EFFECT OF MOISTURE ON STRENGTH OF FOUR DIFFERENT WOOD SPECIES COMMONLY USED IN NORTH CYPRUS

A THESIS SUBMITED TO

THE GRADUATE SCHOOL OF APPLIED SCIENCES

OF

NEAR EAST UNIVERSITY

By

MUSA SALIHU ABUBAKAR

In Partial Fulfillment of the Requirements for
The Degree of Master of Science
In
Civil Engineering

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Musa Salihu Abubakar: Effect of Moisture on Strength of Four Different Wood Species Commonly Used in North Cyprus

Approval of Director of Graduate School of Applied Sciences

Prof. Dr. İlkay SALİHOĞLU

We certify this thesis is satisfactory for the award of the degree of Masters of Science in Civil Engineering

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I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results to this work.

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Date:

ACKNOWLEDGEMENT

All praise is to Almighty Allah (SWT), blessing and bounty mercy be upon to our noble Prophet Muhammad (SAW), his companions, household and those who follow his footstep till to the day of resurrection.

I will like to shear my warmest happiness and special thanks to my able supervisor, my mentor who stay behind my study in North Cyprus, the person of Prof. Dr. Ata ATUN, he is always with me when l need any assistant, regarding my course work, and my final year Dissertation, may Almighty Allah reward him abundantly.

My appreciation goes to all my course lecturers and staffs of Civil Engineering Department Near East University, especially Assoc. Prof. Dr Pinar AKPINAR, Assoc. Prof. Dr. Rifat Resatoglu and other for their own support and advices within the years of my study. I also express my sincere appreciation to the Civil Engineering Laboratory coordinator, Mustafa Turk, who help me and give tremendous support during my Laboratory experiment.

I will like also to thank my parents, brothers, and all my friends for their good contribution in one way or the other. May Allah reward them with Jannah.

Special thanks goes to Kano State Government for awarding me full scholarship to further my study abroad, may Almighty Allah bring peace and tranquility to my able state and Nigeria at large.

Dedicated to my beloved brother Abubakar Salihu (Ababa) who has been always with me.....

ABSTRACT

The effect of moisture on strength properties of four different wood species (Douglas fir, Pine, Redwood and Red oak) commonly used in North Cyprus was examined. The compressive strength of woods was determined parallel to grain using compression test. The critical load, compressive and specific gravity were also determined parallel to the wood grain, after oven drying of wood species for about 24 hours and soaking in water for various amount of time (one part for non soaking, and the other part, for; 2.4 hours, 24 hours and 8 days soakings) respectively.

Among the wood studied, three are softwoods (Douglas fir, Red wood and Pine), and one is hardwood (Red Oak). The mechanical strength performance of the softwood and hardwood are almost going the same, the maximum mechanical performance were observed from Redwood (L, 27.9 KN, and CS=362.6kPa) at non-soaking, while at 8 days soaking, Red Oak was observed to have maximum strength performance (L=9.5KN and CS=116kPa) than others. It was also observed that the strength for compressive strength of the tested woods was reduced as the soaking hours of woods increases.

It is concluded that Redwood shall be used where there is no moisture than other woods studied, and used Red Oak where there is moisture than other wood studied. But both their strengths are decreasing with the increase of moisture content.

Keywords: *wood, Timber, Soaking, Moisture Content, Compression Strength, Modulus of elasticity, critical load*

ÖZET

Dört farklı ağaç türlerinin nem etkisi üzerindeki mukavemet özellikleri (Douglas köknar, çam, kırmızı ahşap ve Kızıl meşe) genellikle Kuzey Kıbrıs'ta kullanılan ağaç türleri incelenmiştir. Ahşap basınç dayanımı ,parallel bir şekilde ahşap numuneye compressıon testi uygulayarak hesaplanır . Kritik yük, elastisite ve özgül ağırlık, bu test ile bulunabilir; aynı zamanda, çeşitli zaman aralığı için su içinde yaklaşık 24 saat ıslatılması (ıslatılmayan ağaç türlerinin fırında kurutulduktan sonra, çeşitli zaman aralığında ıslatılması, 2.4 saat, 24 saat ve 8 gün) sırasıyla daha sonrada compressıon makinesinden basınç dayanımları bulunur.

Ahşaplar arasında 3 tane yumuşak ahşap, (Douglas köknar, Kırmızı ahşap ve Çam), ve 1 sert ahşap (Kızıl Meşe) 'dir. Yumuşak ahşap ve sert ahşapın mekanik dayanım performansı hemen hemen aynı gidiyor, maksimum mekanik performans kırmızı ahşapda gözlendi (L, 27.9 KN, ve CS = 362.6kPa) ıslak olmayan , 8 günde ıslatılmış Red Oak diğerlerinden daha fazla maksimum gücü performansı (L=9.5KN ve CS = 116kPa) olduğu gözlendi. Ayrıca, dayanımda gözlemlenmiştir. (basınç dayanımı ve elastisite basınç Young modülü) ahşapın suda kalma süresi ne kadar fazla olursa mukavemetin azaldığı gözlenmiştir.

kırmızı ahşapın nemin cok olduğu yerlerde diğer ahşaplara göre kullanılması uygundur, ve diğer ahşaplara göre Kızıl meşe da nemli yerlerde kullanılabilir. Ama her ikisinde de nem miktarı ve süresi artış gösterdiği zaman mukavemetin azaldığı gözlemlenmiştir.

Kelime: *ahşap, kereste, nem içeriği, basınç dayanımı, elastikiyet modülü, ıslatmak, kritik yük*

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LIST OF ABBREVIATIONS

ACI	American Concrete Institute
EN 1995-1-2	Design of Timber Structure according Structural Eurocode
MC	Moisture Content
CS	Compressive Strength
MPa	Mega Pascal
kPa	Kilo Pascal
Psi	Pound per Square inch
L	Maximum Load
I	Moment of inertia
Le	Effective Length
A	Area of wood
π	Pi
E	Young's modulus of elasticity

LIST OF SYMBOLS

%	Percentage.
ρ	Density of timber a
Π	Pi

CHAPTER 1

INTRODUCTION

1.1 Overview

Drying of wood is one of the mechanical strength properties of timber and the most essential in industrial process in the sawmill industry and since it has a great major impact on both the manufacturing and cost standard product quality. Therefore this is the main reason behind the several scientists that have aimed to improve the industrial drying process by developing theoretical models of drying process (Harlin and Vikman, 2009).

