# DEVELOPMENT OF A CLASSIFICATION SYSTEM FOR SRI LANKAN TIMBER SPECIES BASED ON PHYSICAL PROPERTIES

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Degree of Master of Science

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Dissertation submitted in partial fulfillment of the requirements for the degree Master of Science

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## Abstract

An investigation was carried out on selected twenty five Sri Lankan timber species to study different wood properties which are commonly applied in the timber industry in Sri Lanka. Wood density, modulus of rupture, modulus of elasticity, compression strength at rupture and compression in elastic limit at direction of parallel to grain were tested by five samples of each specimen at moisture content between 12% - 15%. The obtained results were analysed to find correlation among properties and to develop a classification based on the wood properties. BS 373:1957 (1999) standard was followed to test small clear samples in sample sizing, testing and calculation procedures. Three point bending test, compression parallel to grain test were applied to investigate mechanical properties and by measuring weight and volume at 12%-15% moisture content, density was calculated.

Obtained results described a fair correlation among density and mechanical properties specially, modulus of rupture and modulus of elasticity. These results can be used to predict the mechanical properties with respect to density and vice versa. Above properties were referred to develop the classification into four basic grades as super grade, high grade, medium grade and low grade. Further any relationship could not be found between the timber classification published by State Timber Corporation and it proved that this classification is not based on the wood properties. It is recommended to extent the research by increasing types of properties, number of species and samples with various age limits and growing conditions and height of the trees. This could be benefitted to improve the effectiveness of the classification based on properties and to develop standards of the timber industry in Sri Lanka.

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# LIST OF ABBREVIATIONS

| Abbreviation | Description |
|---|---|
| MC | Moisture content |
| EMC | Equilibrium moisture content |
| MOE | Modulus of elasticity |
| MOR | Modulus of rupture |
| STC | State Timber Corporation |
| UTM | Universal testing machine |
| BS | British standard |
| CCA | Copper chrome arsenate preservatives |

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# 1. INTRODUCTION

## 1.2 Timber Industry in the World

The most common and adaptable material used all over the world is timber throughout the history. People used timber to fabricate tools, weapons and for energy generation frequently in the past and the applications have become more distributed in many more industries at present as building, furniture, bridges, musical and sport instruments etc. People used timber as the key material in building construction and energy generation industries until 19$^{th}$ century. Timber is remaining as a key raw material in the construction industry in contemporary times. It contributes a major role in many more other industries such as paper, pulp, paperboard, adhesives and chemical industries as secondary processed wooden products. Timber usage and international timber trade has increased drastically within last few decades. The economic growth and globalization have directly affected for increasing the demand and supply of timber and many wooden primary and secondary products [1].

Natural forests supplied almost all the timber requirement until 19$^{th}$ century. Since the demand was increased rapidly, the supply from natural forests was not enough and due to many global environmental issues, the forests utilization had to be limited. Subsequently timber plantations were becoming popular even at present, because it will help to reduce green house effect as well as to fulfil the gap between timber demand and supply.

Among various planted types around the world, Eucalyptus is the most common type it supplies around 50% of short fibers of the pulp industry and this percentage is continuously increasing. Pine, red wood, teak, and kempus are few of other planted species which are used for various applications. The tropical countries contribute more than 80% of the plantation timber harvest. When considering the present trend of expanding, plantation industry will become the main supplier of timber in the near future and the supply will reach around 1.8 billion $m^3$ per year by 2020 [1].

Europe and North American countries were the leaders of wooden products until few decades back. By the time, China is leading the industry and the international trade as increasing their share in international trade of wooden products from 1.5% to 7.2% in last few decades by the exports. At present Italy which was a leader in wooden furniture has replaced by China. As a result of expanding the forest plantation industry, China, Brazil and Russia are becoming the leaders in the international timber trade. Considering the current demand for the wooden products, it has been predicted that the international trade will reach around US$450 billion by the year 2020 as doubling their exports [1].

The trend of building construction is becoming more popular with green construction. Hence timber has rapidly increasing demand as a major environmental friendly material in construction. Further superior insulation, very little $CO_2$ emission and environmental sustainability are the other major factors of increasing the demand for the timber. Seasoning and chemical treating are very valuable activities in improving the lifetime and properties of timber.

## 1.2 Timber Industry in Sri Lanka

Timber has been used for many applications throughout the history in Sri Lanka. Sawmilling, furniture production and building applications were the main categories of timber industry in few decades back in Sri Lanka. However, timber seasoning and treating, complex building applications, various outdoor applications and many wooden products such as pulp, paper, and wood based board industries are becoming more popular at present.

The natural forests conservation is strictly managed in Sri Lanka and hence fulfilling the increasing timber demand is becoming a huge risk. The man made forest plantation is introduced and continuing successfully to supply the demand. However the plantation timber harvest also not sufficient to fulfill the demand. As such, timber is imported in large scale at present.

Even if the timber industry is a major industry in Sri Lanka, the authorities do not have correct statistical data, because of many illegal and un-reported activities are functioning. A survey conducted in 1995, explained the situation properly as about 75% of timer based companies were not recorded [1]. However the forest department annual reports say that the company registration is increasing over last few years and it can be predicted as rapid increasing. Further this report says that timber industry is well established in Colombo and Gampaha districts with the timber stock of 23% and 19% respectively [2].

## 1.4 Problem Identification

The Sri Lankan economy and population have increased continuously in last few decades and this has caused to increase the demand of timber and wooden products as well. Supplying continuous timber continuously for fulfilling the demand with high quality is the biggest threat. Poor policy decisions, unnecessary transport regulations and poor regulations are also negatively affecting to the development of the industry. Further the technical knowledge and management of the industry should be developed to have good image on the industry and to motivate the business entity. However, with those poor factors the present timber industry consumes around 1.5 million $m^3$ of logs annually for different usages in Sri Lanka [1].

Properties of timber vary with the timber species and, each property may bring a unique value and important feature to timber and its end-use. This inconsistency of timber serves a variety of uses and if a particular timber is good for one purpose it may not be useful for another purpose. In general, selecting of timber species to a particular application depends on properties of timber such as durability, strength, stiffness, toughness, and density etc. Lack of technical knowledge on mechanical properties of structural timber leads to structural application of unnecessarily high safety factors in timber design. However, comprehensive studies have not been conducted on physical properties, mechanical properties, and anatomical properties, gross features, working properties, durability, timber seasoning and preservation, when the timber properties of Sri Lankan timber species are concerned. Selection of timber for the use is species oriented, sometimes on the basis of traditional use. However, that selection is done on considerations of availability, cost, size and performance frequently. Therefore information related to technical properties is a mandatory requirement for the proper selection of timber species for particular application.

The State Timber Corporation and the Forest Department are the major institutes working on this subject in Sri Lanka. The State Timber Corporation has prepared a timber classification and is being updated annually. However this classification is done based on the commercial value and the availability of the timber and any scientific or technical logic is not considered. Hence there is no proper guide to select suitable timber type for specific tasks and as a result of that the proper usage of timber has been limited in Sri Lanka. Anyway better performances as well as significant economical benefits can be achieved by selecting suitable timber type based on technical properties for particular uses.

Classification of end-use property can be defined in the first place for building construction, furniture and joinery, light construction work and miscellaneous uses, flooring and furniture. Property requirements, their standards and specifications needed for a property classification for end user can be identified with this study.

# 2. FORESTRY AND TIMBER UTILIZATION IN SRI LANKA

## 2.1 Timber Harvest in Sri Lanka

Generally timber harvest of Sri Lanka is acquired by forest and non forest resources. Both natural forests and man- made forests supply types of timber for various requirements. Harvest from home gardens, plantations such as rubber, teak and coconut also supply bulky quantity of timber requirement of Sri Lanka through-out the history.

### 2.1.1 Forest Timber Resources

#### 2.1.1.1 Natural Forests

The natural forest cover was 29.43% of country land area according to the statistical data which measured in 2011 by the forest department. However many other unofficial reports and records have mentioned that the actual forest cover is much lower than the data published by the forest department and those data mentioned that the actual forest cover was 15% in 2015 [2].

According to the data of forest department, the natural forest cover is reducing rapidly and the reduction rate in the last decade was 0.8%. Hence natural forests are protected as conservation by 1989 due to environmental issues and sometimes timber harvesting is carried out with broad study and approval at present [1]. However, the "Sri Lankan forestry outlook study report" mentioned that the supply of timber by forests remain in satisfactory level as 15,666,840 $m^3$ from low land rain forests, 21,578,424 $m^3$ from dry monsoon forests and 8,657,103 $m^3$ from moist monsoon forests by 2011 [2].

#### 2.1.1.2 Man-made Forests

The forest plantation is a well developing industry all over the world. The forest department and few companies which come under Ministry of Plantations are the governing agents of man-made forest plantation in Sri Lanka. The timber harvest from these forests contributes timber for mainly fuel, electrical transmission poles, rail-way sleepers and sawn timber. According to the "Sri Lankan forestry outlook study report", the plantations have grown in about 16463 ha up to 2011 [1]. The trendiest types of planting timber of Sri Lanka are Teak and Mahogani. White Sandal Wood and Kaya plantations are now developing specially by private sector companies with many promoting programs to invest by public. However, current timber supply from the plantations to the industry has not reached the expected level in both quality and quantity.

The harvest form man-made forests also to be consumed in sustainable manner, due to minimizing the wastage and environmental issues. Shortage of long length timber to be fulfilled by man-made forest harvest, because of the harvest from natural forests is very low. Even though *Eucalyptus Camaldulensis* planted in dry zone is used to supply long length construction timber, the supply is not adequate. Further *Eucalyptus Grandis* and *Eucalyptus Microcoris* planted in up country can be utilized for construction. Since major application of this harvest of around 10,000 $m^3$ is manufacturing railway sleepers, supply for the construction needs is not enough as expected [1]. This shortage of timber supply over the demand in industrial and constructional applications has affected to the industry very badly at present.

However, the supply of Teak and Mahogani for furniture and joinery industries is achieved almost reachedthe demand. State Timber Corporation is playing a main role in supplying those timbers to the market by controlling the quality and the price also.

### 2.1.2. Non-forest Timber Resources

Since the natural forest timber is not accessible anymore and man-made plantations are not adequate, timber harvest from non-forest resources are needed to be utilized to full fill the timber demand in Sri Lanka. The "Sri Lankan forestry outlook study report" mentions that around 70% of industrial timber requirement are full filled from non-forest resources such as home gardens, rubber, teak and coconut plantations.

#### 2.1.2.1 Timber supply from home gardens

More than 400 timber types have been planted and some are naturally grown in Sri Lankan home gardens. The main types among them are jak, coconut and mango and those can be utilized in various applications. These three types contribute about 38% for the volume of total home garden timber harvest. Teak, Mahogany, Alstonia, Albizzia and Eucalyptus also contribute considerable supply to the industry by providing around 30% of total home garden timber harvest. However the quality and the durability of timber received from home gardens are poor. Hence effectiveness of using this timber is less specially in industrial constructions [1].

#### 2.1.2.2 Contribution of Rubber and Coconut plantations.

Rubber plantation has been spread in around 114,713 ha in Sri Lanka. A rubber plantation development program was started in 2006 by the Ministry of Plantation Industry to increase the plantation distribution from 116,000 ha to 180,000 ha by year 2020 [1]. Treated rubber is used to manufacture furniture and used in wooden board industry and the ministry expected to full fill the rising requirement of the industry by the development plan.

Even though coconut plantation was well established in past, it has been felled down rapidly over last few decades. Clearing of coconut plantations is rapidly increasing and this has affected to the timber supply badly. Authorities have not found any timber substitute to full fill the gap other than concrete or other material. The “Sri Lankan forestry outlook study report” says that about 49.4 $m^3$ of saw logs from a hectare are losing continuously [1].

### 2.1.3. Imported Timber

The demand for the timber utilization is increasing continuously in Sri Lanka as results of industrial development, green building concept and increasing population. However fulfilling the total requirement is not possible at present by using local timber supply due to forest conservation programs, insufficient plantations etc.

The gap between the supply and demand is filled by the imported timber especially in construction industry in Sri Lanka today. However most of the timber species could not be identified correctly according to the botanical or commercial name. Hence there is a possibility to receive low quality timber to Sri Lanka. Further, due to lack of knowledge in identification of imported species, local customers can get mislead.

Figure 2.1 shows that imported timber supply does an appreciated contribution to the local timber utilization. Hence it is very important to have a proper guideline and knowledge to identify various imported timber species and it is required to have proper rules and regulations regarding timber import as well.

