265.9	0.98	12089

18	-55.65	-2123.4	0.96	7998
19	-56.12	-2141.2	0.98	13588
20	-60.61	-2312.4	0.97	8507
21	-58.41	-2228.6	0.96	9809
22	-60.69	-2315.5	0.97	8564
23	-63.33	-2416.4	0.97	10942
24	-64.33	-2454.7	0.97	9459
25	-59.78	-2280.8	0.96	11240
26	-67.01	-2556.9	0.97	9975
27	-61.40	-2342.6	0.98	11047
28	-63.38	-2418.4	0.97	9247
29	-57.94	-2210.8	0.97	9859
30	-61.18	-2334.2	0.96	11731
31	-61.97	-2364.5	0.98	12538
32	-57.99	-2212.6	0.97	9190
33	-60.61	-2312.5	0.98	6995
34	-60.36	-2303.1	0.96	9572
35	-59.17	-2257.7	0.98	12964
36	-60.17	-2295.6	0.98	9726
37	-58.66	-2238.2	0.96	10649
38	-58.14	-2218.5	0.96	9603
39	-57.02	-2175.7	0.98	11668
40	-58.80	-2243.5	0.97	9551

Table F2: ***Khaya senegalensis***

TEST PIECE MARK	SLOPE,	INTERCEPT	CORRELLATION R^2	MODULUS OF ELASTICITY (N/mm^2)

	$\frac{(F_2-F_1)}{(w_2-w_1)}$.			
1	288.59	-2442.17	0.98	11011
2	291.92	-2423	0.98	11138
3	308.09	-2445.92	0.97	11755
4	327.46	-2518.33	0.98	12494
5	249.25	-2626.31	0.98	9510
6	272.42	-2566.51	0.99	10394
7	277.00	-2429.07	0.98	10569
8	322.06	-2663.81	0.99	12288
9	382.47	-2501.81	0.99	14593
10	371.43	-2744.69	0.99	14172
11	207.99	-2636.81	0.98	7936
12	303.00	-2367.56	0.97	11561
13	403.51	-2467.91	0.97	15396
14	274.38	-2407.93	0.97	10469
15	281.96	-2345.53	0.97	10758
16	274.80	-2404.69	0.99	10485
17	301.30	-2454.56	0.98	11496
18	347.74	-2585.06	0.98	13268
19	400.87	-2460.8	0.99	15295
20	251.84	-2249.48	0.99	9609
21	328.01	-2834.66	0.98	12515
22	300.36	-2405.41	0.98	11460
23	339.20	-2493.86	0.99	12942
24	356.52	-2455.26	0.98	13603
25	381.03	-2499.59	0.97	14538
26	324.10	-2662.87	0.97	12366

27	324.00	-2618.34	0.98	12362
28	454.44	-2234.71	0.97	17339
29	301.90	-2333.59	0.99	11519
30	336.34	-2389.13	0.99	12833
31	184.30	-2733.55	0.97	7032
32	329.42	-2322.42	0.98	12569
33	410.12	-2533.14	0.99	15648
34	338.10	-2570.36	0.98	12900
35	250.66	-2555.76	0.96	9564
36	375.76	-2332.85	1.00	14337
37	313.67	-2394.78	0.97	11968
38	351.23	-2278.94	0.98	13401
39	290.03	-2520.22	0.99	11066
40	247.12	-2393.92	0.97	9429

Table F3:Acacia albida

TEST PIECE MARK	SLOPE, $\frac{(F_2-F_1)}{(w_2-w_1)}$.	INTERCEPT	CORRELLATION R^2	MODULUS OF ELASTICITY (N/mm^2)
1	164.07	-3042.51	0.98	6260
2	285.39	-3208.49	0.97	10889
3	181.00	-3136.81	0.97	6906
4	143.00	-3190.75	0.98	5456
5	267.10	-3071.46	0.95	10191
6	155.97	-3081.61	0.97	5951
7	266.23	-3114.77	0.95	10158
8	177.07	-3023.49	0.99	6756
9	220.52	-3212.83	0.96	8414
10	274.59	-3129.24	0.97	10477

11	246.02	-3206.75	0.97	9387
12	124.26	-3090.39	0.97	4741
13	213.68	-3189.08	0.98	8153
14	286.57	-3032.11	0.97	10934
15	229.72	-2980.56	0.96	8765
16	178.64	-3198.94	0.99	6816
17	169.91	-3039.39	0.96	6483
18	234.52	-3198.73	0.97	8948
19	199.37	-3261.07	0.98	7607
20	214.97	-3003.17	0.99	8202
21	180.87	-3033.58	0.98	6901
22	191.01	-2911.81	0.97	7288
23	136.34	-3076.86	0.98	5202
24	225.74	-3181.8	0.96	8613
25	217.95	-3152.21	0.97	8316
26	256.43	-3041.49	0.98	9784
27	198.53	-3071.37	0.98	7575
28	195.47	-3019.42	0.96	7458
29	141.71	-3103.1	0.95	5407
30	236.48	-3122.13	0.95	9023
31	194.79	-3427.66	0.97	7432
32	292.78	-2973.67	1.00	11171
33	199.53	-3092.35	0.95	7613
34	137.68	-3086.91	0.95	5253
35	195.05	-3019.94	0.97	7442
36	207.63	-3168.08	0.98	7922
37	195.44	-2909.04	0.97	7457
38	173.61	-3082.62	0.96	6624

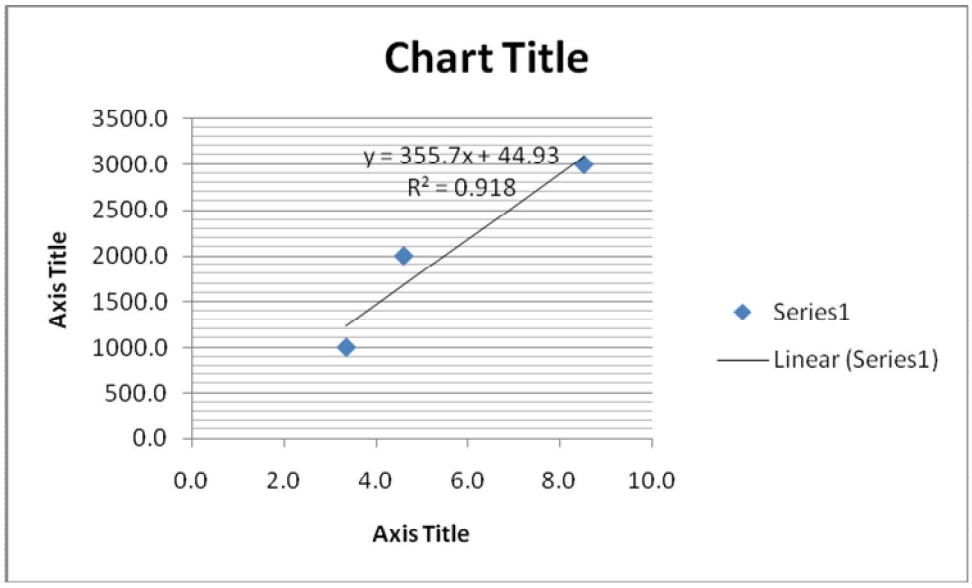
39	176.81	-2985.02	0.96	6746
40	238.08	-3007.01	0.96	9084

Table F4:*Ceiba pentandra*

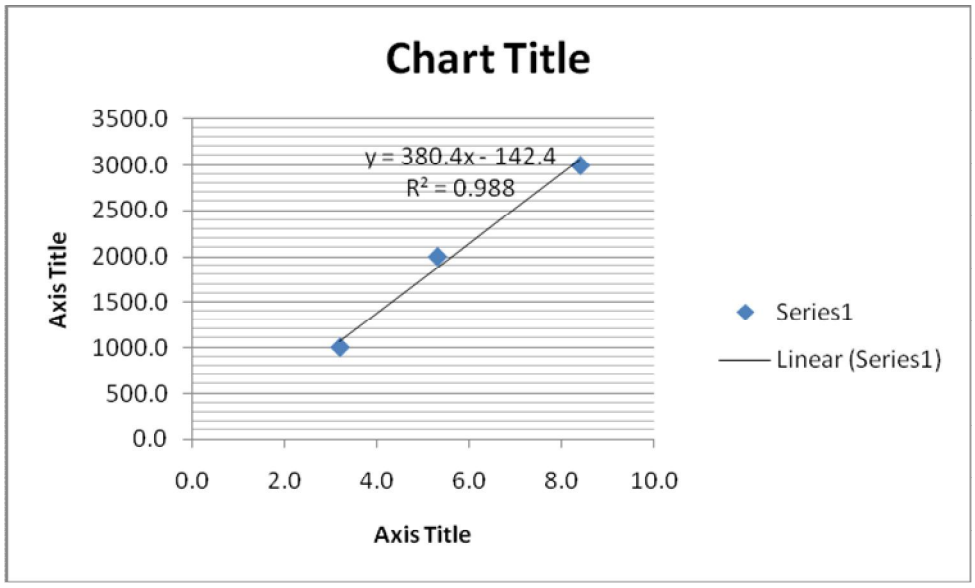
TEST PIECE MARK	SLOPE, $\frac{(F_2-F_1)}{(w_2-w_1)}$.	INTERCEPT	CORRELLATION R^2	MODULUS OF ELASTICITY (N/mm^2)
1	119.67	-2149.76	0.96	4566
2	197.83	-2226.75	0.96	7548
3	161.21	-2127.37	0.97	6151
4	175.91	-2068.81	0.96	6712
5	170.15	-2210.57	0.95	6492
6	1222.57	-1968.99	0.97	46647
7	153.40	-1946.11	0.95	5853
8	137.78	-2168.19	0.96	5257
9	80.41	-2195.71	0.97	3068
10	145.49	-2020.73	0.97	5551
11	145.83	-1994.97	0.94	5564
12	91.94	-2048.85	0.95	3508
13	149.76	-2159.05	0.96	5714
14	121.64	-2093.04	0.95	4641
15	104.94	-2051.76	0.96	4004
16	97.05	-1919.1	0.95	3703
17	139.04	-2219.66	0.95	5305
18	100.83	-2204.8	0.96	3847
19	149.18	-2146.36	0.95	5692
20	135.66	-2135.19	0.98	5176
21	119.67	-1892.35	0.96	4566
22	145.85	-2243.41	0.96	5565