The water content or moisture of wood mostly expressed in percent as the ratio of the weight of water present in the wood to the weight of dry wood substance. For example, a 30-kg lumber, which contains 10-kg of water and 20-kg of drying wood substance, would have a moisture content of 50%. Moisture content may be greater than 100% due to the weight of water in the wood can be bigger than the weight of dry wood substances (Chan, 2009).

Wood Compressive Strength measure in MPa or Psi is refers to a loading of wood block in a direction parallel to the grain till it's deformed. As an Engineer, the knowledge of compressive strength let you to understand how much wood species can withstand a load parallel to grain.

The main purpose of this study is to perform accurate measurements on wood during drying; soaking and compressed them in order to see the effect of water on strength of the wood, and also to describe their own behavior during compressions. Four different timber species commonly used in North Cyprus are used which are; Douglas fir, Pine, Redwood and Red.

Total of four sample of different timber species of the same sizes 20x89x127mm were cut from each species and determine their moisture contents by using oven drying and soaking methods in order to predict the effect of moisture in wood-timber strength by soaking them into water for various amount of time and compressed them in accordance with the Euro code 5 (EN1995-1-1:2004(E)).

1.1.1 Aim and Objectives of the Research Study

The general aim of this research work is to follow variation in the wood strength properties in order to see the effect of moisture (water) in the strength of the wood among the four different wood species commonly used in North Cyprus, in which the standard sizes cut according (EN1995-1-1:2004(E)) standard.

Therefore from the above, the following objectives need to be achieved:

- To study the variation in the wood strength properties of 4 different timber species commonly used in North Cyprus.
- To interpret the effect of water (moisture) on different wood species with various amount of time
- To assemble the 4 woods in according to their compression strength, per soaking time.
- To purely identify subject matter appropriately for further investigation and research on the topic.

1.1.2 Outline of the Thesis

The following research thesis will be outlined into six chapters in ascending orders. Chapter one will introduce the respective topic of the research study; including the reasoning for the study and outlining the objective of the research study respectively.

The chapter two is focused on the previous of research study concerning the main theme of the research thesis together with their conclusion. The third chapter will substantially focused on material for the research thesis and some factors affecting the material, together with advantages and disadvantages of using wood as an engineering material. The chapter four is methodology, which is the experimental work of the thesis. Chapter five is the test result and discussion and lastly chapter six, which is conclusion and recommendation.

1.2 Background of the Study

1.2.1 Overview

From the point of view of material science, wood is generally a composite material, composed of cellulose fibers in a lignin matrix and hemicelluloses. According research investigation, the cellulose is a very common polymer, with a long chain (that is degree of polymerization between eight and ten thousands). The macroscopic organization of these chains is mainly the cellulose fibrils. Hemicellulose is much more amorphous with much shorter chains than cellulose (that is degree of polymerization between two hundred and four hundreds) respectively (Rosenkilde, 2002.).

Although wood timber can be expressed as one of the most powerful and useful material for building and also construction, it is important and crucial as a profession in a field of engineering structure to distinguished the wood timber of one species from another respectively. For example, how a structural engineer can be able to different between white oak and normally do not retained liquid and a red oak which according research can be retained (Rosenkilde, 2002.).

It is simple to identify the wood species of one from another through its unique feature indeed. These can be its odor, texture density color and hardness and so on. Identification of wood timber through reliable required the knowledge of anatomy and its structural species. Through knowing the properties of wood, it shown that each wood species has it own unique cellular structure which through it can understand its differences and although the can be determine the particular useful suitability. Hence, through the knowledge of cellular property, it can get blue print for identification of any wood timber species (Laurilla, 2013).

A good sound understanding of tree growth and wood-timber properties, combined with skilful forest management, ensures that we can reliably plan to meet these future timber demands, while building a world viable forest and forest product resource respectively.

1.2.2 Why Mechanical Test of Timber Species

There is a lot of reason why mechanical testing of timber species is much important, it is because:

- The person that used to produce and manufactured timber raw material into finished product can be able to check its mechanical strength into properties are whether up the specification (for example like, EN, IS, BS and so on)
- To avoid failure in service from the use of materials with inadequate properties. For example, like internal defect damage of wood. These are; knot, bow, twist, crook, cup, etc.

Figure 1.1: Internal defect of wood

- In other to meet the demand of modern industries, through production of a new material by following the step of a Research and Development (that is R & D) through using mechanical strength test respectively.
- Knowledge for young's modulus of elasticity, hardness, bending, compression strength, ductility of material is highly need for a specific situation and in relevant method to the field is considered (Mlouka, 2011).

1.3 Mechanism of Moisture Content

1.3.1 Overview

In most cases moisture in wood follow the process of diffusion, which is the water is transport from the region of higher moisture to the region of region of lower moisture. Therefore drying of wood begins from the wood exterior and then transport to the center and from there the drying is occurring at the outside of the wood. Therefore, wood can attains it equilibrium through surrounding air in water content respectively (Raiskila, 2008).

Normally, when the cell wall of the timber begins to lose water, it is the time that the strength of the wood begin to rise. That is at the fibre saturation point the wood begin to dried below, therefore from this case the wood strength properties continues to increase speedily as drying been progressing. The strength properties of the timber are not normally equal in affected during changes of water and even though, properties like bending strength, stiffness crushing strength and so on changes less rapidly and show slowly change only in dried wood respectively.
It is better to note that due to lose of 5% in water content from the green wood to others as drying in progress in case of end bending and crushing strength, the strength increase with change of weather which can be higher in small wood clear specimen than in large wood specimen, so therefore an increase in strength can cause to extent seasoning with checking development (Raiskila, 2008)..

1.3.2 Why we Dry Wood

Wood is dry for so many reasons, among the most important reasons are as followed:

- **To minimize changes in dimension**; wood always shrink or swell with changes in moisture content. If it is dried to the moisture content, it will attain in use and is then placed in a reasonable stable environment; further changes in main dimension will be undetectable.