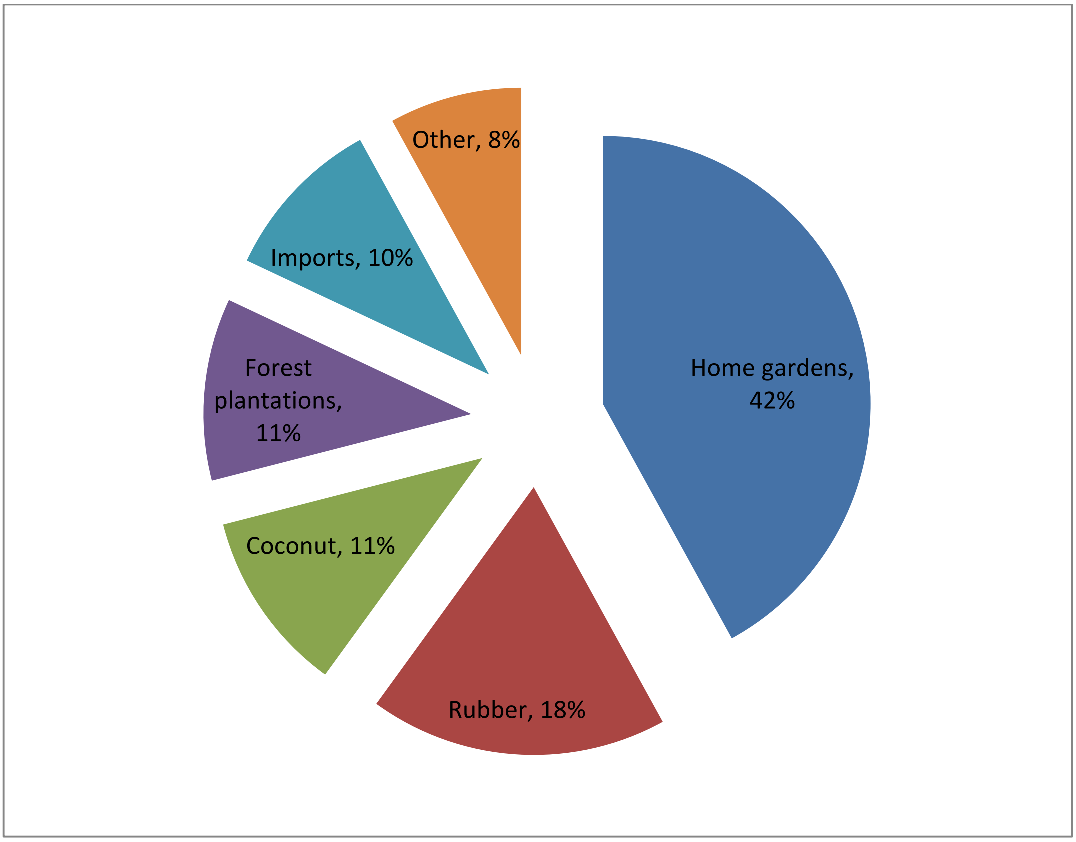



Figure 2.1- The contribution of timber supply by various sources- 2006 (Original in colour)

Source: [2]

## 2.2 Timber Utilization

### 2.2.1. Utilization of Timber and Timber Based Products

Sri Lanka is a country which consumes less industrial timber and produces less timber based products. Pulp, paper and sawn timber consumption per capita was 35 $m^3$ /1000 persons in 2008. Even though 87% of householders used timber as fuel generator, industrial sector consumed only 49% according to the energy consumption in 1992 [1]. The main timber fuel consumer in the Sri Lankan industry is the tea industry, which consumes about 43%. The hotel industry consumes about 16%, Brick and tile industry 14% and bakery industry consumes about 9% of timber as fuel generator [1]. However inefficient timber utilization can be seen all over the country and this may cause the timber shortage. Especially few districts are facing fuel wood shortage such as Nuwara eliya, Gampaha, Badulla and Jafna. However high transportation cost is the main barrier to reduce the shortage in such areas.

### 2.2.2. Past and Present Timber Based Enterprises in Sri Lanka

Timber is a famous construction and building material used since ancient era even in Sri Lanka. "Lovamahapaya" is a well known example of timber based structure constructed in the second Century B.C. by King Dutugemunu. Many more cultural constructions such as Ambakke Dewalaya, Dalada Maligawa, and "tam pita vihara", "bodighara", "mandapa are few examples of grate timber works even can be seen today.

Hundreds of timber species are accessible in Sri Lanka for many applications based on their properties. However, very few types are the well known and freely available in Sri Lanka. Most common timber types were Satin and Palu in past. The wide availability of different timber types with vast range of properties in natural forests was one of the attraction factors for colonizing the country [1]. Further, the timber based fabrication and construction technology were in a very advance level in the past such as "kanimadala" and "madol kurupawa".

The Sri Lankan forest timber utilization has been classified into four basic stages as (a) early exploitation stage up to the 1880, (b) forest management based on timber harvesting stage from 1880 to mid 1950s, (c) peak and decline of timber harvesting stage from mid 1950s to early 1980s, and (d) consolidation stage from mid-1980s [1]. As a result of increasing population, industrialization and underutilization, the requirement of timber and timber based products become more important and demand is continuously increasing. Hence, forest management should be done for sustainable development and utilization of resources at present.

Even though the past industry depend on natural forest resources, present industry depends basically on plantation timer types such as Teak, Mahogani and *Eucalyptus grandis.* Further, instead of using raw timber, present industry uses chemically treated and seasoned timber through new technologies. This will be very supportive to improve sustainable utilization and development of timber resources

### 2.2.3 Selection of Timber

Since the timber plantation areas and natural timber resources are being reduced and demand is increasing, available resources should be managed efficiently and effectively. In this case, properties and characteristics of different timber species play an important role in minimizing the wastage and over usage. The quality and the effectiveness of timber based products depend on the correct selection of timber along with properties corresponding. Selection of most suitable timber for a particular task should be done by considering both properties and other factors such as cost and availability. Mechanical properties, such as density, durability, machine ability and appearance are the major to be considered and the importance of each property varies based on the requirement. There are two methods of selecting most suitable timber for a particular application basically. First method is selecting most suitable grade based on properties required, and choosing one type of timber from the particular grade. Second method is selecting a timber type which suits to the given environment and stress conditions faced.

Most suitable timber selection may lead to minimize tree cutting and frequency of cutting down. Hence the age of trees will increase and it helps to produce high quality and durable timber harvest.

### 2.2.4 Timber Identification

Since the properties and characteristics vary with the type of timber, timber identification is very essential. Especially in timber grading according to the properties, identification is critical, because there are large number of available types and appearance is much similar. Processing of timber such as chemical treatment and seasoning also depends on the type of timber. Furthermore timber identification is very essential in international trading. Anatomical features, smell and appearance can be referred as basic features for timber identification.

Sustainable timber utilization is improve with the identification of wasting stages and amount of wastage happen at each stage until the product is derrived. Major wasting stages are tree cutting and logging. The amount varies with the type of timber and operation method. For an example, *Eucalyptus* planted in upcountry has cutting and logging waste of about 15%, while plantation teak has about 10% of wastage [1]. Management of timber harvesting is very important including method and machines used, because cost of waste depends on the timber type. Advanced technology and machinery will help to minimize the waste and damages to neighbour trees. Saw dust in saw mills also should be used as by product and needed to be minimized the amount by using appropriate machines and tools.

Timber identification is critical in machining also. Tools and machines can be utilized efficiently and effectively along with proper selection according to the properties of timber type.

Hence it is obvious that the suitable timber identification is the foundation of timber industry for sustainable development and utilization.

### 2.2.5. Timber Seasoning and Preservation

Especially timber harvest of wet zone and home gardens contain high amount of moisture than dry zone timber. Due to this, wet zone timber is less durable than dry zone timber. Hence, timber seasoning and chemical preservation is highly recommended to improve the quality and service life of sawn timber and timber based products. Further according to the application, dry zone timber is also subjected to seasoning preservation. Timber seasoning and preservation are essential in sustainable utilization of Sri Lankan timber and to reduce frequent replacements due to long service life.

#### 2.2.5.1 Timber seasoning

As a hygroscopic material, timber should be carefully managed in the applications. Due to the moisture content, timber will change its shape which results the change in properties. Since this affects to the service condition of end use, moisture content should be controlled by the process called seasoning. The objective of seasoning is reducing the green moisture content reducing lower than its equilibrium moisture content. However, most of the timber in local market are not subjected to seasoning or subjected to partial seasoning. It may not be practiced to reduce cost and time or due to unaware of the process and benefits achievable.

Two common seasoning methods are practiced in Sri Lanka. One method is seasoning by industrial type ovens. It is the speedy way of seasoning. However this method consumes a big cost. Further it is needed to identify the timber type and green moisture content, to determine the parameters required to reduce the moisture content below equilibrium moisture content. The other method is keeping logs or sawn timber open to the environment for about 3-4 months to get the moisture evaporated naturally. This method consumes long time. Hence task should be planned and timber should be prepared very early. The time depends on the environmental conditions, timber type and the size of log or plank. The researchers have mentioned that about 2 months are needed to season 1” plank [1].

Normally it is advisable to keep the moisture content below 20% in Sri Lanka to achieve good dimensional stability and to reduce the insect and fungi attacks for commonly used timber species.

#### 2.2.5.2 Timber preservation

Fungal, insects and termite attacks are key factors of reducing the service life of timber and timber based products. Timber preservation is the process of developing a media in timber by using chemical preservatives and it resists grow of deteriorative agents. The most important consideration in preservation is selecting appropriate chemical and selecting a proper application method. It depends on the timber specie, expected shelf life, cost, end type of application, etc. The properties of chemicals vary as poisonous level, penetrating capability, cost, chemical stability, applying ability, non corrosive to iron and retardation of fire [1].

The most common timber preservation methods in Sri Lanka are pressure treatment with creosote. Pressure treatment with copper chrome arsenate preservatives (CCA), diffusion treatment with boron or mixtures containing boron and low pressure treatment with light organic solvent preservatives are also practiced [1].

Diffusion treatment with boron preservation treatment is done in small scale industries because it needs less technical knowledge and equipments. Pressure treatment with creosote is very common in fabrication of railway sleepers and electricity transmitting poles.

Lack of knowledge in timber preservation is a major issue in Sri Lanka at present. Since timber preservation plays a major role in sustainable utilization of timber, relevant authorities have a responsibility to educate public while controlling and monitoring the process properly to achieve sustainable development targets.

# 3. PROPERTIES OF TIMBER

Timber demonstrates unique and complex characteristics as a natural structural material. Its properties vary with the characteristics and composition of grains which is a product of annual growth rings of the tree. Since timber is a non-homogeneous and non-isotropic material, timber shows different properties depending on the orientation of grains. The grain orientation can be described in tangential, radial, and longitudinal planes because grains exist parallel to the length in longitudinal direction.

Structural timbers are produced by various types of timber species. This huge number of varieties can be classified into groups on different basis. Some classifications have been done on the basis of anatomical characteristics such as hard wood and soft wood. Classifications according to the properties are commonly used in industrial applications were complex engineering designs are involved. More classifications are available in several countries which have been done based on planted area.

It is essential to study the structure of timber, because the timber structure determines the classifying basis.

## 3.1 Structure of Timber

Timber is a natural organic material and the properties vary from tree to tree as fibrous structure is changing. However natural fibers of trees are strong in tension and little bit weak in compression. Basically, hard wood and soft wood classification are developed on the basis of structure. The difference of cross sectional structural view between hard wood and soft wood can be observed very clearly.

The anatomy of structure of timber can be described in two distinct levels as microstructure and macrostructure. The properties and characteristics of timber vary according to both of these structural behaviours.

### 3.1.1 Micro Structure

Micro structure is the cell arrangement of timber and it cannot be seen in naked eye. The cell size of various timber species vary from 16 to 42 μm in diameter and from 870 to 4000 μm in length [3]. Even if the strength of single cell is negligible, they will generate strong composite by packing together. However the wood cells are advanced than other common types of cells, because they are multi- layered and highly reinforced as shown in figure 3.1. The cells consist of separate cell walls which is formed with cellulose and hemicelluloses they are linear polysaccharides, except that, lignin is also available and it an amorphous phenol [4]. Lengthy and un-branched chains are constructed with cellulose and short branched chains are constructed with hemicelluloses while lignin provides a wall and strengthens the cells. These layered tubular structures offer large void volume. The carbohydrate and phenolic components of timber are gathered in these voids of cells and because of that, the specific gravity is changed vastly. Consequently, high strength to weight ratio can be obtained [4].

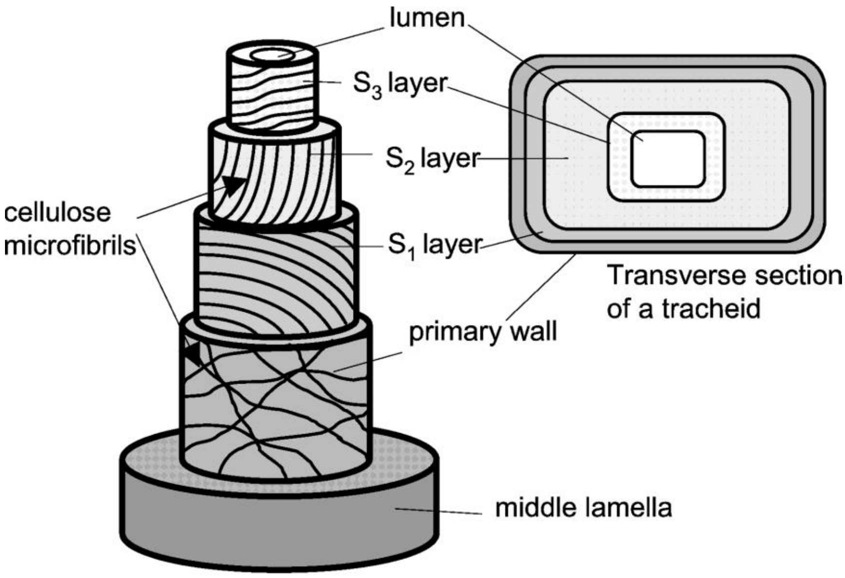



Figure 3.1 – Microstructure of timber

Source: [5]

### 3.1.2 Macro Structure

The view of a cross section of a log shows the macro structure of timber. The basic parts of macro structure of hard wood are different from soft wood. A general macro structure of hard wood is shown in the figure 3.2 and basic parts of that are bark, cambium and heart wood. The dead outer layer of log is called the bark and it consists of very thin live cells closer to the cambium [4]. The cambium is the next layer and heart wood is the valuable section of the log which is located between cambium and pith. The width of each layer depends on type of specie, nutrition level and age of the tree. Basically protection to the heart wood is provided by the bark and nutrition conveyance and storage are done by other inner layers, especially heart wood.