23	102.63	-1981.07	0.97	3916
24	185.74	-1979.39	0.96	7087
25	210.77	-1796.98	0.97	8042
26	125.54	-2068.68	0.96	4790
27	64.40	-2095.37	0.95	2457
28	165.90	-1919.4	0.98	6330
29	134.11	-2114.86	0.95	5117
30	85.39	-2105.17	0.95	3258
31	105.60	-2072.44	0.96	4029
32	86.83	-2309.56	0.98	3313
33	95.85	-2157.3	0.95	3657
34	156.18	-2086.34	0.96	5959
35	132.43	-2202.7	0.95	5053
36	74.64	-2085.02	0.95	2848
37	120.90	-2129.77	0.98	4613
38	121.79	-2056.64	0.94	4647
39	88.82	-2195.92	0.96	3389
40	70.00	-2125.51	0.96	2671

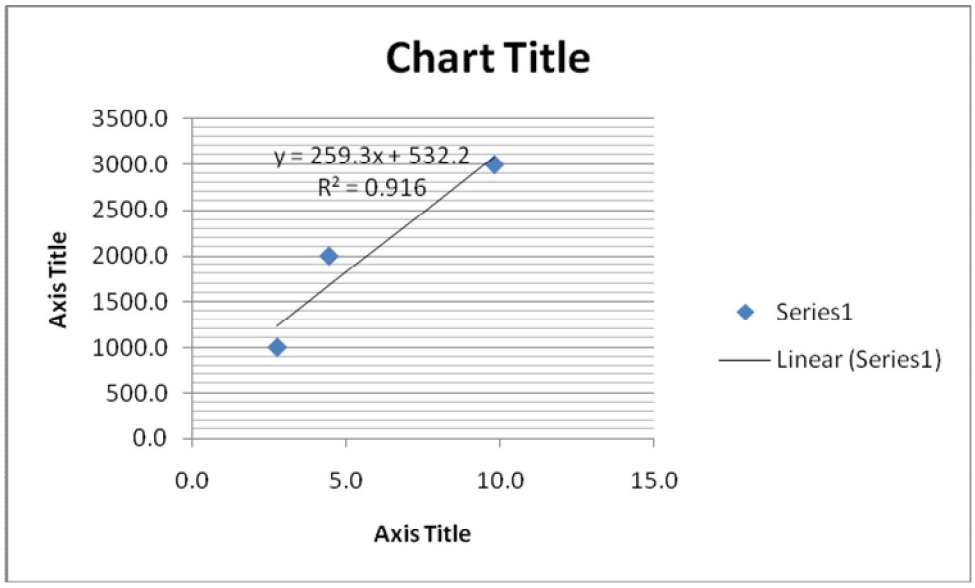
APPENDIX G: REGRESSION ANALYSIS



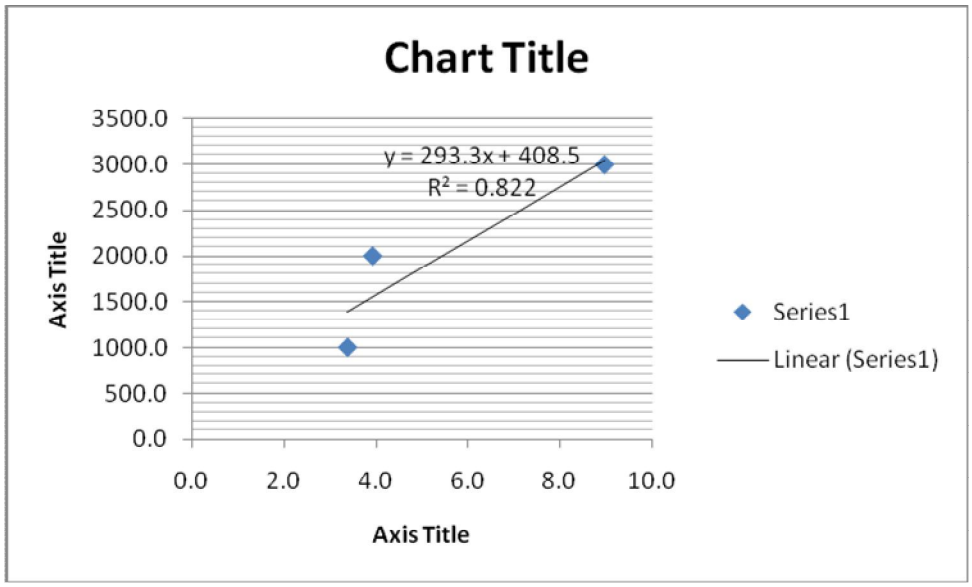
G1: Load-Deformation Plot (Table B1 Test Piece NO 1)



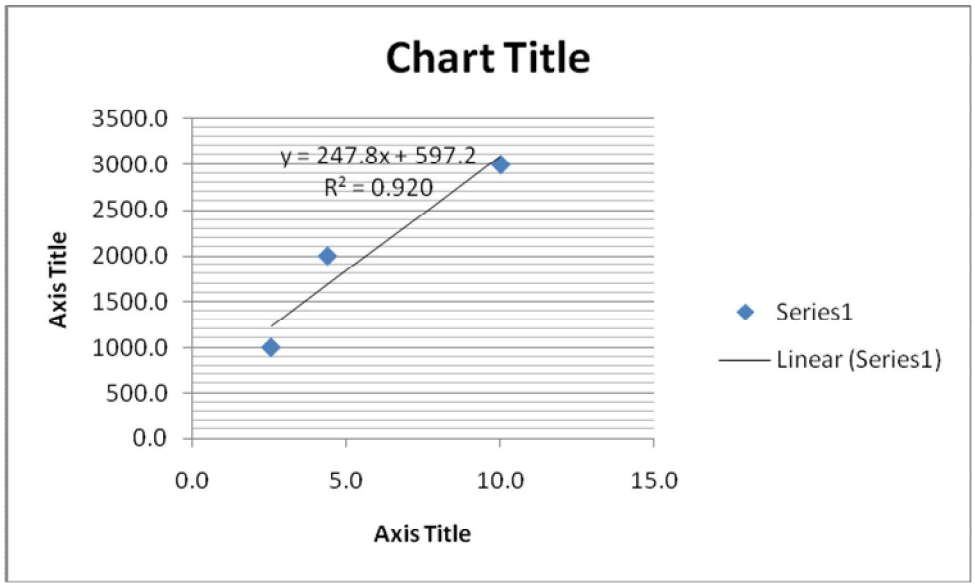
G2: Load-Deformation Plot (Table B1 Test Piece NO 2)



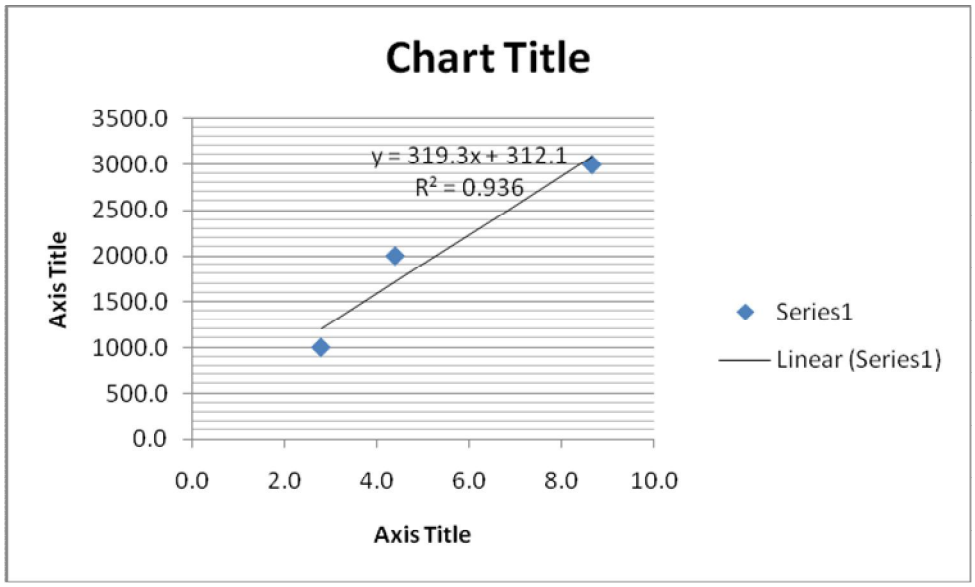
G3: Load-Deformation Plot (Table B1 Test Piece NO 3)



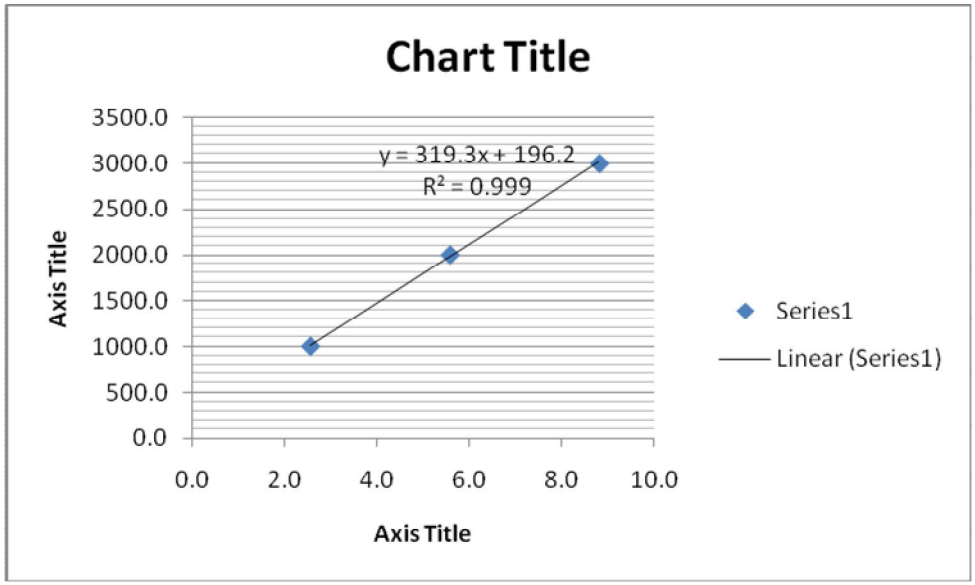
G4: Load-Deformation Plot (Table B2 Test Piece NO 1)