- **To improve strength properties;** as increase in strength properties begin when the fiber saturation point (FSP) is reached. Exception is toughness or shock resistance, which decrease.
- **Prevent Stain & Decay***;* normally no fungal attack occurs when wood moisture content is 20% or less than that. Infected wood is usually sterilized at 150% or even greater that. Wood can be re-infected if rewetted. No insect attack occurs at 10% moisture content or less than that. Exceptions mostly are in dry wood termites and some beetles respectively (Dan Bousquet, 2010).

1.3.3 Important of Drying of Wood

Wood most damages like fungal stain, decay and also all kind of insect attack, can go down when wood are dried and maintain stable without any negative effect. Organism is one of the back bone living thing negate destroyed the quality of wood by cause decay and also stain to the wood species. But generally cannot be continue at the wood that has water content less than 20%, even though there are some insects that still retained in the wood at that particular value of water content. But wood timber is has high probability of decaying at it has water content greater than 20% (Dan Bousquet, 2010).

In additional to the importance of wood timber drying, here are some points regard to importance of wood drying that is crucial to discussed:

- Due to the wood drying, the timber can be lighter, which make handling and transportation cost to be reduced.
- In most of the mechanical strength properties, the drying of wood is stronger than the given green wood timber.
- In order to preserved the impregnation of timber, it has support to be well dried, but in the case of preservatives of oil types, then has to be accomplished.
- In order to accurate reaction the wood timber will be dry to stipulated water content through only looking to modification field of wood chemical product.
- The properties of wood like electrical and thermal insulation are improved by drying the wood.

- Generally, drying of timber work with machine, glues and finishes which is better than green wood, even though there are some exception, so therefore in so many ways green wood is much very easier to twist than dry wood (Dan Bousquet, 2010).

1.3.4 Effect of Temperature on Wood Drying

Generally, the applicable temperature values used in wood product under ordinarily condition range the values of temperature used up to 105^0C. As usual, the strength of wood rises when the temperature is cooled down and then the strength is decreases as the temperature increases. So therefore the members that can be heated to the temperature up to 105 degrees Centigrade can be turned it original strength whenever the goes down. The result of permanent strength may occur when the temperature are above 105 degrees Centigrade respectively. In case of the extended period of time, design values reduction can be good for specific application in order to account the member which result in temperature reduction and also the strength, heated to high temperature up to 105^0C (Industrial Research Organisation Australia, 2009).

Figure1.2: Dried Timber Room

1.3.5 De-gradative changes in strength of wood-species

Wood species with regard to its services may be focused in a so widely range of circumstance, which as a result of that there is de-gradative change of chemical in the wood. According to research investigation, the most essential reaction of the de-gradative that affect some portion of the wood species like cellulose, and also depend upon the various number of interrelated factor like;

- Temperature,
- PH scale which is the system that maintain the condition of the wood species,
- wood moisture content, and
- Time-length for which the temperature can be expose respectively (Wikipedia, 2012).

CHAPTER 2

PREVIOUS RESEARCH

2.1 Overview

Timber-wood today is one of the principal materials with an extraordinary large amount of users. According to research investigation, the total volume of wood harvested annually; including wood for fuel, paper, and tissue is nearly 3500 million m^3 globally, and exceeds the annual volume of cement, plastics, steel and also aluminum combined together (Harlin and Vikman, 2009). Approximately 45% is used for industrial materials, and the many wood advantages, and it is reasonable to expect that its use will grow even further.

2.2 Previous Research Studies on Timber Strength

Laurilla, J (2013), present a research thesis on which he studied the effect of moisture content, loss of weight and potential energy respectively, in order to improve the quality of energy wood and therefore increase the potential of forest energy respectively. He concluded that the properties of energy wood are such in variation widely depending on its assortment, storage conditions, weather conditions and the origin of the energy wood. So therefore, a better understanding of energy wood properties will increase forest energy's potential and the also the use of renewable energy and thus help mitigate climate change world widely (Laurilla, 2013).

In 2011, Suleyman Korkut, presented a research on which he studied the three performance thermally treated wood species that always been used with turkey people, in which he determined the change of various physical strength properties; oven-dry density, air-dry density, weight loss and also swelling and anti-swelling efficient of timber parallel to grain, and also the effect of color different. The timbers used in the research are Sapele, Iroko, and Limba after heat treatment under different temperature and durations. For the study, wood specimens were subjected to heat treatment under different atmospheric pressure and air at two different temperature (160^0 C and 180^0 C) and two different times (2hrs and 4hrs). the graph below give the summary conclusion of the research and also based on the findings of this study, the result showed that oven-dry density, air-dry density, swelling compression strength parallel to grain and surface roughness values decreased with the increasing treatment temperature and treatment time (Korkut, 2012).

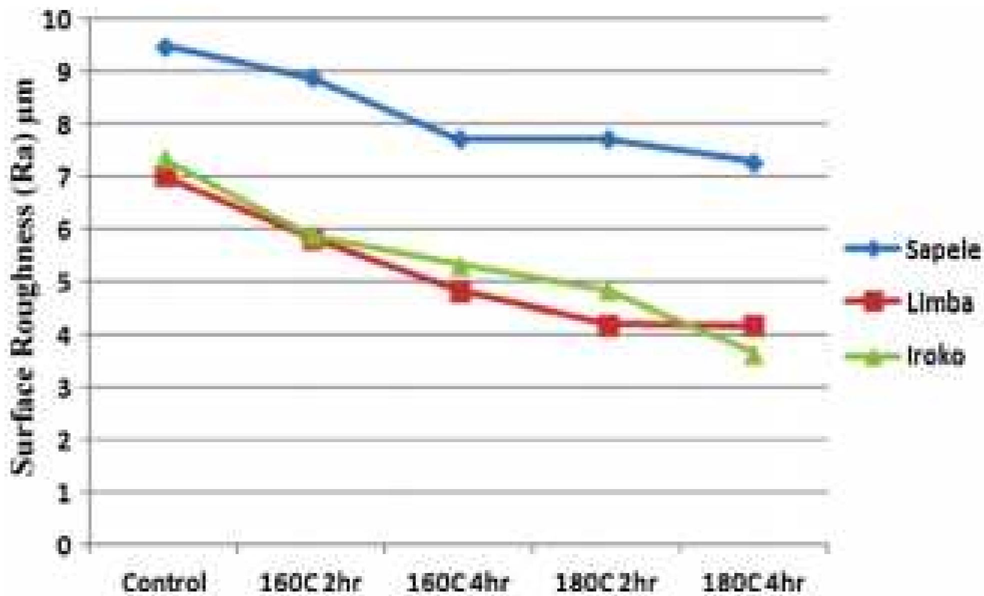

Figure 2.1: Effect of heat treatment on surface roughness of sapele, woods (Korkut, 2012).