The hart wood is normally darker in colour compared with sap wood. Sap wood is prohibited to use in timber applications since the moisture content of sap wood is higher than heart wood and the living cells availability of sap wood allows to grow fungi and insects. Since the cambium is a continuous ring and all bark, sap wood and heart wood cells are initiated from the cambium. Cells of all layers are radially aligned. Growth, growth rings and knots play major roles in the macro structure of hard wood.

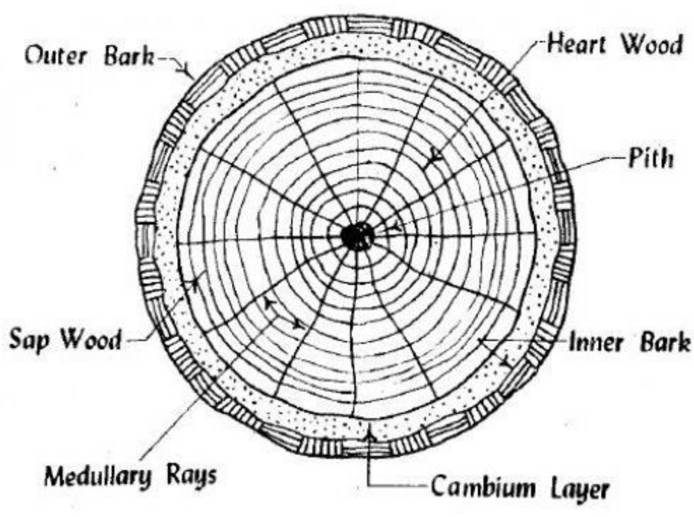



Figure 3.2 – Macrostructure of timber

Source: [6]

#### 3.1.2.1 Growth

Growth of a tree depends on the environmental factors, soil condition and amount and type of nutrients provided. The amounts of new cells generated in the cambium as well as the amount of cells which are moved to heart wood or bark vary with the growth of each tree. Some new cells remain in the cambium itself as the diameter is increased when tree grows. Similarly extra cells of bark try to move outside of the tree resulting cracks with different patterns which are identical for each species.

The growth rate of sap wood and heart wood cells are different in all types of timber. The trees with high growth rate and high density of heart wood have more demand since the effective volume is higher than the sap wood volume. Many plantation projects are being undertaken at present considering the growth because this affects the sustainable development and utilization directly.

#### 3.1.2.2. Growth Rings

The continuous cambium rings form the growth rings. Growth rings provide a significance value to the timber because the appearance of timber depends on the rings architecture. The thickness of ring depends on the factors of growth. The thicknesses of growth rings get reduced when the water volume absorbed by the tree is reduced during dry seasons,. Further thinner growth rings can be obtained in sunny environment than in sheltered environment. This may result nice appearance of sawn timber which can be found from dry zones. The density of timber with thinner growth rings is higher since the void volume is reduced. Hence they perform high strength properties as well.

The number of growth rings gives a prediction of age of the tree. However the number of growth rings for the counting period can be vary with the irregular environmental conditions. Hence directly counting the rings directly would not be an accurate method of predicting the age.

#### 3.1.2.3. Knots

Branches are developed laterally from the trunk as a tree grows. These branches disturb to the usual grains and pattern of growth rings. This effect can be seen in sawn logs clearly by having thinner growth rings specially. Two types of knots can be seen as inter-grown and encased knots. The knots created by the live branches are called inter-grown knots while the knots formed around a dead branch are called encased knots [4]. The commercial value of furniture is increased when there are knots in the sawn timber because it creates nice and unique appearance. However the strength of timber is reduced since the strength is lower in the perpendicular direction to the grain than parallel. Hence knots play a significant role in the performance of timber in many applications.

## 3.2 Physical Properties

Physical properties of timber vary with the micro structural and macro structural behaviour. Moisture content, dimensional stability, thermal properties, density, electrical and chemical properties are some physical properties of timber which affects to most of the industrial applications and performance.

Since timber is an anisotropic material, the physical properties are changed according to the direction of grain direction. Basically, properties differ in three perpendicular directions as longitudinal, radial and tangential. Figure 3.3 shows the directions related to the grains or fibers. The difference of properties between radial and tangential are relatively small compared to the longitudinal direction.

The sawn timber cutting orientation is also very important due to this property difference as timber type selection is very important in the designing stage. More attention is needed in production stage also, because the theoretical strength and other property values are changed by defects such as voids, knots, sap wood, etc with the directional effect.

Few physical properties are described below since the study of these properties is essential in engineering design and production.

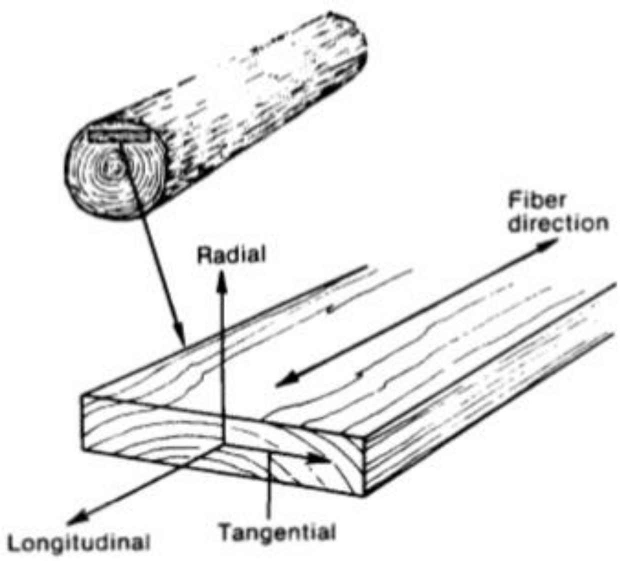



Figure 3.3 – Property changing directions of timber

Source: [4]

### 3.2.1. Moisture Content

Water is a must for the growth of a tree and it is the major component of a tree. Basically moisture content (MC) which is the water level of a tree depends on the timber type, soil condition and environmental condition. Timber absorbs and excrudes water according to the environment as timber is a hydroscopic material. Moisture content approximately varies from 25% to 250% in heart woods and a higher MC is in sap wood than in heart wood. Mathematically MC is expressed in the equation stated below (1).

$$MC = \frac{\text{Moist weight} - \text{Dry weight}}{\text{Dry weight}} \times 100\% \qquad [4]\ (1)$$

The water is present in timber cells in two types. Water percent within the cell wall is called “bound water” while water in the cell voids is named as “free water”. Even though the free water exists as just water, bound water is bond together by secondary or hydrogen bonds. Hence free water can be removed from the timber easily and quickly than bound water. The removal of bound water is resulted in shrinking of timber with reducing the volume. The properties are also changed in this task. Even through the total free water removed from the timber, bound water is still remained in the cell walls by bonding together. This level of moisture content is named as “fiber saturation point” of given a timber. This level is dissimilar for each timber type and varyies from 21% to 28% [4].

The “equilibrium moisture content” (EMC) of timber is the stability level of moisture content within its nominated environment [4]. Figure 3.4 graphically represents the levels of moisture content clearly. Many researchers have shown the maximum strength properties are shown when moisture content exists between 10% and 15%. Even in Sri Lankan context, seasoning is done to reduce the MC up to 15% to achieve great strength properties.

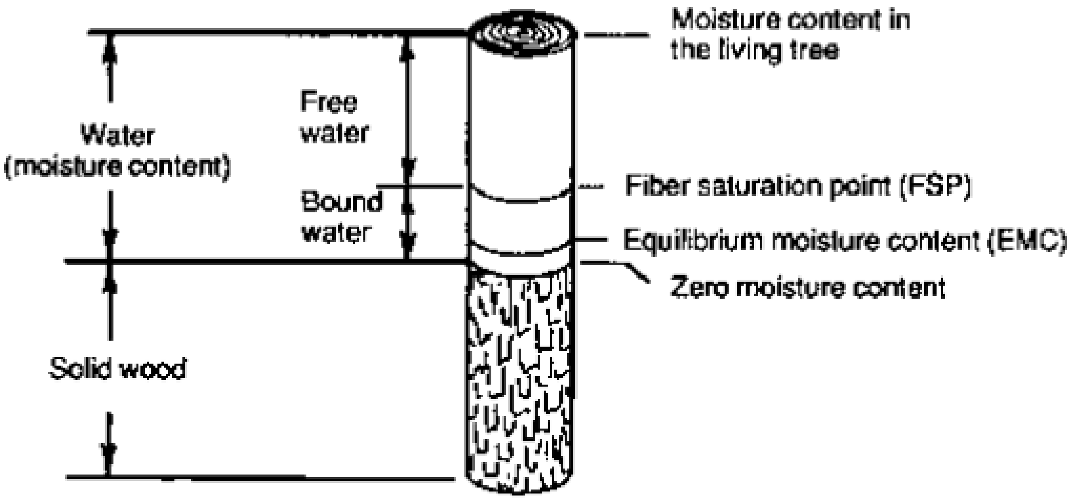



Figure 3.4 – Diagrammatic representation of wood moisture content

Source: [7]

The period of reaching a timber for its EMC depends basically on the size of part, permeability, temperature, method of drying and MC difference between part and EMC. Since water is a hydroscopic material it cannot be kept an absolute constant MC level even in EMC. However this variation can be decreased by chemical treatments or proper coatings.

### 3.2.2. Dimensional Stability

The dimensions of timber are altered according to the MC. However it is not altered above the fiber saturation point since bound water amount is fixed. Timber is subjected to shrink when the MC is reduced below fiber saturation point and get swelled when MC is increased up to fiber saturation point. Due to this dimensional instability, cracks, warping such as twist, cup, bow and crook are occured.

As timber is anisotropic material, dimensional stability is different in the three directions. Many researchers have proven that the dimensional changes in longitudinal direction are not much countable as 0.1% to 0.2% between EMC and fiber saturation point [4]. However the dimensional changes in other two tangential and radial directions are considerable as shape changers occur. This occurs due to difference of shrinkage or swelling and the curvature of growth rings as shown in figure 3.5. Generally the tangential dimensional changing ability is two times in radial direction and it is between 2.2% to 5.6% [4].

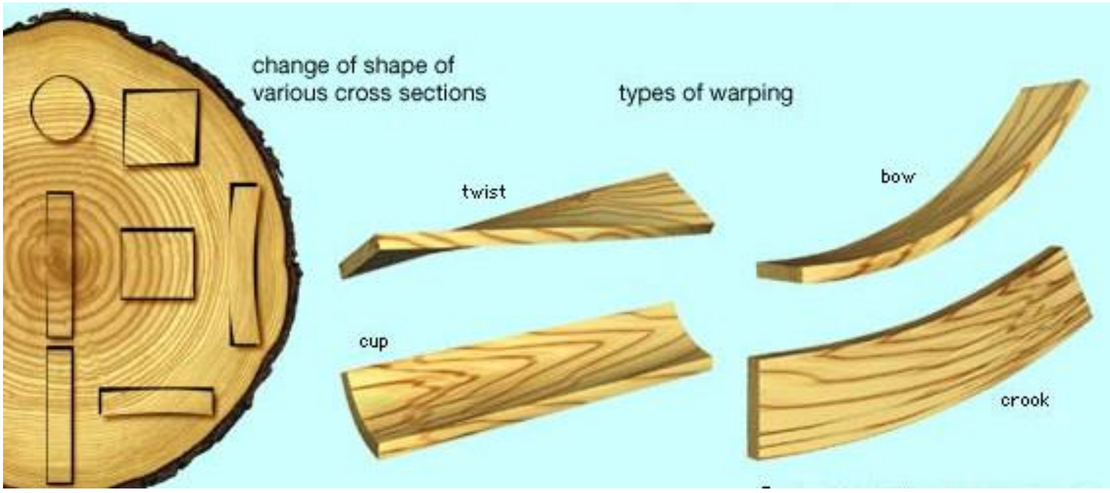



Figure 3.5 – Distortions of wood warping due to shrinkage and swelling (Original in colour)

Source: [8]

### 3.2.3. Thermal Expansion

Timber is expanded in all three directions when heated and vise versa. The reaction of moisture in timber affects the dimensional change and the amount depends mainly on temperature difference, moisture content and timber type.

Expansion happens due to usual thermal expansion when moist timber subjected to heating,. However the moisture content is reduced and timber get shrinked when timber is heated. Hence dimensional change occurrs due to these two opposite phenomena and according to the net result, either expansion or contraction is resulted. For an example, if moisture content is not below 3% or 4% the net dimensional change is shrinkage [4].

### 3.2.4. Density and Specific Gravity

Since a hydroscopic material, timber density significantly depends on the moisture content. Hence timber shows different density values for various moisture contents. Therefore density should be given with the moisture content, otherwise it becomes meaningless information. It is obvious that if the moisture content is high, the density value is increased.

Relative measurement of timber material content of a given timber sample is given by the specific gravity [4]. Specific gravity is a dimensionless ratio and normally it is calculated by using oven-dry weight and volume at 12% MC.

### 3.2.5. Electrical Resistance

Timber has high electrical resistance so that it is a superior electrical insulator. However, electrical conductivity is changed according to moisture content, temperature and grain direction. Since the conductivity differs according to grain direction, it varies in three directions. The conductivity in longitudinal direction is roughly twice of radial or tangential directions. Further, electrical conductivity is increased with increasing temperature as it twice by an increment of $10^oC$ [4].