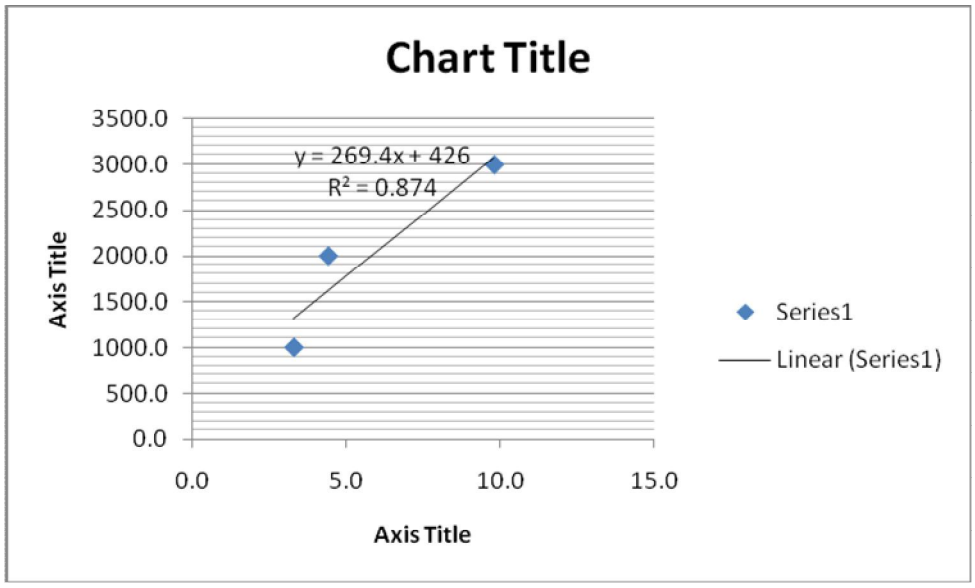
G5: Load-Deformation Plot (Table B2 Test Piece NO 2)



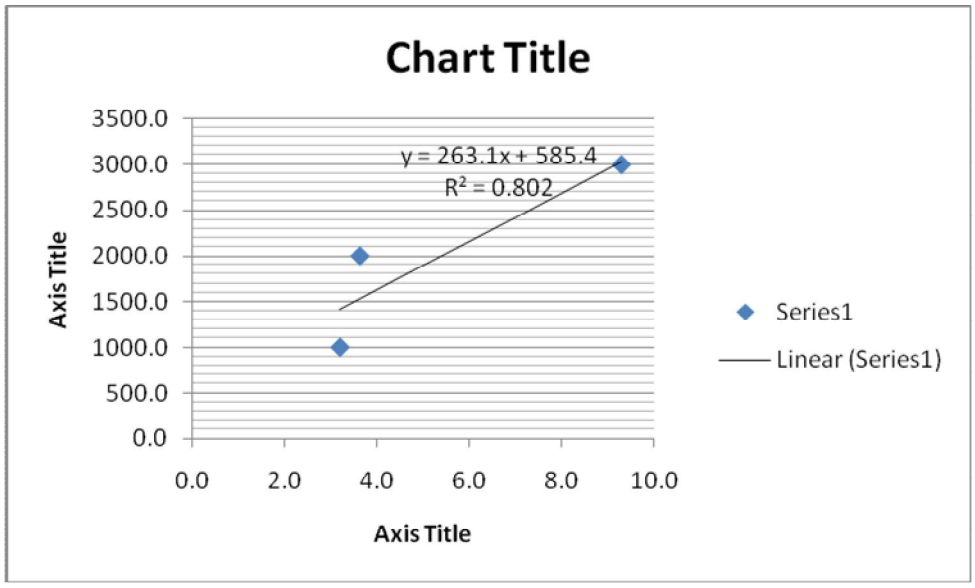
G6: Load-Deformation Plot (Table B2 Test Piece NO 3)



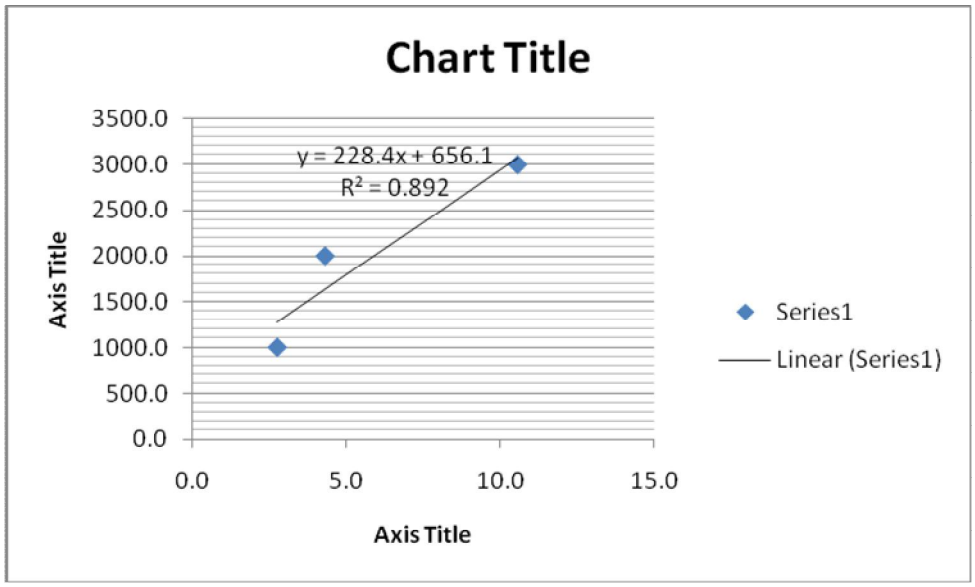
G7: Load-Deformation Plot (Table B3 Test Piece NO 1)



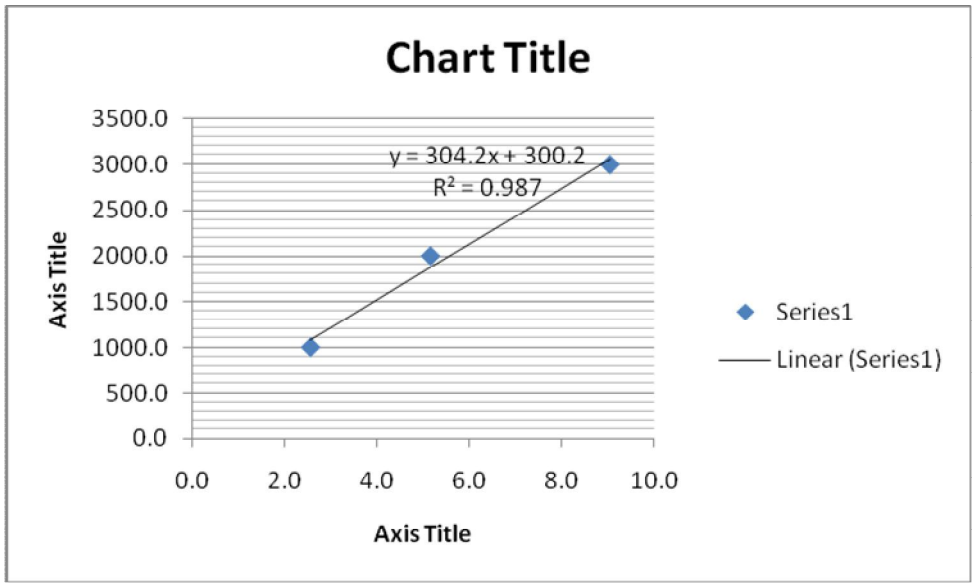
G8: Load-Deformation Plot (Table B3 Test Piece NO 2)



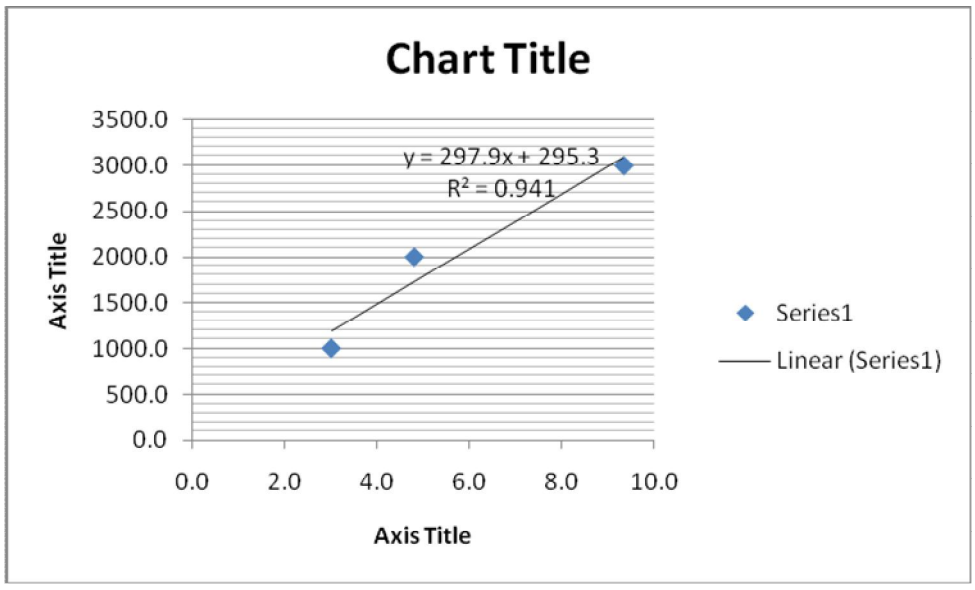
G9: Load-Deformation Plot (Table B3 Test Piece NO 3)



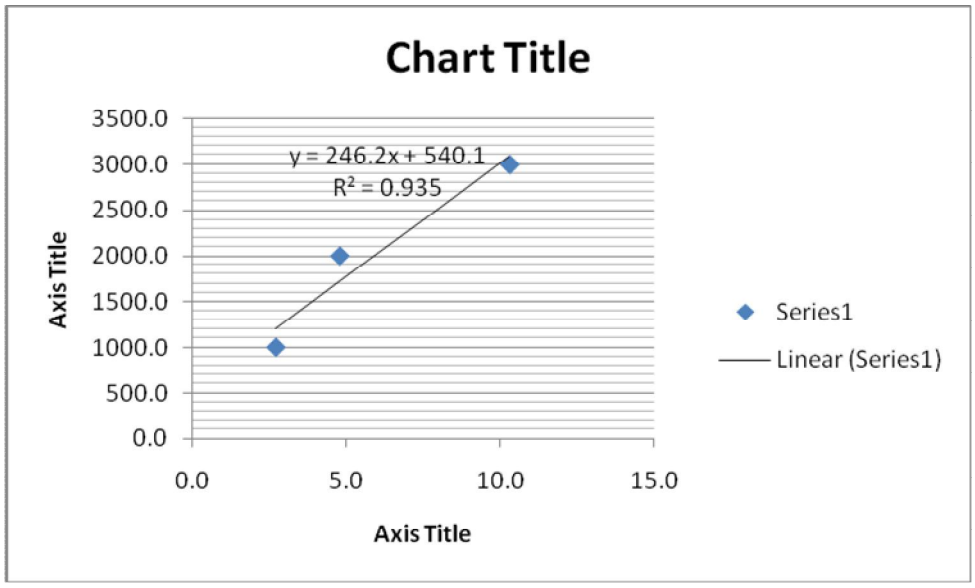
G10: Load-Deformation Plot (Table B4 Test Piece NO 1)