In 2007, Aydin and Yardimci made their own research on four wood mechanical properties that always been used by Turkish people, in which the compression strength, flexural strength and toughness of four different timber species (poplar, fir, hornbeam and pine) were determined both parallel and perpendicular to the grain. The modulus of elasticity of timber specimens was also determined from the experimental result parallel to the grain for the compression test and perpendicular to the grain for the flexural test. It is found that loading direction affects all mechanical properties in accordingly, among the timber tested, the maximum and minimum mechanical performances were obtained with 2 different hardwood, that is horn-beam and poplar and also for the softwood, that is fir and pine, the mechanical performance of the wood were obtained. Figure 2.2 below show the summary conclusion of the research. In conclusion of the research, from all four timber species, except the hornbeam, the timber specimens showed very low compressive strength when loaded perpendicular to the grain and low flexural strength when loaded parallel to the grain respectively (Aydin, et-al, 2007).

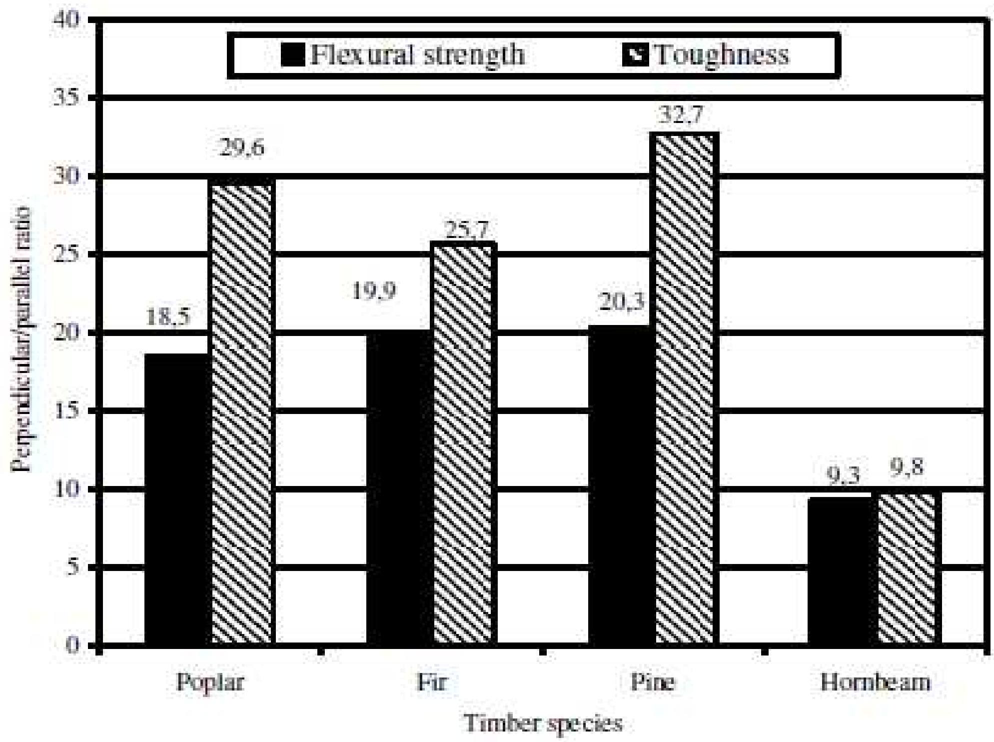

Figure 2.2: the Perpendicular/parallel ratio of mechanical properties of timber

In 2012, Isopescu, et-al, presented their research article in which they provide analysis properties of bending for structural size beam and standardize bending, they considered beams in structural size and tested it as standard laboratory specimen in accordance with the requirement of standard force for simple bending. The method used for testing is three points bending which is normally used for small sample of timber species and together with the real scale beams method in which four beams has tested for four points. Wood independent of their mechanical strength properties and has much uniqueness, therefore, their mechanical and physical properties have extended a number of factors. This strength properties of wood has varies from species to another and though sometime within species, this is due to the condition of environment during the rate of growth respectively. They concluded that if the timber wood has come from the same region, then result fall through values population that confirmed during an experiment, this is because they found that both test on structural size beams or specimen has come from the same region. Moreover, the design properties of tabulated are used in this case only where there is not the one to be match with (Isopescu, et-al, 2010)

In 2006, A. Zziwa, et-al, made a research, studied the mechanical and physical properties of Uganda wood in which they investigate the remarkable changes that has been occur within properties of wood both in mechanical and physical condition within the 4 that are not utilized in native Uganda wood species. Zziwa considered some of the some of the mature species from it root; like Cletis mildbraedii, Alstonia boonei and so on were chosen from the main forest, that is Forest of Budongo, then cut down by using the saw tool machine, the wood then used in making experiment in which they determined the strength properties by using the machine equipment Mansania Tessometer (Zziwa, et-al, 2006) for wood testing respectively. The standard used in this test is based on (ISO) procedure, that international standard Organisation together with BS 373 (1957). It is conducted in the laboratory at room temperature 20.3 degree celcious also relative humidity 65.3 percent according BS 373 (1975). They concluded that the wood strength properties and the basic dry density of wood varies drastically from one wood species to another and also within the location of individual tree, that means there is a great gab from near pith and bark of the tree species which is necessary to optimal its structure. In their conclusion, they recommended that the assortment of log that has better strength has to be priced higher than top logs which are mostly used for structure purpose and that of the top logs are used for non structural purposes (Zziwa, et-al, 2006).