### 3.2.6. Chemical Resistance

Timber is extremely resistant to various chemicals. It is an excellent advantage of many types of industrial applications. Especially timber has high resistance to mild acids (pH more than 2.0), acidic salt solutions, and corrosive agents than concrete or steel [4].

Liquid penetration of heart wood is less than sap wood. Hence the heart wood is more resistant to chemicals than sap wood. Furthermore, the timber types having less moisture content are more chemically resistant than moist timber types. Hence chemical resistant property should be considered in timber selection for chemical containing environments.

Many chemical treatments containing different oil types support to increase the chemical resistance. This oil penetrates into the cell voids and doesn't allow to penetrate any other chemical or any liquid [4]. Consequently the durability of timber and timber based products are increased.

## 3.3 Mechanical Properties

Reactions to the externally applied loads are described by the mechanical properties [9]. Mechanical performance of timber is very important in all applications such as constructions, industrial, furniture, etc. The mechanical properties are also different in three directions of timber as anisotropic properties. Normally there is a considerable difference of mechanical properties in longitudinal direction than tangential or radial directions.

Other than the directional properties, moisture content is a major factor which determines mechanical properties. Hence, mentioning of relevant moisture content is a must when stating the mechanical property values.

Elastic and strength properties including bending, compression and tension are the most important properties which are considered in many end uses.

### 3.3.1 Elastic Properties

If a material is fully elastic, all deformations are recoverable within the elastic limit. Then the initial shape of the material piece can be obtained, if the deformation is recoverable. However, almost all the elastic materials don't perform elastic properties fully.

Timber also shows a little deformation which is not recovered instantly when load is removed. Hence it's not a fully elastic material. The shape recovering time period depends on the timber type and the load. However the deformation is not much as in metals, plastics, etc.

### 3.3.2 Strength Properties

The strength properties of timber depend on various major factors such as timber type, environmental factors, age of trees, anatomical features, load type and loading duration. The strength properties along with the longitudinal are named as "parallel to grain properties". Since properties of tangential and radial directions are almost same, testing for both directions is not needed. However "parallel to grain" and "perpendicular to grain" in any direction properties are obtained since there is significant difference [4].

Many types of strength properties are considered in various timber applications as the way of loading is applied. Some of them are bending, compression, tension, shear and fatigue.

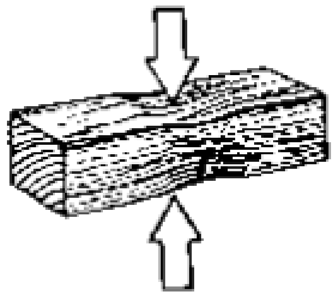
- **Compression**

When the compression force is applied along the longitudinal direction, the timber plank is subjected to the length reduction. Compressive strength is applied commonly in columns in the structures. There is a significant difference of compressive strength between parallel to grain and perpendicular to grain, since the load acting behaviour on grains is different.

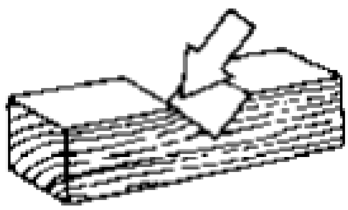
When load is applied parallel to grains, fibers start to fold within the cell wall. This phenomenon creates planes of weakness of the cell wall. Then cells fold into “S” shape if the load is increased continuously. This creates wrinkles on timber surface and it is able to be seen and failure is occurred finally [4].

The failure mechanism happens differently when the load is applied in the direction of perpendicular to grain. The strength is increased fairly since the voids are removed when the cells are distorted due to the load [4]. Then a failure is occurred due to reduction of load bearing capacity since cell wall is demolished. Figure 3.6 describes the methods of compressive force applied on a timber piece.

(a) Compression parallel to grain



(b) Compression perpendicular to grain



(c) Compression at an angle to grain

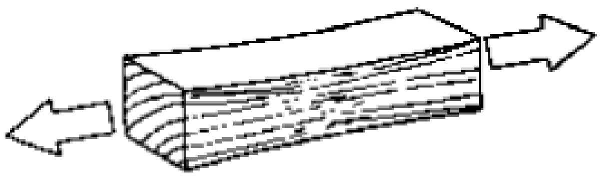
Figure 3.6 – Compression types in timber members

Source: [7]

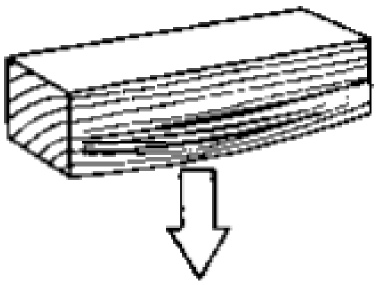
- **Tension**

Tensile strength of timber parallel to grain is very much higher than it is perpendicular to grains. Hence timber is used in many applications with other materials to bear the tensile forces such as girders. The cells slip on another neighbouring cell when the tensile force is applied. Then final failure occurs due to cell wall rupture with a little deformation [7].

Both in radial and tangential directions, tensile force acts perpendicular to the cells and the cracks occurred along the grains prior to the final failure [4]. Figure 3.7 describes the tensile force acts on both parallel to grain and perpendicular to grain directions. As shown in figure 3.7(b) the resistance to tensile force is very low so that it is not suitable to use timber in such situations.



(a) Tension in parallel to grain



(b) Tension in perpendicular to grain

Figure 3.7 – Tension in timber members

Source: [7]

- **Bending**

Timber is used for beams or rafters, where bending strength is applied. Figure 3.8 shows the loads acting at bending of a timber plank. The bending strength is less than its tension and more than compression because there is a difference of tensile and compressive strengths in longitudinal direction. It is compulsory to consider the bending strength in "parallel to grain "as beams or rafters are formed in longitudinal direction normally.

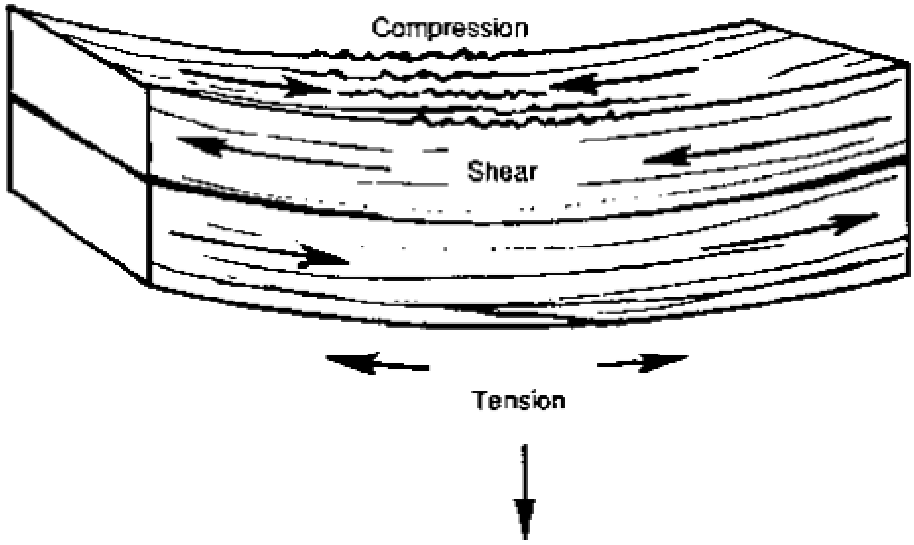


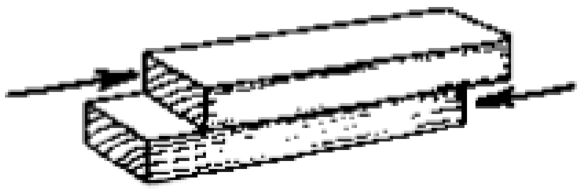

Figure 3.8 – Directions and types of forces acting on bending in longitudinal direction

Source: [7]

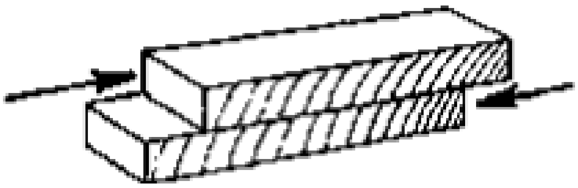
- **Shear**

Timber beam is subjected to compression force on one surface and tensile force on the opposite surface on service. Consequently, shearing is taken place through the beam. If this occurs in parallel to grain, it is called horizontal shear. The failure occurs due to slippage of cells and separation happens in parallel to grain direction.

On the other hand, if the force is applied in the direction of perpendicular to grain, it is called rolling shear [7]. The rolling shear is not considered in solid or laminated applications.



(a) Horizontal shear



(b) Rolling shear

Figure 3.9 – Shear in timber members

Source: [7]

- **Fatigue Resistance**

Fatigue resistance of timber is a considerable factor in some industrial applications where cyclic load is applied. Timber is quite resistant to fatigue as a fibrous material. The fatigue resistance of timber which is used in industrial applications is considerably higher than commonly used metals at comparable stress levels.

### 3.4 Factors Affecting Properties of Wood

Many researchers have conducted their research analysis by referring defect free parallel to grain specimens since properties of defect free timber is important especially in grading. However it doesn't mean that those properties represent structural timber with actual size and defects. Since there is a huge impact on properties by some anatomical and environmental factors, it is needed to follow standards, rules and regulations needs to follow in engineering designs and awareness as a must. The effects of such factors may lead to fail the structures even.

#### 3.4.1 Anatomical factors

##### 3.4.1.1 Knots

Knots disturb the original grain pattern and hence the properties are changed at the places where knots exist. Most of the times mechanical properties are reduced when there is a knot than defect free members. Especially this occurs in tensile strength and bending strength than in compressive strength.

##### 3.4.1.2 Grain Orientation

The mechanical properties directly depend on the grain orientation. There is a significant difference of mechanical properties between parallel to grain and perpendicular to grain directions. Further the failure mechanism also differs and as a result of that final failure occurrence also differ. Hence the consideration of grain orientation in practical applications is very essential.

#### 3.4.2 Environmental factors

##### 3.4.2.1 Moisture Content

Moisture content is a major factor of both mechanical and physical properties of timber. It is a must to mention the moisture content, for a given property value.

Generally mechanical properties are increased by reducing the moisture content from its fiber saturation point and it will be maximized within 10%-15% of MC.

### 3.4.2.2 Temperature

Mechanical properties of timber are reduced with increasing the temperature. Even though the effect of heating is reversed for low heating, it is permanent in elevated temperatures. This effect depends on moisture content, temperature difference, timber type and size, heating method, etc. However, timber should not be exposed to temperatures higher than $65^{O}$C as a general rule [4].

# 4. METHODOLOGY

There are many methods, rules and standards available in property based grading developments and maintaining of timber around the world. This grading can be carried out by two methods as machine based method and visual method. The mechanical properties can be obtained by the machine based method and visual method gives growth characteristics. Knots, cracks, wanes and fungal or insect attacks are few growth characteristics which affect the performance of timber. The rules and standards provide limitations on quantity, type, size and many more parameters to improve the smartness of the grading.

Correlation among mechanical strength properties of timber such as bending strength and stiffness can be achieved by machine based strength grading method. Two types of machines such as radiation type and bending type are used for strength based grading. The bending type is the most frequently used machine type and two different load applying methods are also undertaken.

- The first method is applying pre defined load to the timber sample and achieving the maximum deflection. This deflection provides a sign of strength of the sample and it gives an indication of the grade.

- In the second method load is applyed until a defined deflection is achieved. The required minimum load gives an indication of the grade of timber sample [10].

The machine based strength grading using bending type machine with maximum deflection was used in this research with small clear specimens.

Development of a grading system will facilitate to design projects based on the strength class, without considering specific timber type. Since the grading developed with groups of timber species, engineers can consider the relevant group with required strength level. If the strength based grading is to be used, the visual inspection of timber sections is a must, because the growth characteristics affect the properties directly.

Timber industry in Sri Lanka is a major actively functioning industrial sector at present including producing, importing and exporting different types of timber in large scale. However a comprehensive quality and identification data of these activities are not cannot be found easily specially at importing.

Hence the objective of this research was to estimate mechanical properties of Sri Lankan timber and to develop a grading system according to property classes and to find the relationship among the properties.

Previous researchers have found that the timber density is a very important indicator of various mechanical properties. Other than density, bending strength, stiffness, compressive strength and tensional strength are the significant mechanical properties of structural timber applications. Bending strength can be obtained by Modulus of Rupture (MOR) and the Modulus of Elasticity (MOE) which indicates the stiffness of timber specimens. Density, bending strength, stiffness and compressive strength (parallel to grain) are the only properties studied during this research due to difficulty of sample preparation for the tensile test.

Further, studs, vertical beams and many more applications were subjected to compression forces in construction applications. Hence, it is important to involve the assessment in compressive forces and the relationship with the density. The grouping of timber types with similar properties is very important in machine based strength grading

The State Timber Corporation has prepared a timber classification and is being updated annually. However this classification is done based on the commercial value and the availability of the timber and any scientific or technical logic is not considered. Hence there is no proper guide to select suitable timber type for specific tasks and as a result of that the proper usage of timber has been limited in Sri Lanka. Therefore the relationship between the State Timber Corporation’s classification and the property based grading was also developed while considering the commercial value under this research as it helps to engineers to select proper timber type.