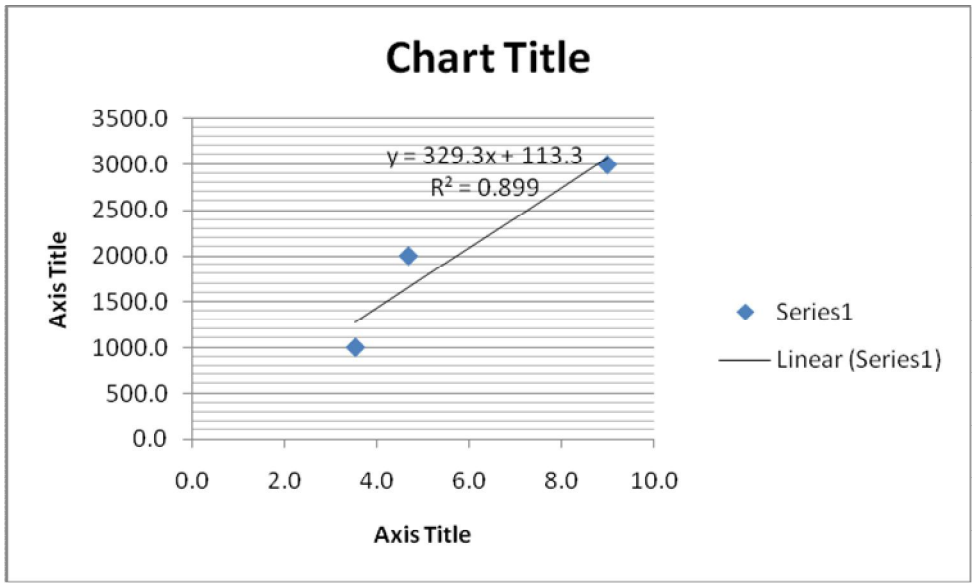
G11: Load-Deformation Plot (Table B4 Test Piece NO 2)



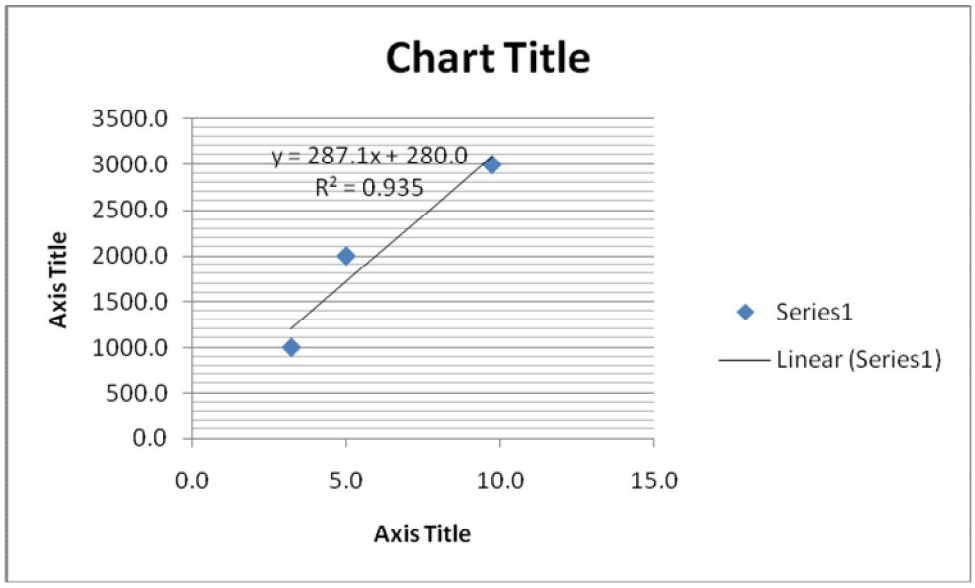
G12: Load-Deformation Plot (Table B4 Test Piece NO 3)



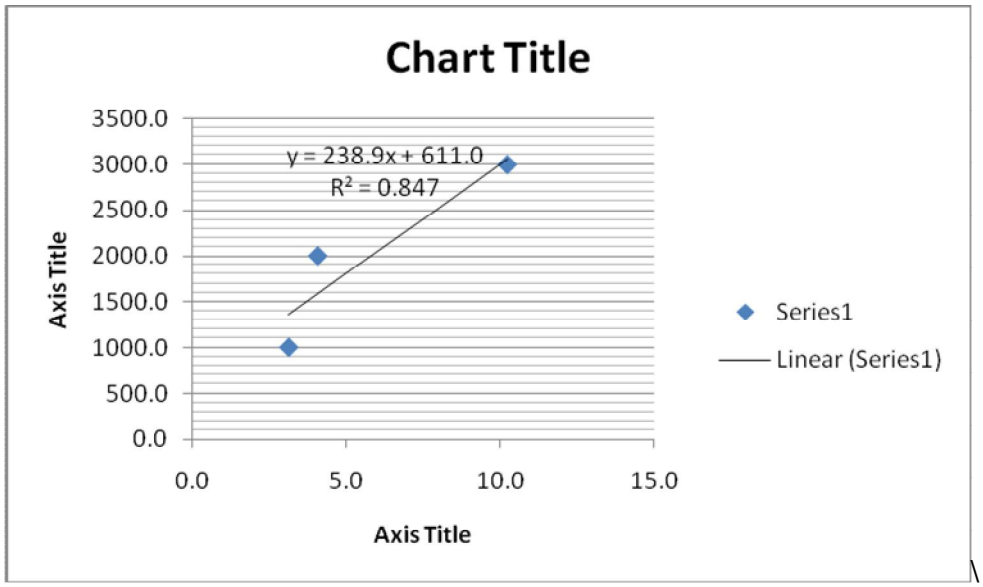
G13: Load-Deformation Plot (Table C1 Test Piece NO 1)



G14: Load-Deformation Plot (Table C1 Test Piece NO 2)

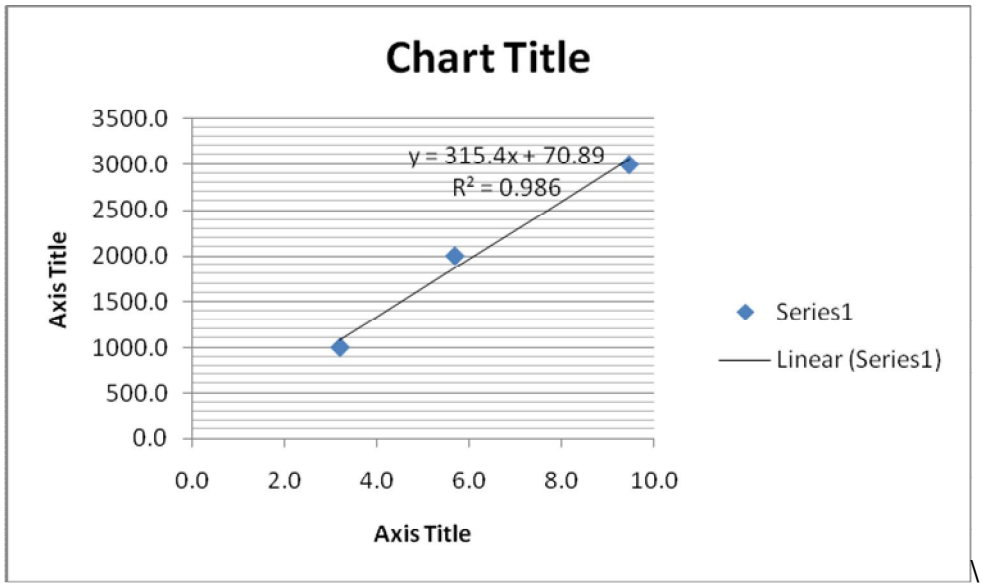


G15: Load-Deformation Plot (Table C1 Test Piece NO 3)