In 2012, Elzaki and Khider presented research journal they provide their own contribution for Sudanese potential timber, in which they determined the focused on the properties of timber both mechanical and physical properties are been considered potentially to an alien wood tree species. They determined the basic density (that is by calculating manually) and oven dry density (laboratory) of the woods used. Then they determined the the ratio of bark to timber by considering their masses and a given volume and also tangential shrinkage and radial were calculated. Then they used the method of static bending test in which they determined the both modulus of elasticity (MOE) and modulus of rupture (MOR). Then other mechanical properties that has founded were compression strength parallel to grain, impact bending, maximum crushing strength and also shear stress respectively. Osman et al, compared the obtained result of the wood properties with that obtained from another country (Costa Rica and India) of same wood species (Elzaki & Khider, 2013).

Table 2.1:(Elzaki & Khider, 2013) strength properties parallel to grain in compression for both W/Sudan and Sudanese Clustarica from compared with the same wood species from Costa Rica and India .

Wood Origin	W/Sudan			India Cypress S.	C/ Rica Moya
	Mean.	Minimum.	Maximum.		
Max. Crushing Stress (KPa cm^{-2})	421.00	392..00	477.00	319.00	143.00

Therefore according result obtained in the table 2.1, the wood obtained from the Western Sudan were been considered at middle since its density that exotic from softwood has a good strength properties in both compression parallel to the grain and Modulus of Rupture (MOR). According to the obtained result, it shows that the wood from the Sudanese cypress has a remarkable medium to tough in durable, and also has very good quality by compared with the one from Costa Rica and India respectively (Elzaki & Khider, 2013).

In 2011, Marius C. et-al, presented a research journal “Physical and Mechanical Properties of Oriented Strand Lumber made from an Asian Bamboo (Dendrocalamus asper Backer (Elzaki & Khider, 2013) the study was carried out to determined the physical and mechanical properties of; modulus of elasticity, modulus of rupture, internal bond, thickness and water absorption of Oriented Strand Lumber (OSL) which made from the Asian bamboo Dendrocalamus as per Backer. Thirty-six lab boards were produced from these bamboo strands with two manufacturing parameter varying. That is four resin types exhibits superior strength properties compared to the commercial products made from wood for the building sector. The resin type has a significant effect on board properties on board properties.

Moreover, all properties of the board improve generally with increasing of resin content. According to the conclusion of the research, the internal bond, bamboo-based OSL shows less strength of the wood than based boards (Malanit, 2011).

Kristian Berbom Dahl, in 2009 on his made a research on his Doctoral thesis “Mechanical Properties of Clear Wood from Norway Spruce (Dahl, 2009)” on which he comprises each orthotropic material direction and plane over the complete loading range till it failure. The material strength properties are quantified in a set of linear, non-linear and also failure parameters. In addition, statistical distribution and inter-parametric corrections are presented. Several quantities have hardly been studied for Norway spruce (Dahl, 2009) earlier, and also are scarcely documented for spruce softwood in general. The properties were determined by means of experimental test in conjunction with the numerical analyses. Numerical was investigated by means of compressive and tensile tests, whereas shear properties were based on the Arcan method (Dahl, 2009).

In conclusion of the research thesis, the relative large quantity of parametric observations enabled investigation of statistical distribution for each material parameter. In addition to that correlations between values determined from the same test could be estimated, the work constitutes a basis determined and probabilistic numerical analyses of spruce softwood on the macro scale level (0.1 – 1.0m), suitable for general three-dimensional studies of details and joints timber constructions (Dahl, 2009).

In 2010, Ahmad et-al, on their article, that provide contribution using tropical hardwood in which they investigate their strength properties using tensile test with structural size testing machine. They select specimens from different environment which are from Tropical hardwood from Malaysian, the wood are Keruing (that is Dipterocarpus spp (Ahmad, et-al, 2010), Bintangor (that is Calophyllum spp(Ahmad, et-al, 2010), Kedondong (that is Canarium spp(Ahmad, et-al, 2010) under the strength SG5 respectively. According their conclusion, modulus of elasticity, poison ratio, tensile strength which are all tensile strength properties of hardwood was evaluated and also statistically analyzed, in which they found that the structural size specimens for grade stresses were much very high than that of the one that has used to published in the code of practice used in Malaysia (Ahmad, et-al, 2010)

In July, 2011, Carrillo, et-al, releases a research article "Physical and Mechanical Wood Properties of 14 Timber Species \from Northeast Mexico" in which the investigation is on Thorn scrubs vegetation types from Northeast Mexico, which consist of 60 to 80 tree shrubs species that are used for a wide range of decorative, energy and also constructive purposes. However, basic researches of the physical and mechanical wood properties are still highly needed to establish uses and, in this method, increase their values in the timber market. In the research wood from 14 native species were studied with view to their basic density, modulus of elasticity and modulus of rupture, as well as the relationship between these three properties. According to research they concluded that the values of modulus of elasticity and modulus of rupture species make them a shows potential general utility wood that can be optional for a variety of structural and non-structural uses (Carrillo, et-al, 2011).

In 2008, Escobar W. In his dissertation thesis for doctor philosophy, "*Influence of Wood Species on Properties of Wood/HPE Composites*" (Escobar, 2008).analyzes the effect of wood species on performance of wood plastic composite. In his experimental design, he analyzed the physical interaction between a molten thermoplastic and solid wood, which result showed that a high correlation between the potential area for transverse flow and the interaction between HDPE and species. Collapse of cell in specific wood species was recognized as probable mechanisms impede mobility of the thermoplastic and thus the interpretation and interfacial area. It was possible to quantify the mechanical interlocking type of adhesion using a viscoelastic model and its parameters as an analogy. The new model also introduced a modification factor affecting filler properties. This factor represents the modulus reduction in wood cells due to processing, and is expressed as a reduction in modulus in the I-direction, where the modulus of the natural filler in a composite was estimate with nanoindentations. A model was developed a more detailed calculation model based on these measurements, which provided very good approximations to experimental results in the modulus of elasticity for chalet people pine and imposing fir composite in coupled and uncoupled systems (Escobar, 2008).

Another development is, in 2011 C. B. Wessel's. F and Malan. T. Rypstra, presented a research in which they review some of method of measurement on timber mechanical properties based on standard tree, they predict properties of mechanical strength that highly needed from the wood species. This comprises the allocation decision of tree processing, the breeding selection of tree, together with site and also planning of dispensation production respectively. The research methods used are measurement system used from Australian multi-properties which are also referred to as Silvican and method of near infrared spectroscopy. The researchers also review the current writing basically on the new obtainable non destructive or to say that are limited the characteristics measurement methods which are limited to destructive on it own standing tree species which can be support with prediction, both the elastic of modulus and that rupture were found (Wessels, et-al, 2011).