## 4.1 Species and Resources Used in Testing

### 4.1.1 Machines

- **Universal Testing Machine**

Universal testing machine (OZ –UTM -100PC) is the machine used to perform the testing of small clear specimens. The maximum load can be applied by the machine is 100kN. Both 3 point bending test and compression parallel to grain test can be carried out by using the machine with standard size specimens according to British standard BS 373:1957(1999) [11]. Other than above tests, tension test, compression perpendicular to grain and many more tests of wood samples can be performed by this machine. The deflections and the corresponding loads were recorded and load deflection curves were prepared automatically by the computer connected to the machine.


Figure 4.1 – Universal testing machine (Original in colour)

**➢ Moisture tester**

The moisture tester (BD-2100) was used to verify the moisture content of all specimens to calculate the density at 15% moisture content. This tester can be used to measure moisture content from 6% to 40% of wood. The two probes should be pressed into the wood sample and instantaneously it displays the moisture content.

Figure 4.2 – Moisture tester (Original in colour)

➢ Scale

The digital scale was used to measure the weight of samples to calculate the density. The least count of the scale is 0.1 g.

Figure 4.3 – Digital scale (Original in colour)

- Oven

The oven was used at temperature of $102^0$C for several hours depending on the green moisture content to dry the samples till the moisture content was decreased up to 15% to calculate the density.

Figure 4.4 – Wood drying oven (Original in colour)

### 4.1.2 Specimens

Authentic specimens planted in Sri Lanka, were tested as listed in (table 4.1). Five samples of each type of timber were tested which were collected as whole island is covered. Small clear samples were prepared according to the B.S 373-1957(1999) – "Methods of testing small clear specimens of timber" [11]. A total of 25 specimens with 5 samples of each small clear wood specimen containing 375 samples were collected for all three tests. Huge attention was paid to minimize defects of the samples as clear specimen to minimize the false results.

The table 4.1 indicates that the scientific name of the specimens as well as the class, according to the State Timer Corporation timber classification. The list was sorted from highest class to lowest class of the classification. Since the Burma Teak and Oak are not much used in the Sri Lankan furniture and common applications, Timber Corporation has not included above timber in the classification. However, their contribution in heavy constructions and special applications is considerable so that Burma Teak and Oak were selected to test the properties.

Table 4.1 – Timber specimen list

| No | Common name | Scientific name [12] | Class(State Timber Corporation classification) [13] |
|---|---|---|---|
| 1 | Teak | *Tectona Grandis* | Supper Luxury Class |
| 2 | Milla | *Vitex Pinnata* | Luxury Class |
| 3 | Mahogani | *Swietenia Microphyla* | Luxury Class |
| 4 | Satin | *Chloroxylon Swietenia* | Luxury Class |
| 5 | Jak | *Artocarpus Heterophyllus* | Luxury Class |
| 6 | Halmilla | *Berrya Cordifolia* | Luxury Class |
| 7 | Burma Teak | *Tectona Grandis* | |
| 8 | Oak | *Quercus Ssp.* | |
| 9 | Kolon | *Adina Cardifolia* | Special Class Upper |
| 10 | Palu | *Manickara Hexandra* | Special Class Upper |
| 11 | Wewarana | *Alseodaphane Semecarpifolia* | Special Class Upper |
| 12 | Kohomba | *Azadirachta Indica* | Special Class Upper |
| 13 | Kumbuk | *Terminalia Arjuna* | Special Class |
| 14 | Micro | *Eucalyptus Microcorys* | Special Class |
| 15 | Tamerind | *Tamarindus Indica* | Special Class |
| 16 | Hora | *Dipterocarpus Zeylanicus* | Class I |
| 17 | Katakala | *Bridelia Retusa* | Class I |
| 18 | Madan | *Syzygium Cumini* | Class I |
| 19 | Panakka | *Pleurostylia Opposita* | Class I |
| 20 | Grandis | *Eucalyptus Grandis* | Class I |
| 21 | Ahala | *Cassia Fistula* | Class II |
| 22 | Ginisapu | *Michelia Champaca* | Class II |
| 23 | Domba | *Syzygium Gardneri* | Class II |
| 24 | Pinus | *Pinus Spp* | Class III |
| 25 | Lunumidella | *Melia Dulia* | Class III |

## 4.2 Methodology Undertaken

### 4.2.1 Sample Collection

The defect free heartwood samples were collected from State Timber Corporation deports located in many districts, private saw mills and Department of Government Factory. The collection was done to represent different types of timber as well as to cover all over the island. This collection was consisted of species grown only in up country, grown only in dry zone and grown in most of the areas of the country. Table 4:2 and figure 4:5 describes the locations from where samples were collected.

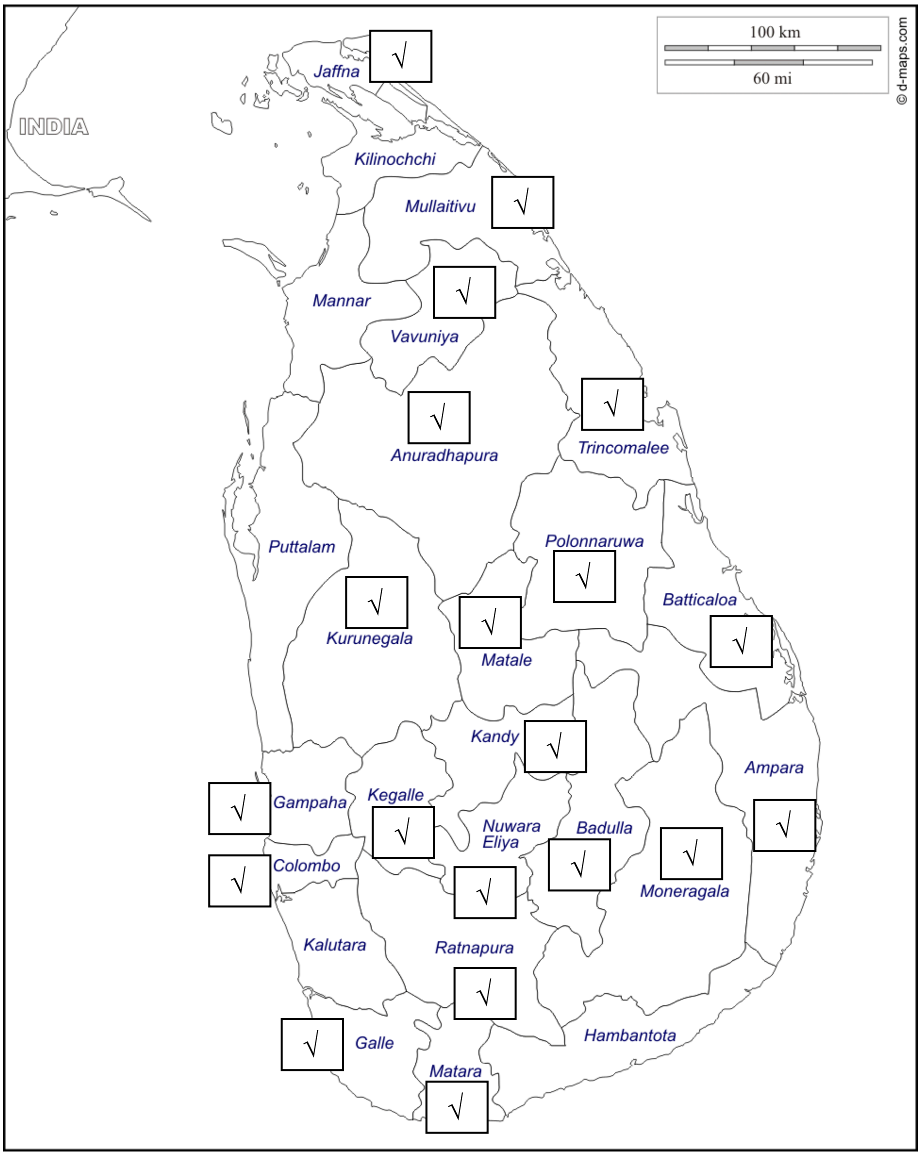



Figure 4.5 – Specimen collection distribution of Sri Lanka

Another consideration in selecting the specimens is the end use application. The set of specimens were consisted of the end-user applications such as heavy construction applications, furniture, light constructions and many miscellany applications according to the experience in the industry.

Table 4.2 – Sample collection distribution

| No | Common name | Sample collected district | | | | |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 |
| 1 | Teak | Ampara | Batticaloa | Vavuniya | A'pura | Kurunegala |
| 2 | Milla | Colombo | Colombo | Colombo | Colombo | Colombo |
| 3 | Mahogani | Kurunegala | Rathnapura | Kegalle | Gampaha | Kandy |
| 4 | Satin | Badulla | Monaragala | Ampara | Batticaloa | Batticaloa |
| 5 | Jak | Kegalle | Kurunegala | Rathnapura | Kandy | Mathale |
| 6 | Halmilla | P'aruwa | Trincomali | Kegalle | Kurunegala | Colombo |
| 7 | Burma Teak | Colombo | Colombo | Colombo | Colombo | Colombo |
| 8 | Oak | Colombo | Colombo | Colombo | N'eliya | N'eliya |
| 9 | Kolon | Colombo | Colombo | Colombo | Colombo | Colombo |
| 10 | Palu | A'pura | Kurunegala | P'aruwa | Ampara | Jaffna |
| 11 | Wewarana | Colombo | Colombo | Colombo | Colombo | Colombo |
| 12 | Kohomba | A'pura | P'aruwa | Kurunegala | Mullaitivu | Monaragala |
| 13 | Kumbuk | Gampaha | Ampara | Jaffna | A'pura | Kegalle |
| 14 | Micro | N'eliya | N'eliya | Badulla | Badulla | Badulla |
| 15 | Tamerind | A'pura | P'aruwa | Kegalle | Gampaha | Ampara |
| 16 | Hora | Rathnapura | Kegalle | Galle | Mathara | Gampaha |
| 17 | Katakala | Kegalle | Kurunegala | Monaragala | Badulla | Badulla |
| 18 | Madan | Colombo | Colombo | Colombo | Colombo | Colombo |
| 19 | Panakka | Colombo | Colombo | Colombo | Colombo | Colombo |
| 20 | Grandis | N'eliya | N'eliya | Badulla | Kandy | Mathale |
| 21 | Ahala | A'pura | P'aruwa | Kegalle | Kurunegala | Kandy |
| 22 | Ginisapu | Kegalle | Kegalle | Colombo | Colombo | Kurunegala |
| 23 | Domba | Galle | Colombo | Colombo | Mathara | Mathara |
| 24 | Pinus | Kandy | Kandy | N'eliya | N'eliya | Badulla |
| 25 | Lunumidella | Kegalle | Kegalle | Rathnapura | Rathnapura | Kandy |

### 4.2.2 Sample Preparation and Testing

All the samples were prepared according to B.S 373-1957(1999) [11] at the Department of Government Factory carpentry work shop. Table 4.3 shows the sizes of samples of each test. The defects free samples were prepared as the clear small samples to minimize the false happen in readings. All the samples were cut from the heart wood of the specimens and hence the results are valid for the heart wood of the specimens.

Table 4.3 – Standard sample sizes

| Test | Sample size | | |
|---|---|---|---|
| | Length/mm | Width/mm | Depth/mm |
| Density | 75 | 50 | 25 |
| 3 point bending | 300 | 20 | 20 |
| Compression parallel to grain | 60 | 20 | 20 |

#### 4.2.2.1 Three Point Bending Test

As the first part of the research, 3 point bending test was carried out by applying the centre point loading to the specimen. Amount of applied load and vertical mid span deflection was measured during the test. Timber samples of 20mm×20mm×300mm were tested according to the standard with span of supports were 280 mm as illustrated in figure 4.6.

The load was applied by Universal Testing Machine (UTM) at the rate of 2mm per minute up to ultimate failure was occured as shown in Figure 4.7. Obtained test results were used to compute both Modulus of Elasticity (MOE) and Modulus of Rupture (MOR) by using below equations.