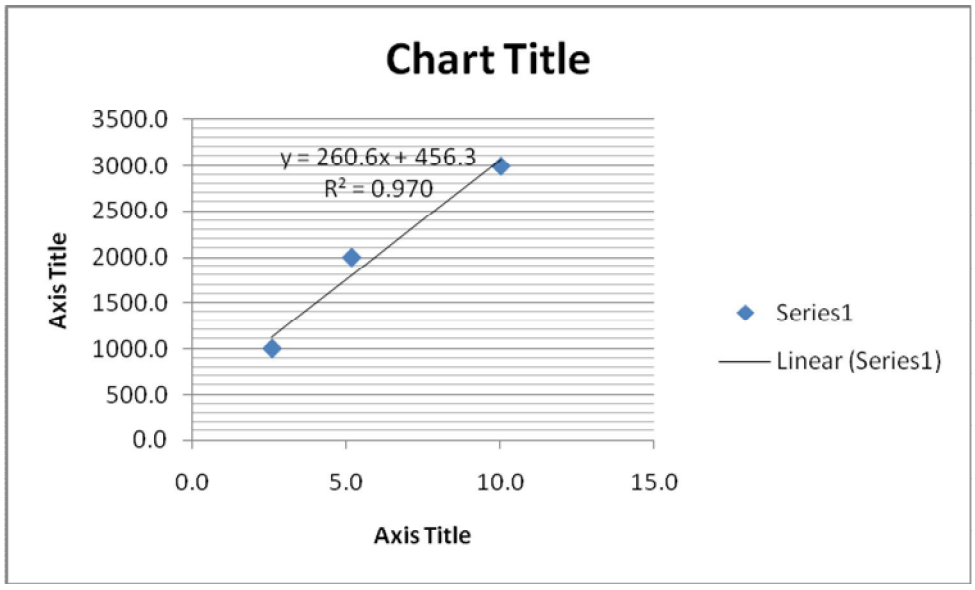


\

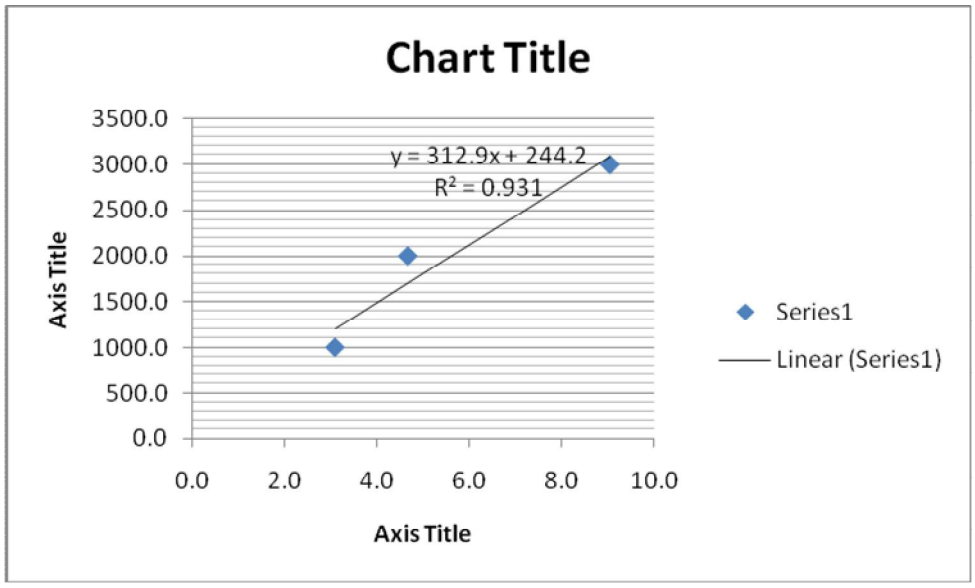
G16: Load-Deformation Plot (Table C2 Test Piece NO 1)



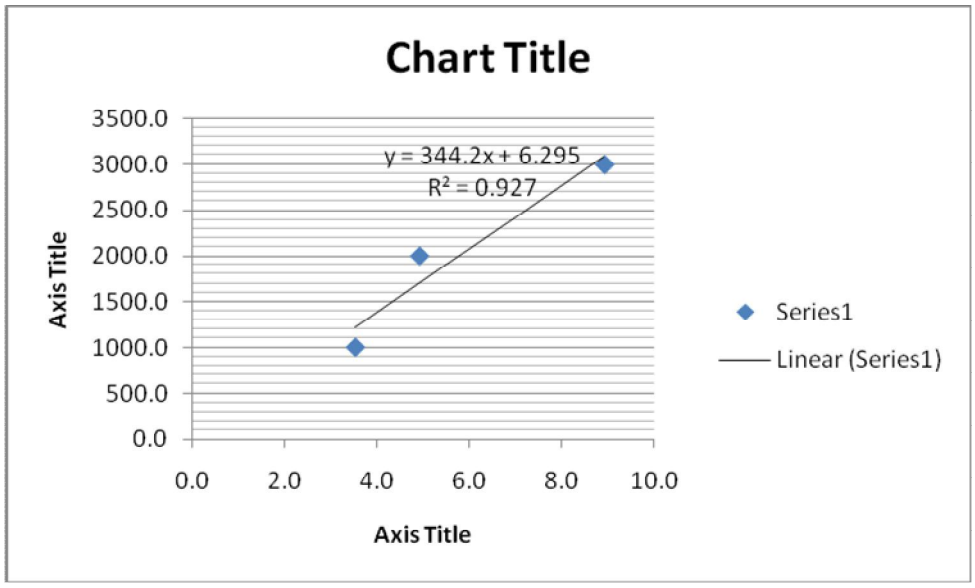
G17: Load-Deformation Plot (Table C2 Test Piece NO 2)



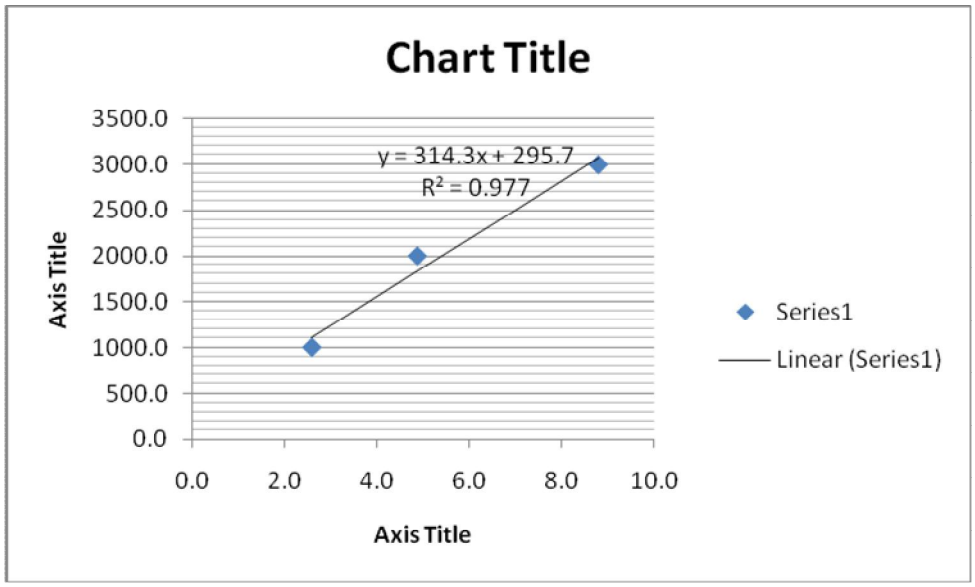
G18: Load-Deformation Plot (Table C2 Test Piece NO 3)



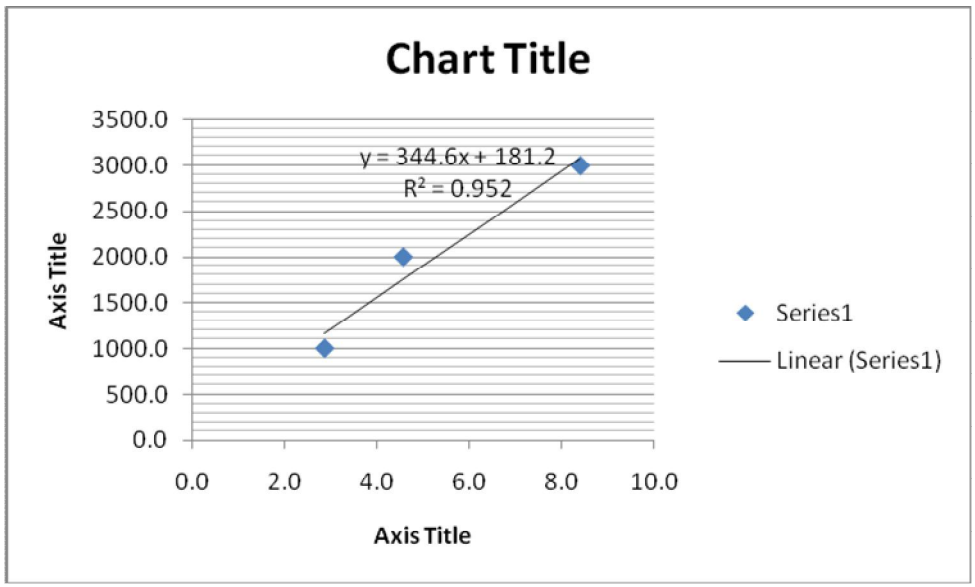
G19: Load-Deformation Plot (TableC3 Test Piece NO 1)



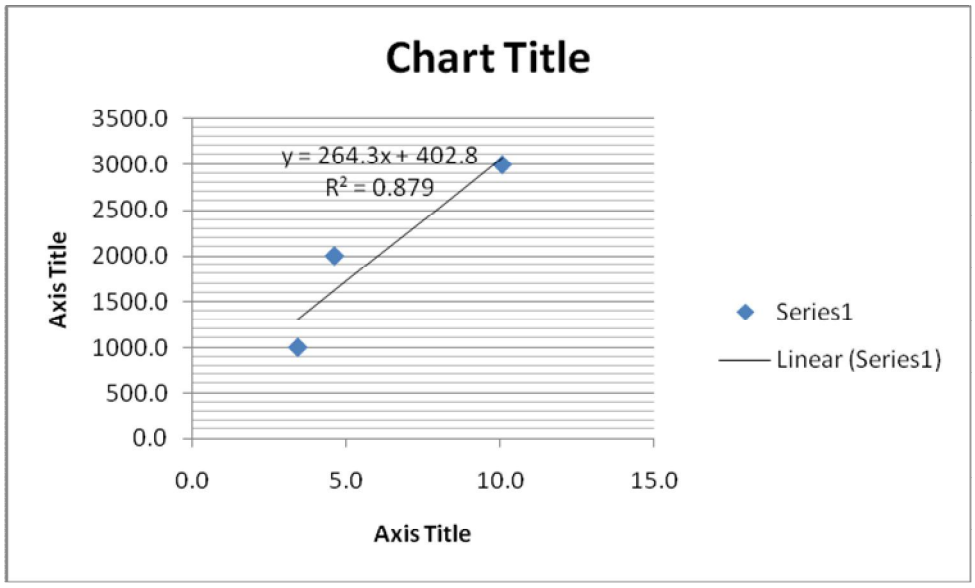
G20: Load-Deformation Plot (Table C3 Test Piece NO 2)



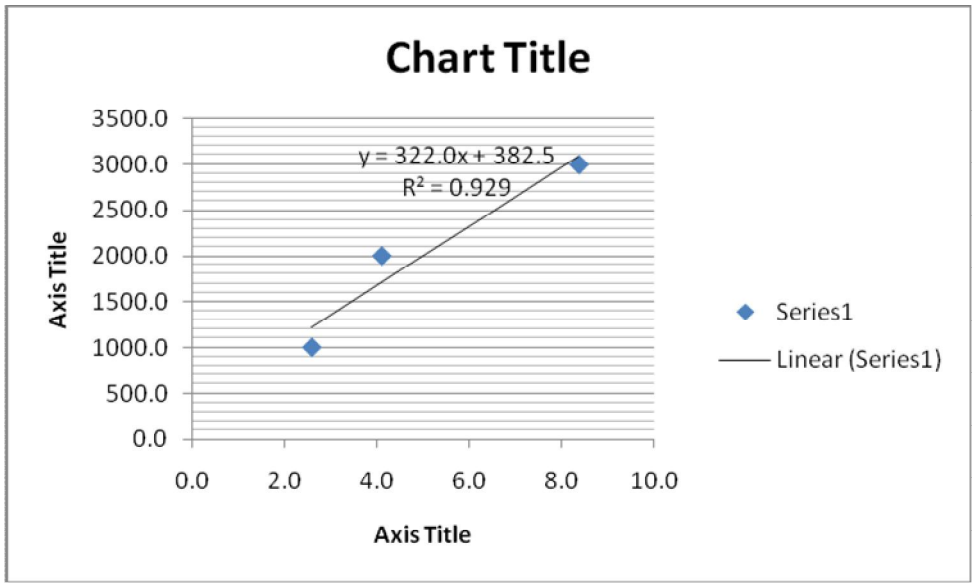
G21: Load-Deformation Plot (Table C3 Test Piece NO 3)