CHAPTER 3

STRUCTURE OF WOODS

3.1 Wood as Material for Structure

The used of timber as a building and construction material is a paramount important that started about thousands years ago through it natural state. Now a day's our, in many companies, wood become crucial engineering material globally (Dahl K. 2009).

Wood served as a product of tree, in other way tough plant material, fibrous plant and so on which are used in building and construction purposes through cutting them into standard size are normally called Timber, others such as board, planks and also similar material respectively. Timber is well known as a primary construction material and is used in so many ways in which it used as bending and strength materials, they elevate in strong and compression at any direction. Moreover, there are many different wood categories with different quality in the same or different species. With regard to this, it means that wood species has a specific and better suitable in used material and for others. So also the way it grow is an extra importance for fix on quality respectively (Kretschmann, 2010).

In so many ways, the term 'Timber' and 'Lumber' are confusion to the people, but in reality there is different between the two. In country like USA and others they refers Timber alike with Lumber, The wood species that are cutting into commercial product is called Timber, while the commercial timber that used in structural product are called Lumber. Therefore, bole log, and trunks are converted to timber when it cut with saw, split in the same used as a minimally routed log and rearrange, stuck on top of one another respectively (Dahl, 2009; Kretschmann, 2010).

3.1.1 The Structure of Wood

Wood naturally obtained from two broad categories of plants clearly known as hardwood (Biomass, 2009) which come from angiosperms, deciduous trees and softwoods (Biomass, *2009*) come from gymnosperms, conifers tree.

It was observed that wood without optical aids shows not only differences between softwoods and hardwoods and also differences between species, but differences within one specimen, for good example in this case is sapwood and heartwood, early-wood and latewood, the arrangement of pores and the appearance of reaction wood. All these phenomena are the result of the development and growth of wood tissue (Wisconsin, 2010).

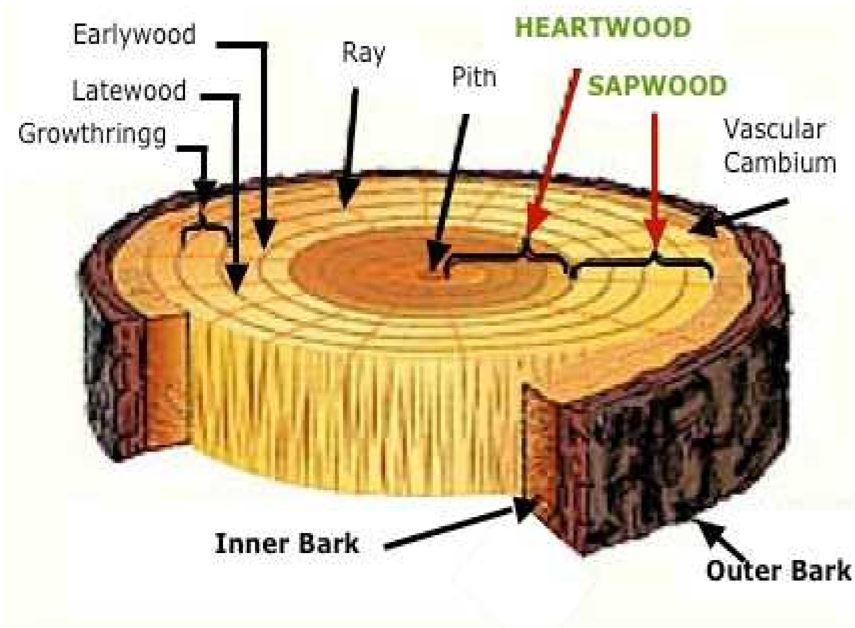

Figure 3.1: Layers of the Tree Species (Poku & Vlosky, 2001)

Wood itself is fibrous, that is cells are long and slender and are aligned with the long axis of the trunk. It is these fibres that give the grain in the wood, not the growth rings. They also make the properties of wood quite anisotropic with much higher stiffness and strength parallel to the grain than across the grain. We can liken the structure of wood to a bunch of parallel straws (representing the fibres or grain of the wood), which are bonded together using a weak glue as detailed in figure 3.1.

Some of the properties that Civil Engineer needed are function of the microstructure of the wood:

- **Density:** Cell structure and size, together with moisture content
- **Strength:** density, moisture content, and cell size
- **Stiffness:** density, cell structure, size, and moisture content
- **Colour:** Extractives
- **Fire Resistance:** Density, extractives
- **Electrical Resistance: M**oisture content, cell size.

3.1.2. Description of the Properties of Timber

The trunk is the primary interest to the structural engineer as it is from the trunk that structural timber is milled. In order to understand the behavior and limitations of timber, some basic information and understanding of wood from the trunk is very necessary. Figure 3.2 below shows a cross section of a trunk indicating its main features in a growing tree