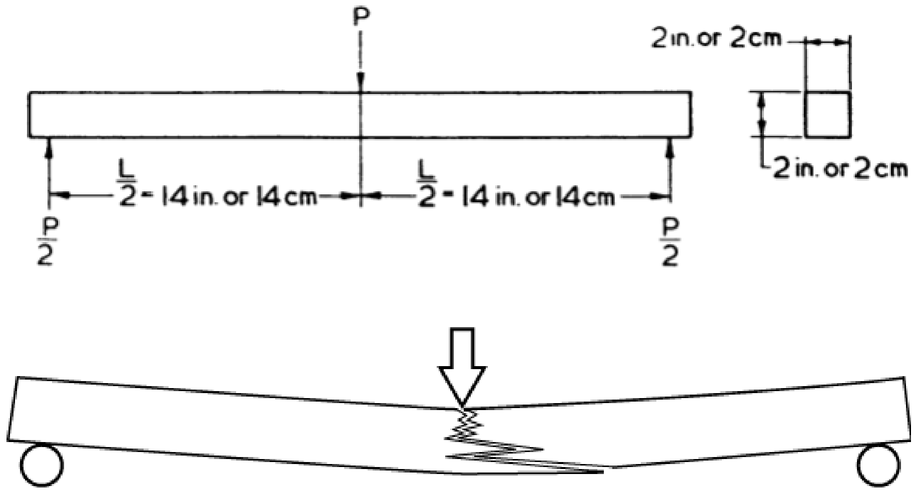



Figure 4.6 – Load applying in 3 point bending test [11]

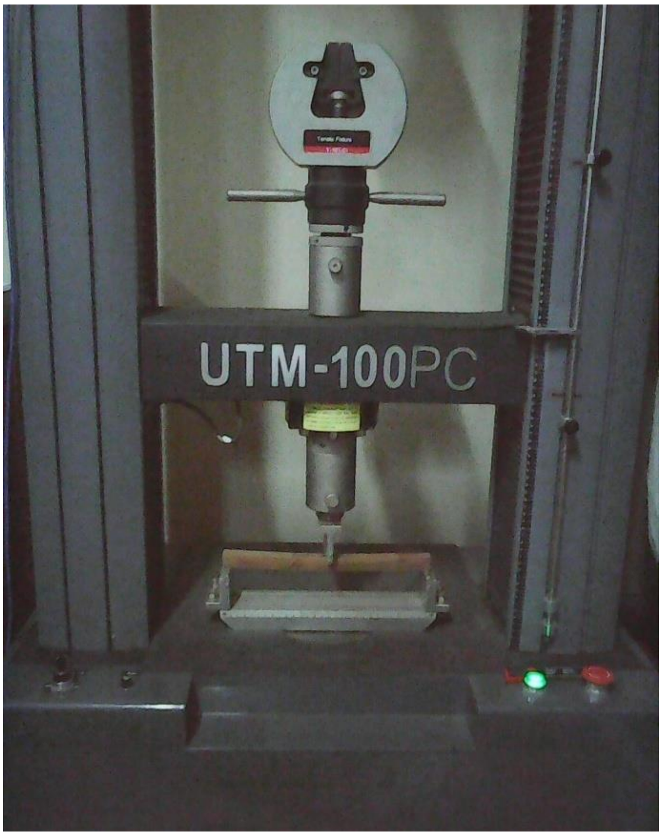



Figure 4.7 - Three point bending test through universal testing machine (Original in colour)

$$MOR = \frac{3 \times P \times L}{2 \times b \times h^2} \quad (2)$$

MOR – Modulus of Rupture in $N/mm^2$

P – Maximum load at rupture in N

L – Span of testing in mm

b – Width of specimen in mm

h – Depth of specimen in mm

$$MOE = \frac{P' \times L^3}{4 \times \Delta' \times b \times h^3} \quad (3)$$

MOE – Modulus of Elasticity in $N/mm^2$

P’ – Load at limit of proportionality in N

L – Span of testing in mm

Δ' – Deflection at mid length at limit of proportionality in mm

b – Width of specimen in mm

h – Depth of specimen in mm

Bending strength which is generally called specimen’s strength is measured by Modulus of Rupture (MOR) and it provides a measurement of a specimen’s strength before the rupture. However MOR is not an indication of its ultimate strength but it is a measure of deflection.

Stiffness of timber is indicated by MOE (Modulus of Elasticity) and it is very important parameter to determine the deflection of timber beams which is applied in the construction industry.

#### 4.2.2.2 Compression Parallel to Grain Test

The second part of the research was undertaking the compression parallel to grain test. This test was also carried out by same Universal testing machine using timber sample of 2×2 cm (cross section) and 6 cm long specimen as figure 4.8 illustrates below.


Figure 4.8 – Form of test pieces for compression parallel to grain test [11]

Test results were used to calculate Compressive stress at limit of proportionality and Compressive stress at maximum load by using below equations.

$$\text{Compressive stress at limit of proportionality} = \frac{P'}{A} \qquad (4)$$

Compressive stress at limit of proportionality in $N/mm^2$

P' – Load at limit of proportionality in N

A – Cross sectional area in $mm^2$

$$\text{Compressive stress at maximum load} = \frac{P}{A} \qquad (5)$$

Compressive stress at maximum load in $N/mm^2$

P – Maximum crushing load in N

A – Cross sectional area in $mm^2$

The sample was set to the bottom plungers of universal testing machine and the compression load was applied as below (figure 4.9 and schematic diagram of figure 4.10).

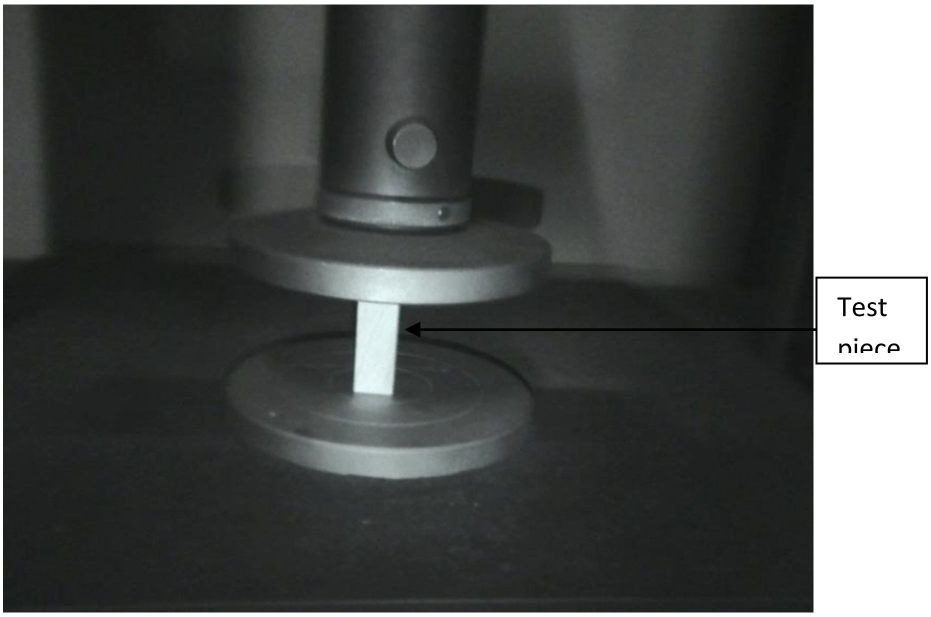



Figure 4.9 – Test piece under compression load parallel to grain through UTM (Original in colour)

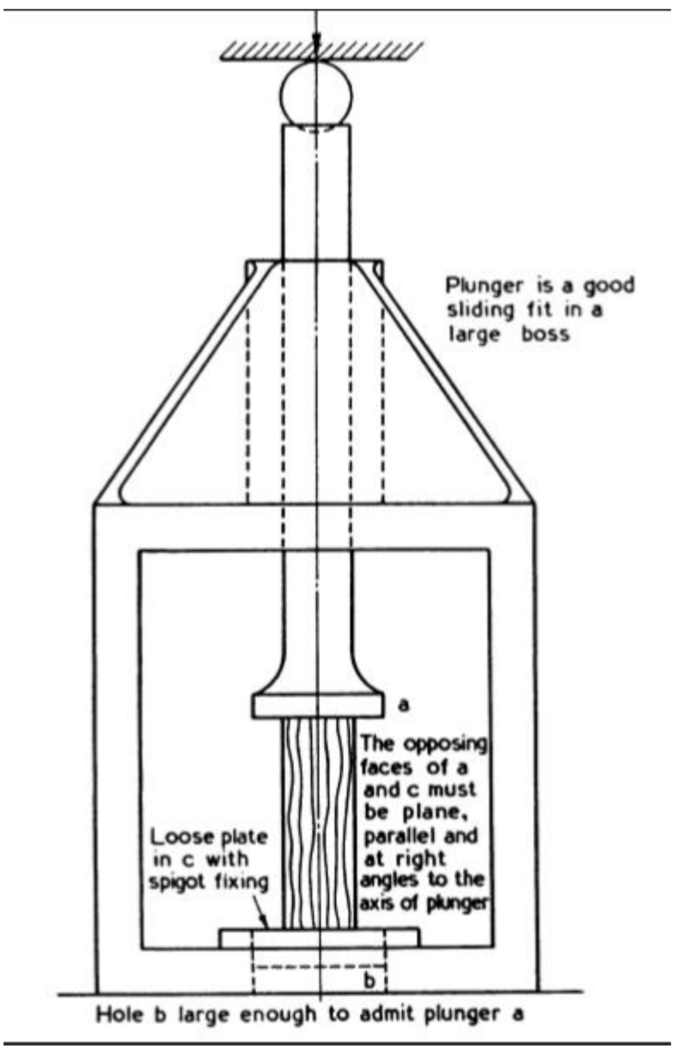



Figure 4.10 – Schematic diagram of UTM of compression test parallel to grain [11]

#### 4.2.2.3 Density

Timber decay begins when its' moisture level is greater than 20% with other favourable environmental conditions [12]. Hence, seasoning is applied in most applications at 15% moisture content in Sri Lanka according to the average temperature and humidity of the island. Further early researches mentions that the strength of timber is maximized at about 10 to 15% moisture content [12]. Considering these two factors conducted above tests and derivations of density were obtained at the moisture content of 15%. The moisture tester was used to verify the moisture content as below figure 4.11.

Figure 4.11 – Moisture content testing (Original in colour)

Timber density was determined considering the oven-dry weight and moist volume at around 15% moisture content by the equation below.

$$\text{Density} = \frac{W}{V} \qquad (6)$$

Density in $Kg/m^3$

W – Weight of sample at 15% moisture content in Kg

V – Volume of sample in $m^3$

### 4.2.3 Tabulating and Analyzing Data

The densities of all samples were computed and average density of specimens were calculated.

The load into deflection curve which was generated while the load was applied by universal testing machine was used to calculate MOR, MOE and compressive strength values of both tests. Achieved five individual figures were averaged to get the relevant values of specimens.

The specimens have the standard deviation less than 50% of average value was only used to analyse the data.

The mechanical properties of specimens were obtained and the data received from bending test and compression parallel to grain test were analysed with the density, to find interrelationship among properties.

The difference between two MOE values in bending and compression was analysed as wood is anisotropic material.

Twenty five specimens were graded into classes according to properties for easy end user applications. Further the results achieved were compared with the classification of State Timber Corporation to provide cost to be spent by the end user.

# 5. RESULTS AND DISCUSSION

This section of the report presents the results achieved and discussions of the experimental works carried out on the mechanical properties of the selected 25 timber species with 5 samples from each specimen. The timber properties considered include density, bending strength and compressive strength parallel to grain. The number of samples was not the same as five for all specimens because very few samples had defects. Therefore test results of some samples were neglected as one sample from Satin in 3 point bending test, two samples from Domba and one sample from Micro in compression test.

The load into displacement and load into deformation curves were generated while the load was applied to the test piece in both bending and compressive strength tests. Figure 5.1 and 5.2 shows two curves generated in bending and compression tests respectively.