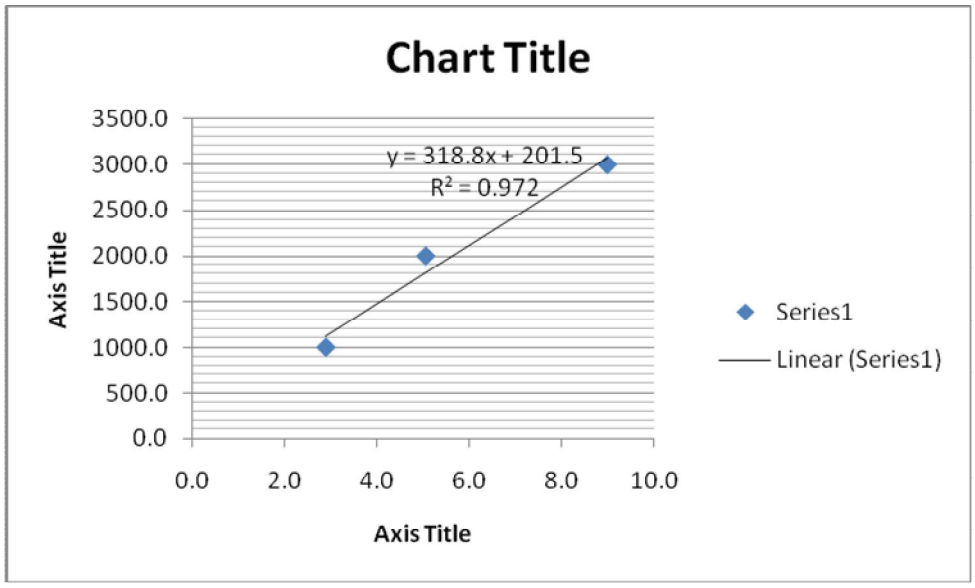
G22: Load-Deformation Plot (Table C4 Test Piece NO 1)



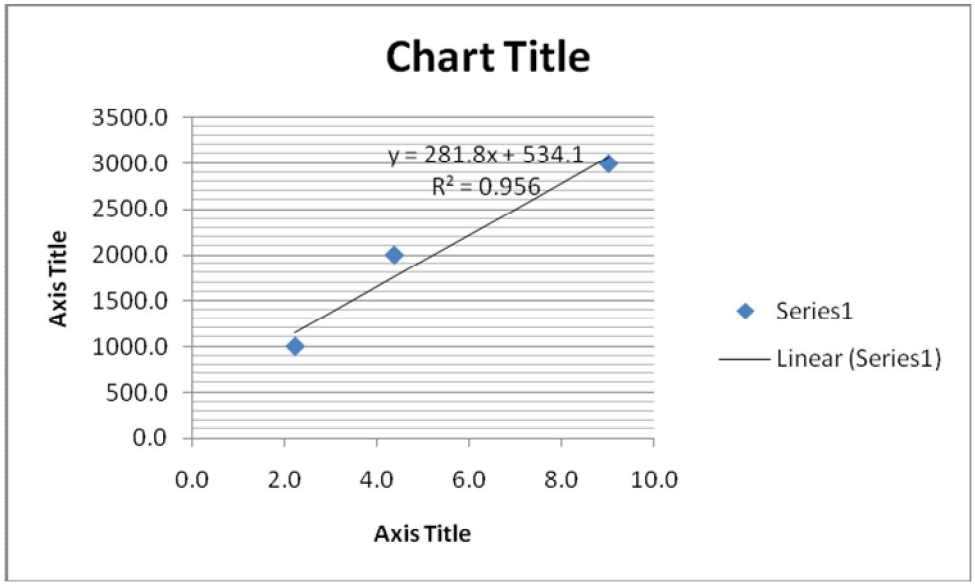
G23: Load-Deformation Plot (Table C4 Test Piece NO 2)



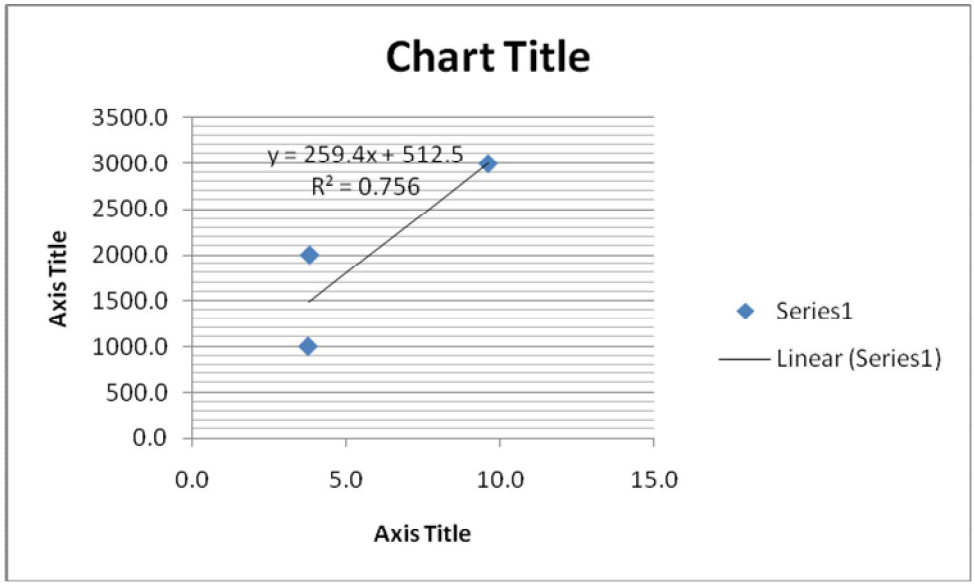
G24: Load-Deformation Plot (Table C4 Test Piece NO 3)



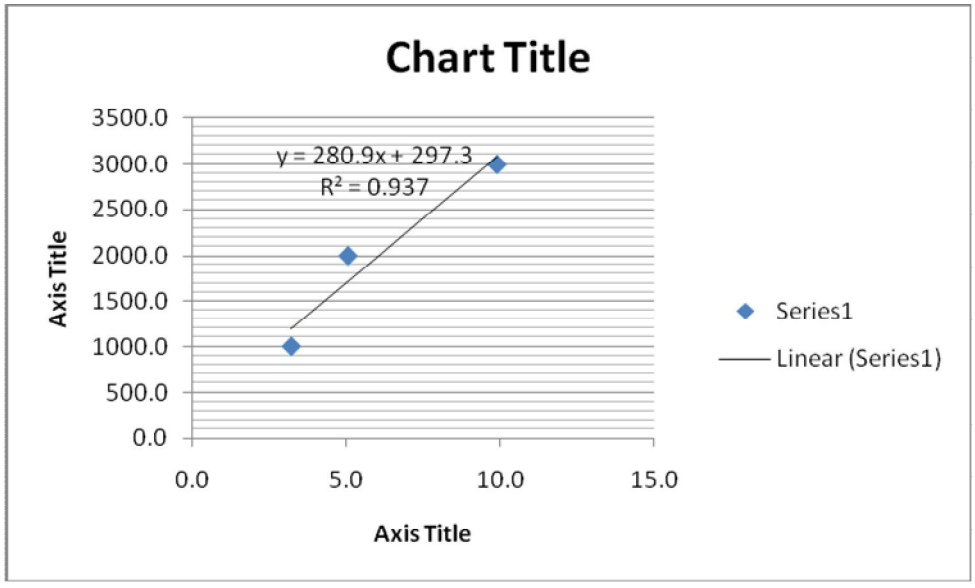
G25: Load-Deformation Plot (Table D1 Test Piece NO 1)



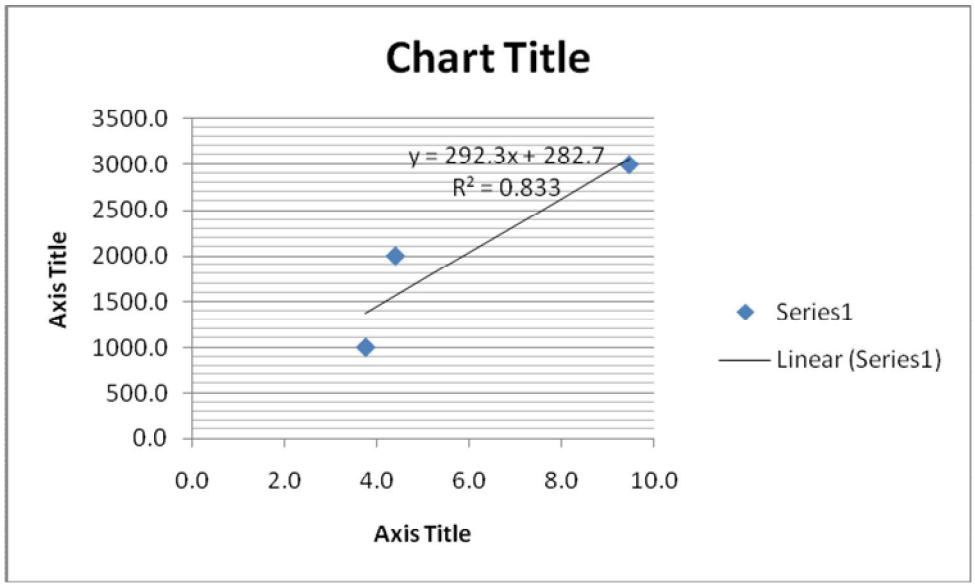
G26: Load-Deformation Plot (Table D1 Test Piece NO 2)