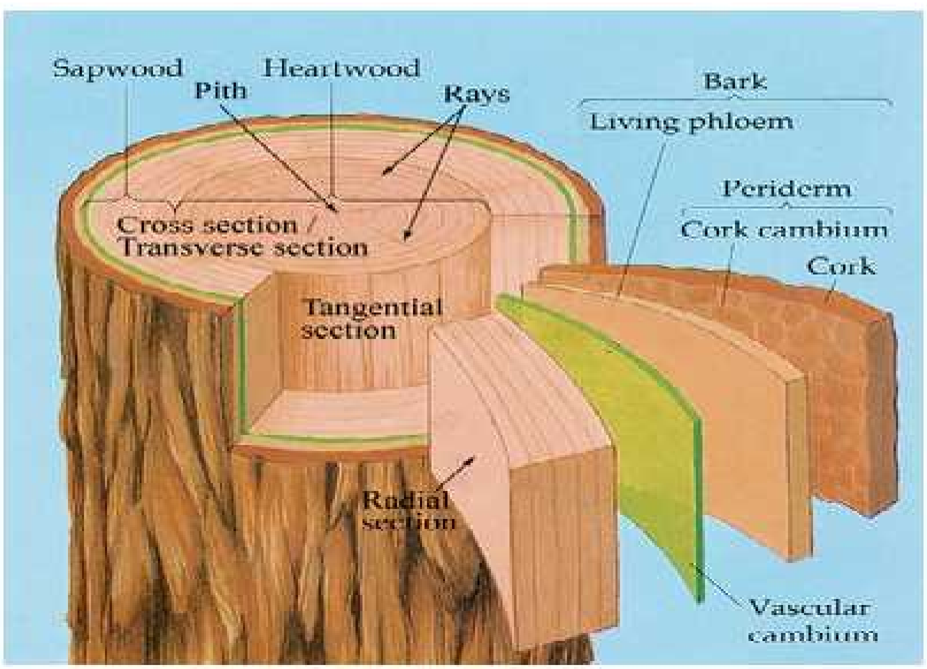

Figure 3.2: Cross section of the Trunk Tree (DoIpoms, 2013)

The cross section of wood tree are so many in number and are divided into sections, we are they; the *heartwood* which is a dead and visibly never work, the *sapwood*, this is paramount place in the wood in which all form of conduction and food keeping are occur, the *bark*, this is served as a protector and it protect the internal structure of the tree, therefore these are some of the main properties of internal wood species which can be summarize below (Wisconsin, 2010);

- **Bark*:*** The outer layers protect the trunk from temperature, fire, injury. The inner layers carrying nutrients from leaves to growth areas.
- **Cambium:** The growth centre where new wood cells are formed, new wood cells grow towards the inside and the new bark grows toward the outside of the cambium.
- **Sapwood:** New cells that figured vertical conduits for water and nutrients from roots to leaves. Cell walls are still growing inwards, and are loaded with starches for their own growth.
- **Heartwood:** Cells in the heartwood stopped growing and form receptacles for waste products (extractives). This is older and often harder wood, although it is not necessarily stronger.
- **Extractives:** This is a by-product of growth reaction that are stored in cells of the heartwood. The actual composition of the extractives varies from species to species and in the minor elements. Some extractives are toxic to fungi and some are insects.
- **Juvenile wood:** This is the also the essential part of the wood species that laid down by the wood tree which is very early in it's and growth, and is, therefore, nearly the centre of the tree. It tends to be interior in density and cell structure. Generally, Juvenile wood is a very small part of the cross section except in rapidly grown plantation grown timber.
- **Pith:** This is the very center of the trunk which is thin, dark band that once was a twig shoot (Wisconsin, 2010).

Naturally, wood is organic cellular solid, which is a composite, made out of a chemical complex of hemicelluloses, cellulose, lignin and extractives respectively. Besides, wood is extremely anisotropic due mainly to the complete shapes of wood cells and the oriented structure of the cell walls. Besides, anisotropy results from the separation of cell size all over the growth season and in part from a preferred direction of certain cell types (e.g. ray cells).

The minute structure of cell walls, the aggregate of cells to form clear wood and the anomalies of structural timber represent three structural levels which all have a profound influence on the properties of wood as an engineering material. For instance, the ultra-structure level of the wall provides the fully explanation of why shrinkage and swelling of wood is normally 10 to 20 time larger in the transverse direction than in the longitudinal direction (DoIpoms, 2013).

3.2 Timber Grading

3.2.1 Overview

In comparison to building material such as concrete and steel, the properties of structural timber are not designed or produced by means of some recipe but to ensured it fulfill given requirements only by quality control procedures which is referred to "Grading".

Wood is a natural resource with a wide range and high dispersing of physical and mechanical properties depending on species, growth, genetics and environmental conditions of the tree. To be able to utilize the potential of given properties and use it as a carrying member in an effective and dependable way, wood-timber has to be graded. Even due to depending on the use of the product, the grading process can be done with respect to (Lowes 2014):

- Strength
- Appearance and
- End-use

Various scheme for grading have been developed using different principles, moreover, the basic idea behind them all is that the material properties of interest are assessed indirectly by means of other properties, measured non-destructive such as the modulus of elasticity modulus of rupture or the visual appearance of the timber. As a result of timber grading, timber is represented at the market as a graded material. The graded imply that the material properties lie within desirable and predictable limits (Lowes 2014).

However, the visual strength grading method is based on the correlation of the occurrence, the size and type of growing characteristics, for example, size of the knot and the mechanical properties behind. In general it is done manually by experienced persons. Simple and uncomplicated to learn rules which are national defined, are specified for the classification into different strength classes. Currently the European Standard EN 14081 part 1 defines only minimum requirement for the development of standard of grading. The following properties should be defined in this code as a minimum:

- Limitations for strength reducing characteristics,; such as knots, slope of grain, density, cracks and rate of growth
- Limitations for geometrical characteristics; wane distortion, bow, twist, or spring
- Limitations for biological properties: fungal and insect damage
- Other characteristics: like mechanical damage and reaction wood (American Hardwood Export Council, 2003)

3.2.2 The Steps in Determining Grade

- Determine the species
- Calculation of the surface Measurement (SM)
- Determination of the poor side of the board (wood)
- Then from this face, calculate the percentage of clear wood that is available. Note: *If Number one common is the grade of the poor face, then check the better face to see if it will grade FAS for the F1F or selects grades to be achieved*.
- Once the grade is determined, then quickly for any special features such as sapwood or heartwood cutting for special color sorts.
- Sort to bundles according to buyer and seller specifications respectively (American Hardwood Export Council, 2003)

3.2.3 Advantages of Using Strength Grading

- Rules of it are very simple and easy to understand and application does not require great technical skills and expensive equipment.
- It is refers as labour intensive and inefficient because the wood structure and density, which are very important parameters for the strength cannot be considered, only to be estimated indeed.
- If the rules are applied correctly, surely the method can be cheap and effective.
- Specification for the allocation of national visual grading classes to the system of strength classes given in EN 338 can be found in the European standard EN 1912 respectively (American Hardwood Export Council, 2003).

3.3 Types of Wood-Timber

3.3.1 Overview

Basically, there are two main kinds of wood from which to choose, i.e. softwood and hardwood. Besides, there are certain characteristics that are common in all wood types.