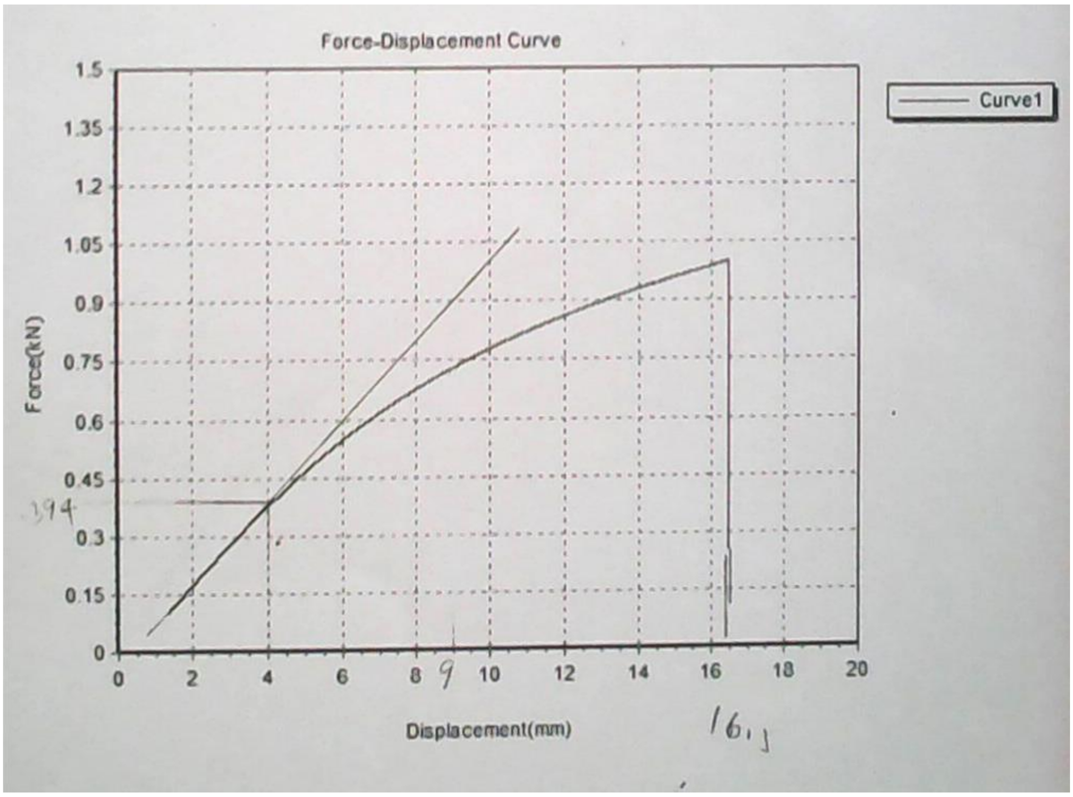



Figure 5.1 – Force into displacement curve in 3 point bending test

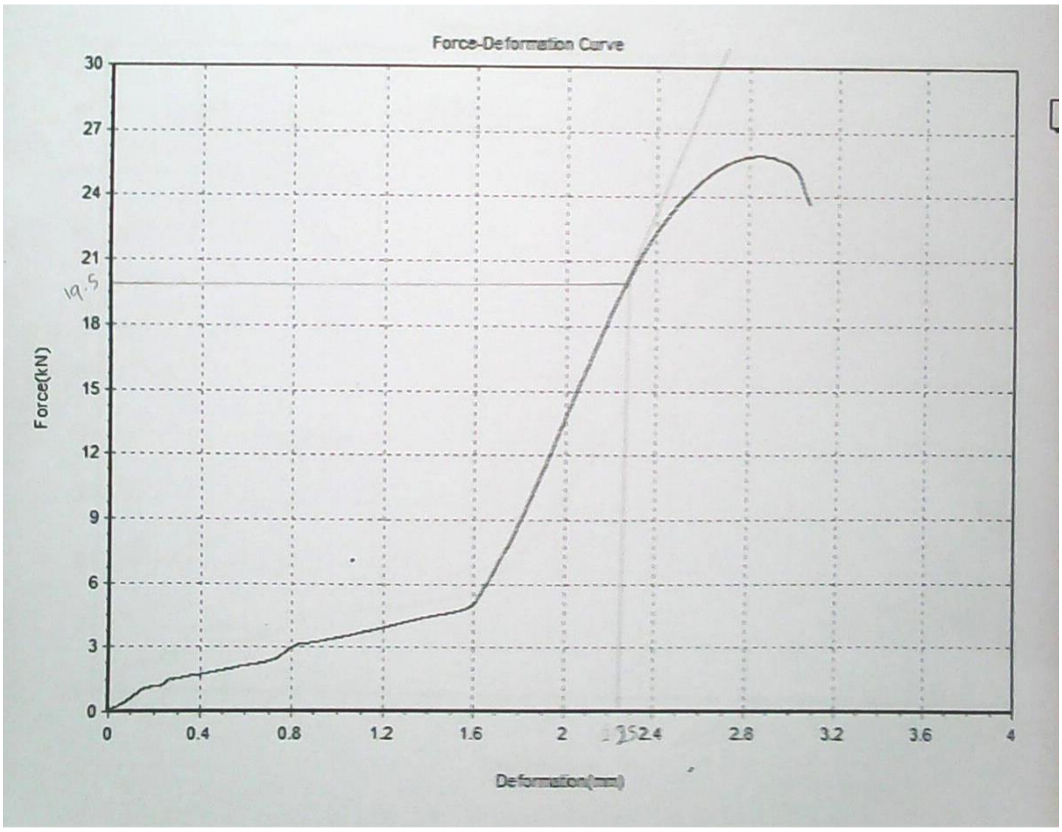



Figure 5.2 – Force into displacement curve in compression parallel to grain test

The maximum force at rupture is given by the software with the above curve. The force and the displacement or deformations at the elastic limit were obtained manually by the curve.

Substituting the above data to the relevant equations, MOR and MOE were calculated by the 3 point bending test to find the strength and the stiffness of wood specimens. Compressive strength at elastic limit and in rupture were calculated to obtain the compressive strength and obtained results including timber density, are presented in Table 5.1. The summary was prepared to identify the relationship of mechanical properties with density.

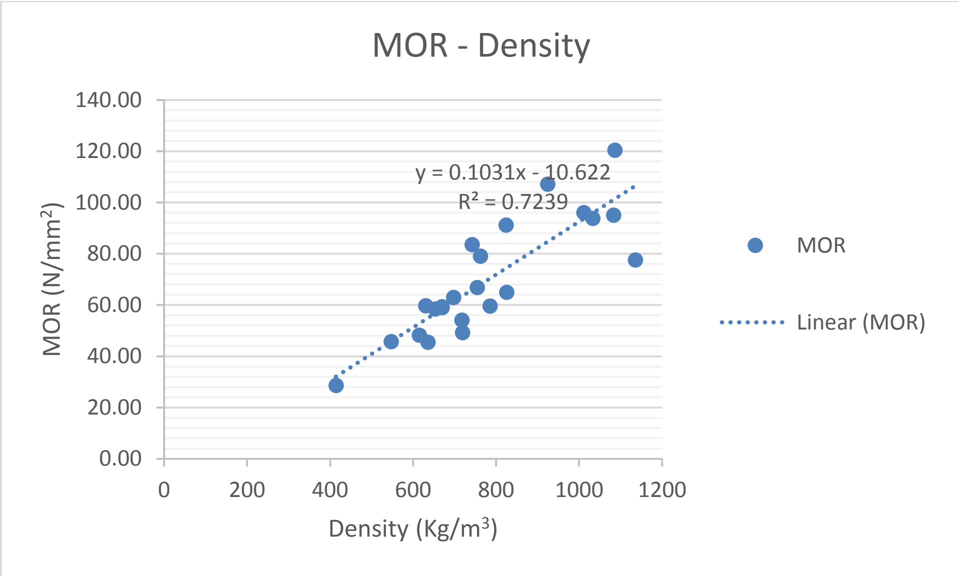
The obtained results are also comparable with many other research achievements in the relationship between timber density and mechanical properties which were tested in this research.

Table 5.1 – Summary of results

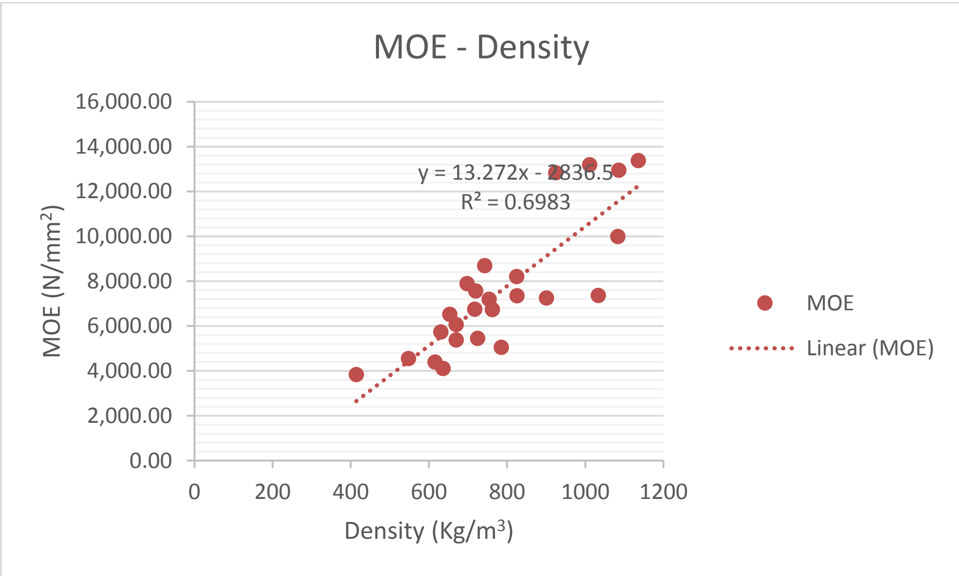
| No | Type | Average values | | | | |
|---|---|---|---|---|---|---|
| | | | 3 point bending test | | compression parallel to grain test | |
| | | Density (Kg/m$^3$) | MOR (N/mm$^2$) | MOE (N/mm$^2$) | Comp. at elastic limit (N/mm$^2$) | Comp. at rupture (N/mm$^2$) |
| 1 | Palu | 1,134.93 | 77.53 | 13,383.95 | 55.20 | 71.30 |
| 2 | Tamarind | 1,132.59 | 93.80 | 7,373.37 | 51.13 | 58.19 |
| 3 | Ehala | 1,083.31 | 95.03 | 10,003.93 | 59.08 | 81.50 |
| 4 | Satin | 1,010.77 | 123.73 | 13,190.72 | 45.19 | 64.05 |
| 5 | Milla | 900.05 | 74.76* | 7,258.26 | 45.10 | 57.75 |
| 6 | Micro | 888.96 | 120.40 | 12,957.78 | 53.29 | 64.08 |
| 7 | Panakka | 826.24 | 45.94* | 5,462.50 | 20.19 | 28.63 |
| 8 | Kohomba | 824.96 | 64.89 | 7,359.58 | 40.00 | 49.60 |
| 9 | Halmilla | 824.32 | 91.14 | 8,217.18 | 37.50 | 48.45 |
| 10 | Hora | 821.76 | 107.10 | 12,832.95 | 44.91 | 58.44 |
| 11 | Kumbuk | 785.07 | 59.54 | 5,052.70 | 34.56 | 45.80 |
| 12 | Berma Teak | 759.68 | 79.01 | 6,746.15 | 35.65 | 44.45 |
| 13 | Wewarana | 754.35 | 66.78 | 7,205.10 | 35.25 | 41.90 |
| 14 | Teak | 741.76 | 83.58 | 8,699.70 | 45.94 | 57.00 |
| 15 | Ketakala | 718.51 | 49.18 | 7,564.84 | 22.00 | 27.00 |
| 16 | Madan | 717.01 | 54.08 | 6,752.66 | 25.13 | 32.00 |
| 17 | Grandis | 696.96 | 62.90 | 7,894.00 | 47.23 | 57.75 |
| 18 | Mahogani | 669.44 | 58.91 | 6,072.26 | 29.88 | 37.50 |
| 19 | Jak | 669.23 | 59.33 | 5,388.82 | 42.75 | 54.25 |
| 20 | Pinus | 653.44 | 58.38 | 6,534.17 | 49.38 | 68.44 |
| 21 | Domba | 635.09 | 45.41 | 4,116.34 | 22.79 | 29.75 |
| 22 | Kolon | 629.76 | 59.64 | 5,748.01 | 35.13 | 43.31 |
| 23 | Oak | 615.25 | 48.13 | 4,406.33 | 26.75 | 33.95 |
| 24 | Ginisapu | 546.77 | 45.68 | 4,553.94 | 23.98 | 29.45 |
| 25 | Lunumidella | 413.87 | 28.53 | 3,845.58 | 14.19 | 17.44 |

* – The standard deviation of average is more than 50% of average.

The relationship of mechanical properties vs timber density is presented in Figure 5.3 with the regression equations. The obtained results confirm that timber density has a strong linear relationship with MOR ($R^2$ = 0.723) and MOE ($R^2$ = 0.698).



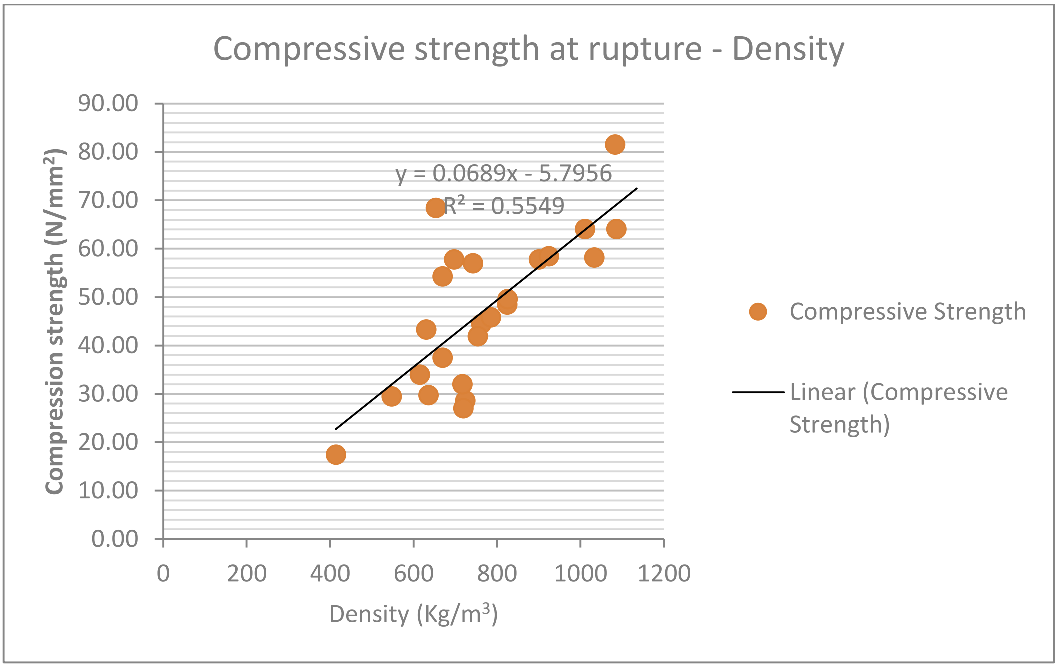

(a)



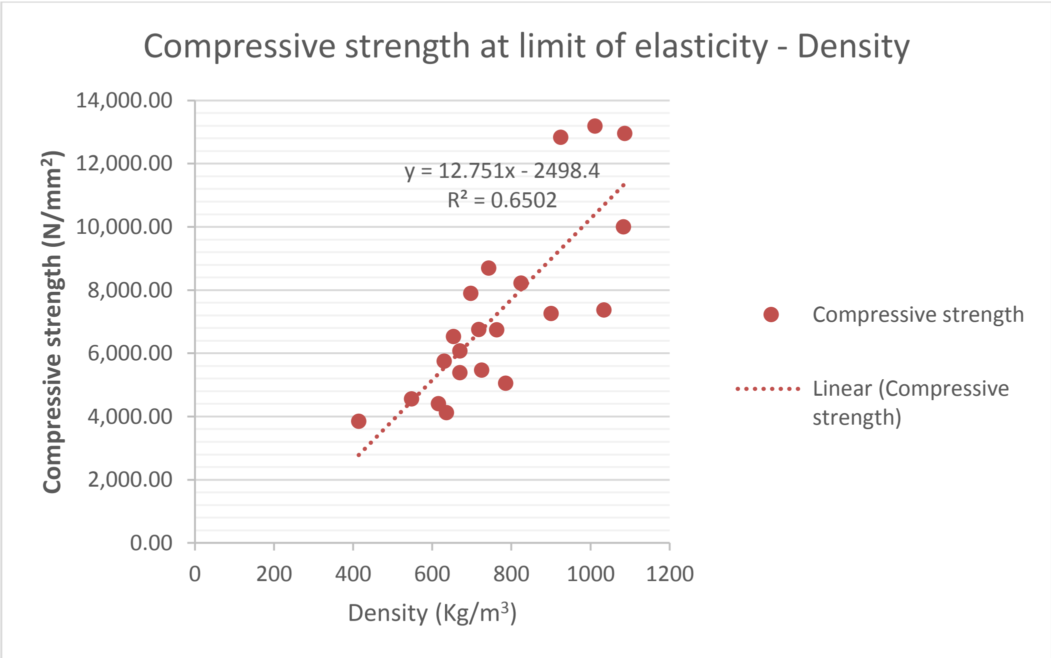

(b)

Figure 5.3 - Relationship between (a) wood density & MOR and (b) wood density & MOE

Further the relationship between compressive strength and density was also obtained. The results show in the graphical representation of figure 5.4. The regression equations show that the relationship is not strong as MOR and MOE. However the compressive strength also can be predicted by density.