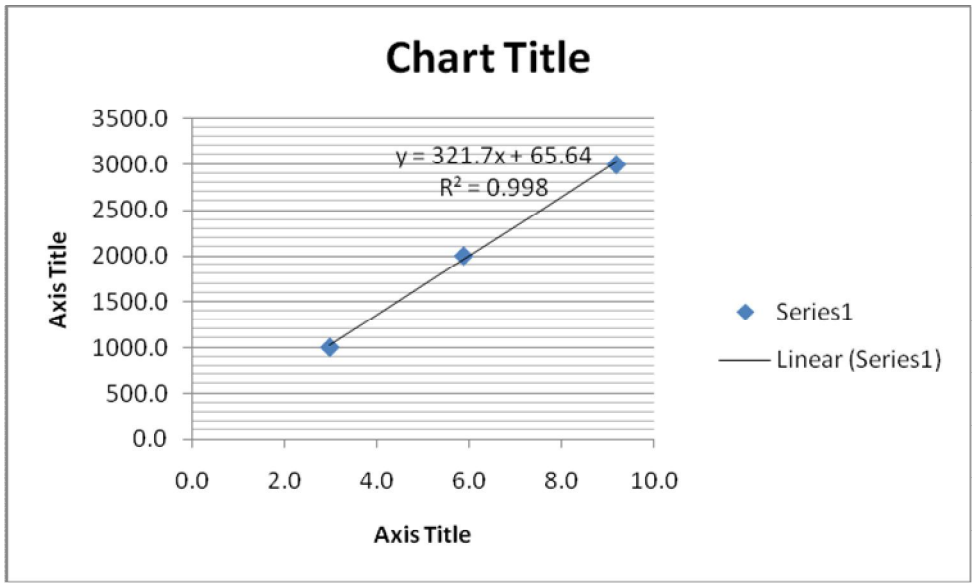
G27: Load-Deformation Plot (Table D1 Test Piece NO 3)



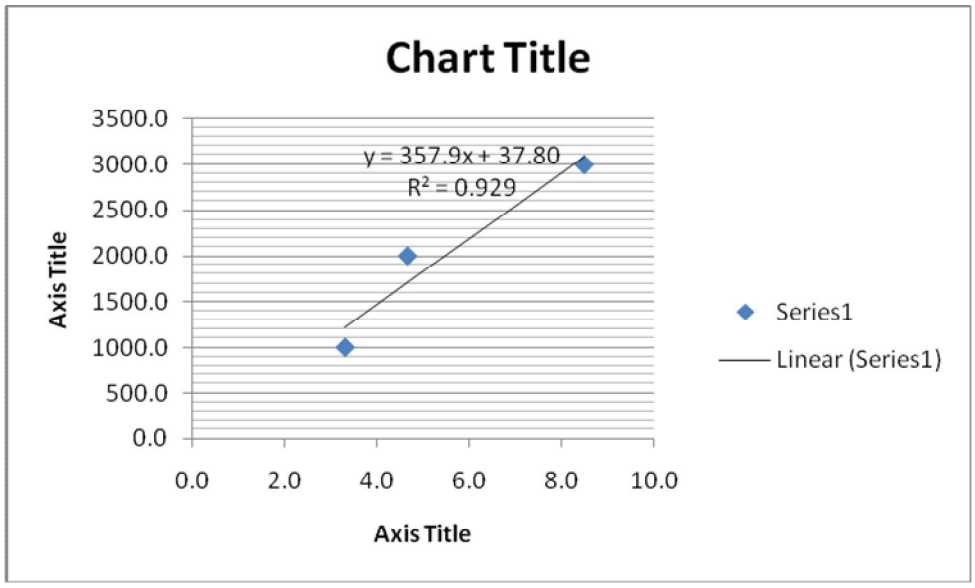
G28: Load-Deformation Plot (Table D2 Test Piece NO 1)



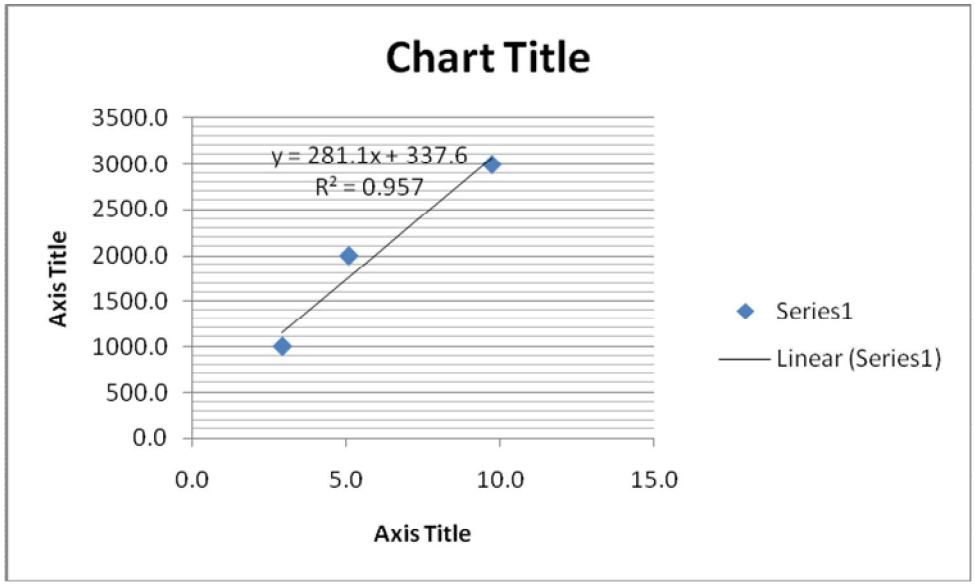
G29: Load-Deformation Plot (Table D2 Test Piece NO 2)



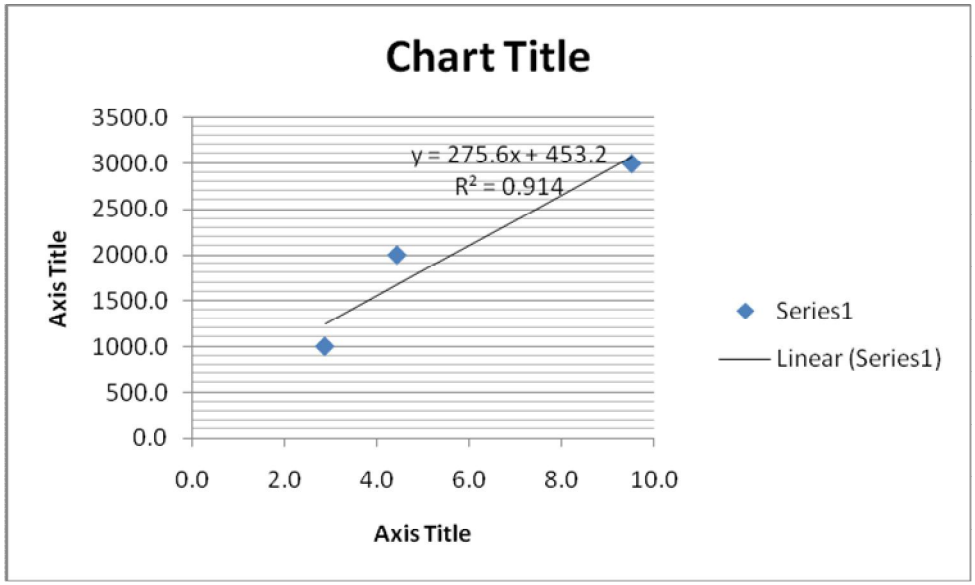
G30: Load-Deformation Plot (Table D2 Test Piece NO 3)



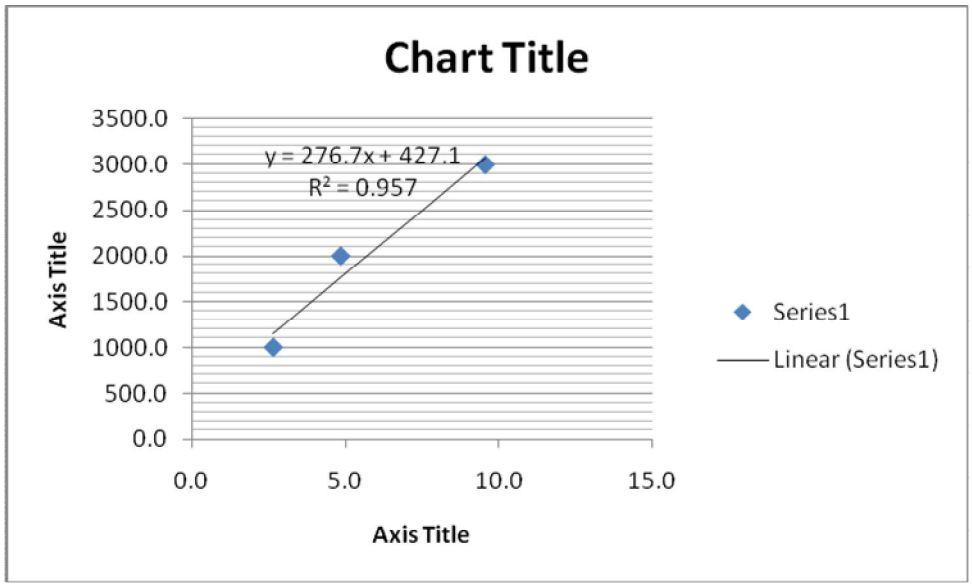
G31: Load-Deformation Plot (Table D3Test Piece NO 1)



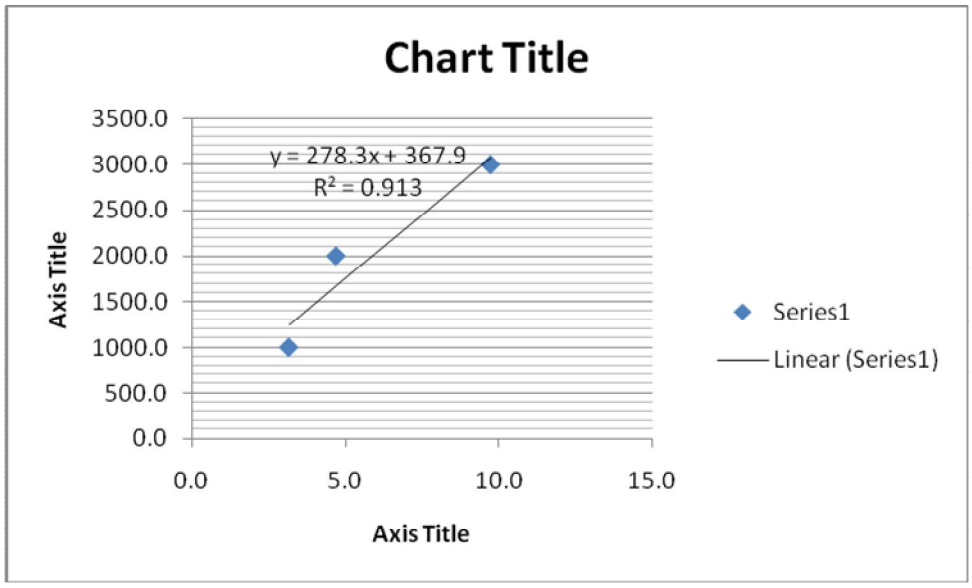
G32: Load-Deformation Plot (Table D3 Test Piece NO 2)