(a)




(b)

Figure 5.4 - Relationship between (a) wood density and compressive strength at rupture and (b) wood density and compressive strength at elasticity limit

The relationship between bending strength values (MOR) and stiffness (MOE) was obtained considering all the sample details. The value of bending strength gives an estimate of the stiffness as in figure 5.5. Reliance is therefore placed on a good correlation between stiffness, and bending strength, ($R^2$ = 0.794).

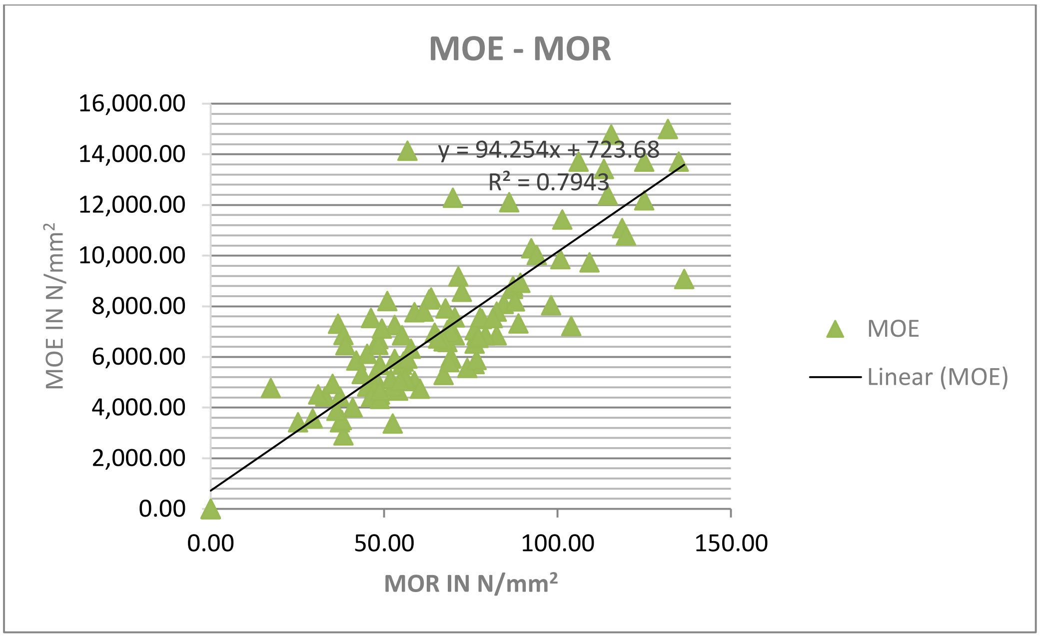



Figure 5.5 – Correlation between stiffness and bending strength

Table 5.2 shows that any relationship could not be found among the mechanical properties tested and the State Timber Corporation classification. Since there is a strong relationship among density, MOR and MOE, only density and the compression strength at rupture is considered.

It can be understood that, when popular or well known timber is not available or not affordable due to high cost, another timber species can be sought often on the basis of comparability. In this timber selection process, the cost involvement is often considerable and users may be reluctant to take risk of recommending uncommon timber types. It can be altered by providing guidance on property needs for the suitability to end-use.

Table 5.2 – Relationship between properties and STC classification

| No | Type | Density (Kg/m$^3$) | comp. @ rupture (N/mm$^2$) | STC Class [13] |
|---|---|---|---|---|
| 1 | Palu | 1,134.93 | 71.30 | Special Class Upper |
| 2 | Tamarind | 1,132.59 | 58.19 | Special Class |
| 3 | Ehala | 1,083.31 | 81.50 | Class II |
| 4 | Satin | 1,010.77 | 64.05 | Luxury Class |
| 5 | Milla | 900.05 | 57.75 | Luxury Class |
| 6 | Micro | 888.96 | 64.08 | Special Class |
| 7 | Panakka | 826.24 | 28.63 | Class I |
| 8 | Kohomba | 824.96 | 49.60 | Special Class Upper |
| 9 | Halmilla | 824.32 | 48.45 | Luxury Class |
| 10 | Hora | 821.76 | 58.44 | Class I |
| 11 | Kumbuk | 785.07 | 45.80 | Special Class |
| 12 | Berma Teak | 759.68 | 44.45 | |
| 13 | Wewarana | 754.35 | 41.90 | Special Class Upper |
| 14 | Teak | 741.76 | 57.00 | Supper Luxury Class |
| 15 | Ketakala | 718.51 | 27.00 | Class I |
| 16 | Madan | 717.01 | 32.00 | Class I |
| 17 | Grandis | 696.96 | 57.75 | Class I |
| 18 | Mahogani | 669.44 | 37.50 | Luxury Class |
| 19 | Jak | 669.23 | 54.25 | Luxury Class |
| 20 | Pinus | 653.44 | 68.44 | Class III |
| 21 | Domba | 635.09 | 29.75 | Class II |
| 22 | Kolon | 629.76 | 43.31 | Special Class Upper |
| 23 | Oak | 615.25 | 33.95 | |
| 24 | Ginisapu | 546.77 | 29.45 | Class II |
| 25 | Lunumidella | 413.87 | 17.44 | Class III |

The end-use property classification provides the means to make an objective assessment of the suitability for a particular purpose of timber use. Correct use of timber always increases the life time of the final product, whether it is constructional application furniture or any craft work. This research provides most important wood properties facilitating to select timber species according to end-use or end use requirement of twenty five Sri Lankan timber species.

In general, the proposed property classification in this research can be referred in building construction, furniture and joinery, light construction and many miscellaneous uses according to the application.

Very high density timber such as Palu, Micro, Ahala, Tamarind and Satin studied in this research work are often chosen for heavy construction work due to not only its high strength properties but also good performance experience in use. It was found that timber density of Palu, Micro, Ahala, Tamarind and Satin are 1133 $kgm^{-3}$,1085.8 $kgm^{-3}$, 1081.5 $kgm^{-3}$, 1033 $kgm^{-3}$and 1009.4 $kgm^{-3}$ at moisture content 15% respectively. In addition, above four species showed high values of mechanical properties such as modulus elasticity, modulus of rapture and compression parallel to grain (Table 5.1).

End-use property classification for furniture and joinery category which involves in door and window joinery and frames, flooring, cabinet works etc. can be derived for the construction timber category as mentioned earlier. It was found that all the species can be categorised as medium to high density such as Teak, Mahogani, Jak and Kumbuk when variations of timber density of furniture and joinery category were analysed. This group of timber has somewhat lower density than construction timber category as results in (Table 5.1).

Lunumidella is one of most popular timber species among many timber varieties used for light construction work in Sri Lanka.It was possible to list out major property requirements and to identify the levels for end-use property classification by recognising these wood properties. According to (Table 5.1) all the above timber species belong to light to medium density categories have low mechanical properties.

Finally, if there is a timber property classification, required technical information can be obtained for engineers as the end uses and the timber properties are compatible. Subsequently timber suppliers can easily quote and supply the most suitable timber which is complying its technical performance with the requirement of end-use with low cost.

According to the results obtained and the industrial experience, proposed timber grading in this research can be done in four levels as table 5.3.

Table 5.3 – Sri Lankan timber grading levels

| Grading level | Density ($Kg/m^3$) | Bending strength(MOR) ($N/mm^2$) | Stiffness (MOE) ($N/mm^2$) | Compressive strength(at rupture) ($N/mm^2$) |
|---|---|---|---|---|
| Super Grade | >840 | >100 | >10,000 | >60 |
| High Grade | 640-840 | 75-100 | 7,000-10,000 | 50-60 |
| Medium Grade | 500-640 | 50-75 | 5,500-7,000 | 35-50 |
| Low Grade | <500 | <50 | <5,500 | <35 |

Even though the testing method of grading using small clear specimens according to the standard is not perfectly practical situation, it can be referred to characterize the timber properties since this method is the basis of the actual structural stresses of timbers. However testing of structural size timber will provide more reliable results with reference to the actual condition in application with defects such as knots, sap wood, bark pockets etc. However, performing large structural size testing of Sri Lankan timbers is extremely difficult due to high cost and long time requirement.

As a basis, the grading can be developed by using the small clear specimens as the research followed. The timber types which were tested in this research are classified under proposed four grading levels according to four properties (Table 5.4, Table 5.5, Table 5.6, and Table 5.7).

Table 5.4 - Grading according to density

| Grading level | Timber type |
|---|---|
| Super Grade<br>>840 | Palu, Tamarind, Ehala, Satin, Milla, Micro |
| High Grade<br>640-840 | Panakka, Kohomba, Halmilla, Hora, Kumbuk, Burma Teak, Wewarana, Teak, Ketakala, Madan, Grandis, Mahogani, Jak, Pinus |
| Medium Grade<br>500-640 | Domba, Kolon, Oak, Ginisapu |
| Low Grade<br><500 | Lunumidella |

Table 5.5 - Grading according to bending strength

| Grading level | Timber type |
|---|---|
| Super Grade<br>>100 | Satin, Micro, Hora |
| High Grade<br>75-100 | Ehala, Tamarind, Halmilla, Teak, Burma Teak, Palu |
| Medium Grade<br>50-75 | Milla, Wewarana, Kohomba, Grandis, Kolon, Kumbuk, Jak, Mahogani, Pinus, Madan |
| Low Grade<br><50 | Ketakala, Oak, Panakka, Ginisapu, Domba, Lunumidella |

Table 5.6 - Grading according to stiffness

| Grading level | Timber type |
|---|---|
| Super Grade<br>>10,100 | Palu, Satin, Micro, Hora, Ehala |
| High Grade<br>7,000-10,000 | Teak, Halmilla, Grandis, Ketakala, Tamarind, Kohomba, Milla, Wewarana |
| Medium Grade<br>5,500-7,000 | Madan, Burma Teak, Pinus, Mahogani, Kolon |
| Low Grade<br><5,500 | Panakka, Jak, Kumbuk, Ginisapu, Oak, Domba, Lunumidella |

Table 5.7 - Grading according to compressive strength

| Grading level | Timber type |
|---|---|
| Super Grade<br>>60 | Ehala, Palu, Pinus, Micro, Satin |
| High Grade<br>50-60 | Hora, Tamarind, Grandis, Milla, Teak, Jak |
| Medium Grade<br>35-50 | Kohomba, Halmilla, Kumbuk, Burma Teak, Kolon, Wewarana, Mahogani, |
| Low Grade<br><35 | Oak, Madan, Domba, Ginisapu, Panakka, Ketakala, Lunumidella |

# 6. CONCLUSION

The research will be helpful to develop standards to Sri Lankan timber species and to find the interrelations between international standards and requirements of the standards. This will help to improve the sustainability of timber industry and forest coverage in Sri Lanka with better quality management.

Allocating the timber specimens into grading according to mechanical properties and density confirms high strength properties as well as superior performance of Sri Lankan uncommon timber species with considerably low cost.

It was observed that timber density has a good positive relationship with strength and stiffness properties. Hence it implies that there is a possibility to improve wood density, strength and stiffness properties of Sri Lankan timber simultaneously. Therefore, controlling one parameter will have a good positive impact on other parameters of Sri Lankan timber. Since achieved results are based on small clear specimens those can be used as groundwork results and it will provide a basis for further improvements for a wealthy grading of Sri Lankan timber.

Variations in strength properties are arising due to age-dependence and environmentally responsiveness. Therefore it is suggested to conduct more research work considering above factors based on more timber samples representing the entire timber population.

The proposed property grading according to the property in this research can be categorised as (i.) super grade, (ii.) high grade (iii.) medium grade and (iv.) low grade. It is an imperative exercise to find out the most influential wood properties for each grade of end use property grading given here with.

These findings of the relationship between density and mechanical properties might be used to define the standard for quality requirement and quality level for end-use property classification for construction timber. In this grading, some more important quality requirements such as seasoning defects, dimensional movement etc. can be included as further improvement. Further it is recommended that preferable property level of timber for major end-uses such as rafters, beams, columns, flooring, joinery etc should be studied in future research.

According to this finding, property requirements and level for the end-use classification for construction, furniture and joinery might be derived from these research findings and further development can be made with increased number of timber species as well as number of samples.

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# Appendix A – Data - Three point bending test

# Appendix B – Data - Compression parallel to grain test

## Appendix C – Data- Density