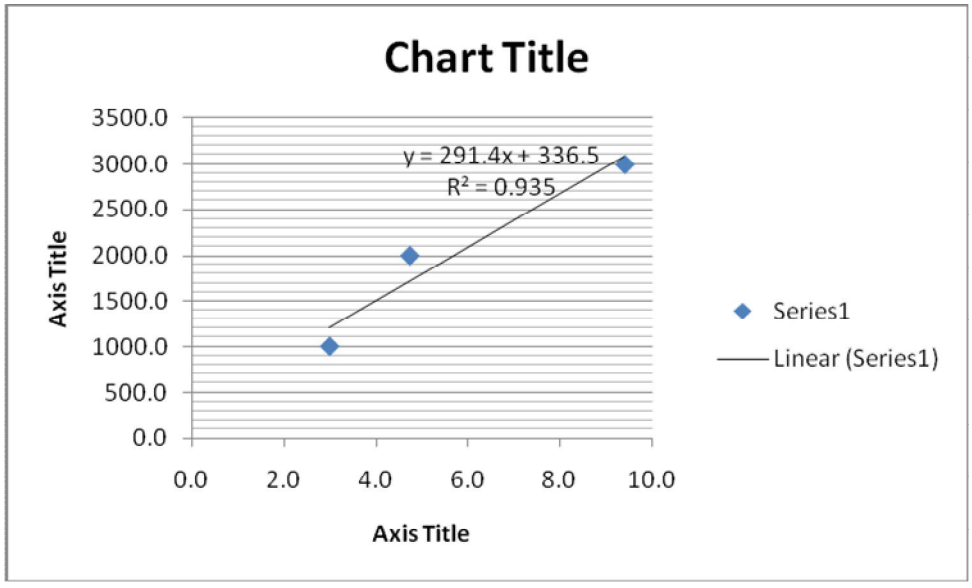
G33: Load-Deformation Plot (Table D3 Test Piece NO 2)



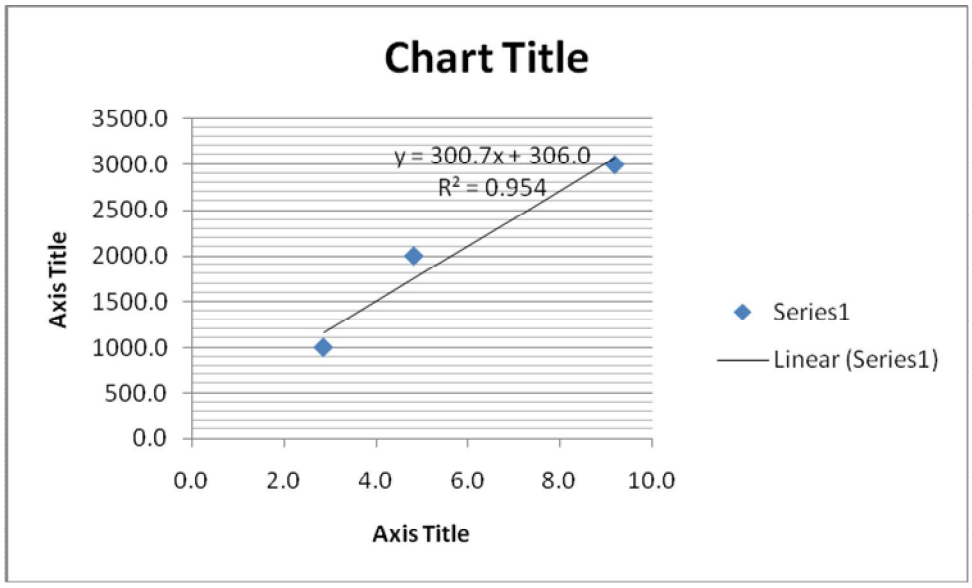
G34: Load-Deformation Plot (Table D3 Test Piece NO 3)



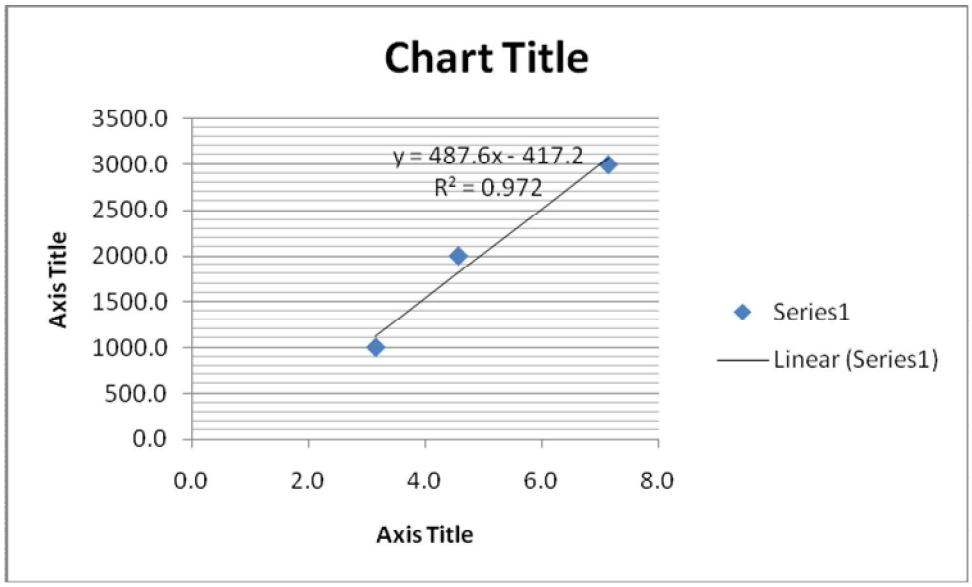
G35: Load-Deformation Plot (Table D4 Test Piece NO 1)



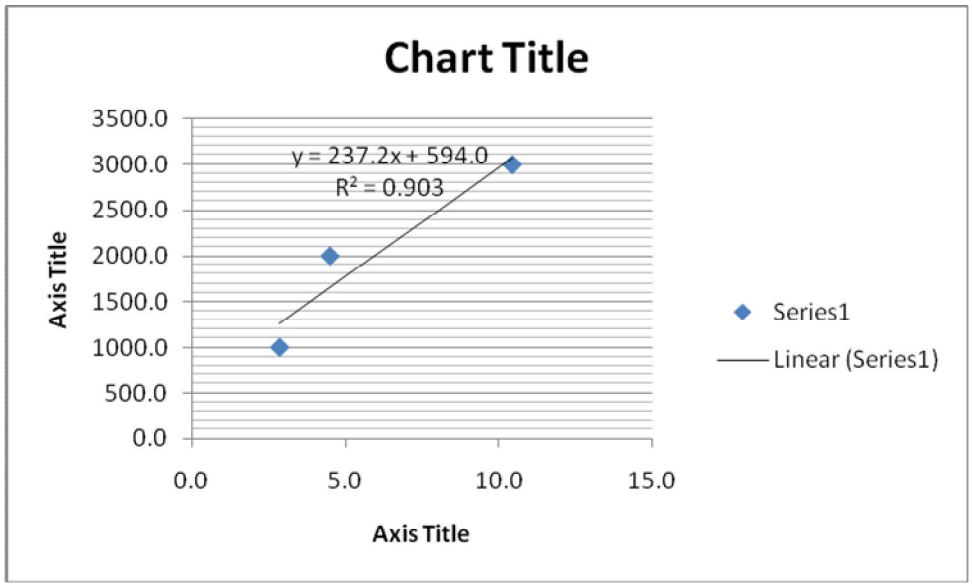
G36: Load-Deformation Plot (Table D4 Test Piece NO 2)



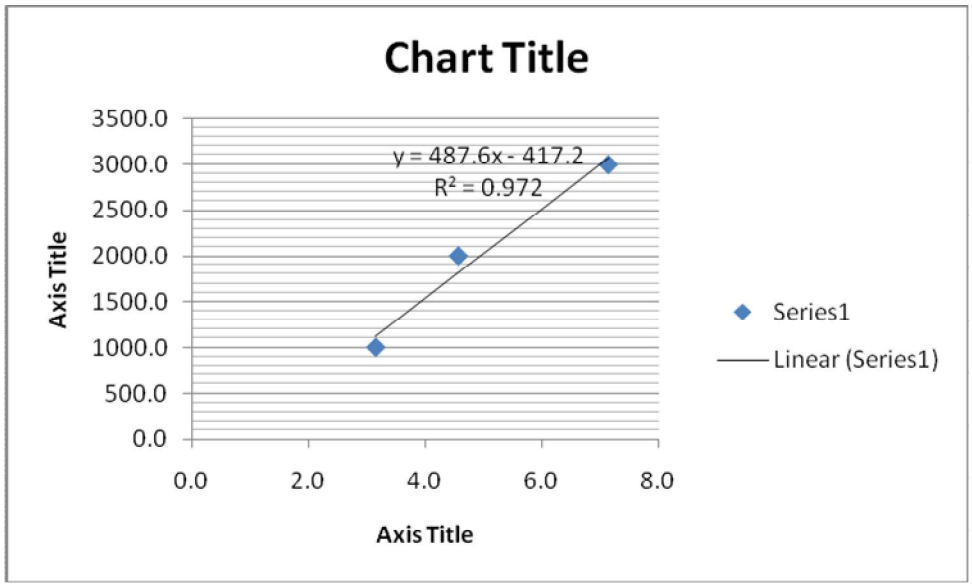
G37: Load-Deformation Plot (Table E1 Test Piece NO 1)



G38: Load-Deformation Plot (Table E1 Test Piece NO 2)



G39: Load-Deformation Plot (Table E1 Test Piece NO 3)



G40: Load-Deformation Plot (Table E2 Test Piece NO 1)