3.3.2 Hardwoods

These are the deciduous trees that lose their leaves in the all fall. Even though there is an abundant variety of them, only 200 are plentiful and pliable enough for woodworking. In most cases like our skin, hardwoods have tiny pores on the surface. The size of these pores is then determines the grain pattern and texture. This is because of this, hardwoods are classified by pore opening as either; Closed Grained (which is smaller in pores), like oak, ash and poplar (Daive, 2011)

Hardwood has a basic tissue for strength contain libriform fibres and fibred tracheids. These vessels are long pipes ranging from a few centimeters up to many meters in length and consisting of single elements with open or perforated split ends. Hardwood fibres have thicker cell walls and so also smaller Lumina than those of the softwood tracheids. The distinctions in wall thickness and lumen diameter between early-wood and latewood are not as excessive as in softwoods (Daive, 2011) .

Figure 3.3: The hardwood-logs

3.3.3 Softwood

Softwood originally comes from the coniferous trees, which is commonly referred to as evergreen trees. According to research investigation only 25% of all softwood are used in woodworking. All softwood has a closed grain (i.e. small pores) that is not very noticeable in the finished product. The most popular softwood is cedar, fir, spruce and pine (Daive, 2011).

According to research investigation shows that a relative simple structure a sit consist of 90% to 95% tracheids, which are long (2 to 5mm) and so also slender (10 to 50 µm) cells with flatted or tapered, closed ends. The tracheids are arranged in radial files, and their longitudinal extension is sloping in the direction of the stem axis. In evolving from early-wood to latewood, the cell walls become thicker, while the cell diameter becomes smaller. At the end of the growth period, tracheids with small cell Lumina and small diameters are developed, whilst at the beginning of the consequent growth period, tracheids wit large cell Lumina and diameters are developed by the tree. This difference in growth may result in a ratio between latewood and early-wood density as high indeed (Daive, 2011) .

Figure 3.4: The Softwood-logs

3.4 Variation of the Physical Properties of Wood

3.4.1 Growth Rings

Wood timber as already known is the product of tree, that is it yield by tree can be been increase in diameter through formation that exist between inner bark and other part of the wood species, as structurally, the woody layers that surrounded the entire part of the tree; stem, root and other living branches respectively. This is what is refers to as "secondary growth", it is cause from the result of vascular cambium of cell division, together with meri-stem of lateral and follow by the new cell expansion. Therefore, clear season can only be growth within dispersion of annual or seasonal pattern, that lead to the growth ring of wood species (Daive, 2011) .

Within a very small volume in the stem of a tree, the properties of the wood are varying analytically. The different properties of wood cell build that is been considered in spring and early summer (that is early-wood) and the cells produced from summer to fall (late wood) are wood which mostly pronounced for many wood species grown in a temperate climate.

3.4.2 Sap and Heartwood

This is the younger part of a tree stem which is located upward flow of sap from the root to the crown of the tree species. This part of the stem is known as Sapwood. As the cells grow old, they stop functioning physiologically indeed; Heart-wood in this case it arrangement normally occur unexpectedly, that is it is normally automatic method. Heartwood as long as it form, it then complete at once and then it truly dead (Daive, 2011) .

Generally, heart-wood has shaped differently, it is not much dark with compare to the living wood, it has cross section that can be seen remarkably, and follow the shape of the growth rings respectively.

The tree may be from one species to another decidedly, especially if the tree is mature enough and is particular and big and unique. There are some trees that their wood may lighter, weaker softer in case of their laid and late in their life cycle and even though more in their textures than when they are young or early life. But the reverse is the case in case of other tree species that normally had been used. Due to the time variation in the life of the tree species at growth condition level, the sapwood that lower it toughness, hardness together with strength which is regularly good from it log (Wisconsin, 2010).

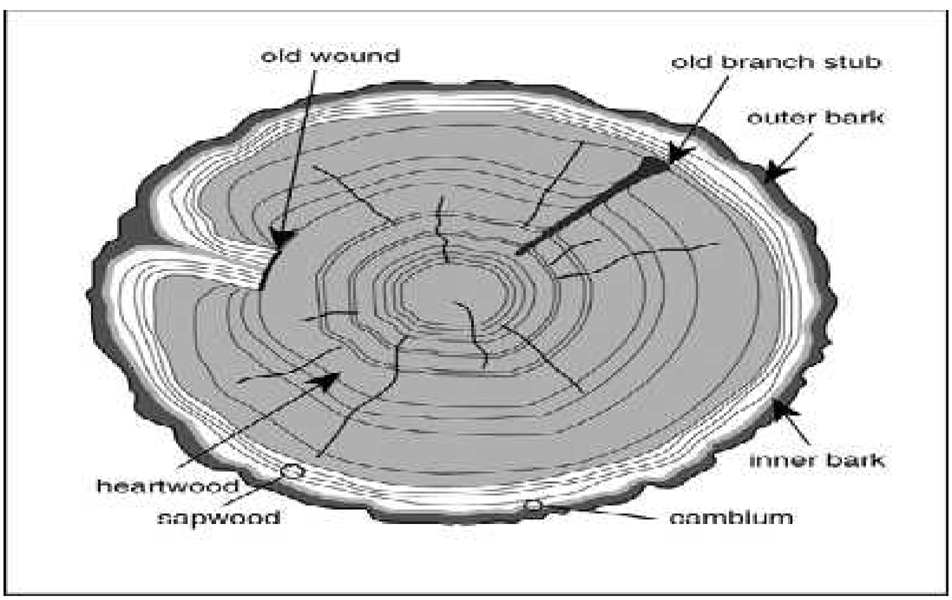

Figure 3.5: Sapwood & Heartwood Component

3.4.3 Knots

The knot is another imperfection that occurs in a particular wood species which structurally affect the strength characteristics of the species and usually worse condition, which cause the visual effect to be oppressed. In some conditions, the knot can be appear in a circular or solid visibly especially in a state of plank of longitudinal sawn. Knot normally, is dark in color and the wood pieces around the grain can be rest flows through the wood species. According research investigation, inside the knot, the wood direction (that is grain direction of the wood) measure and found about 90 degree which is different from the standard direction of the wood grain respectively (Wisconsin, 2010).

Figure 3.6: the knot on a tree (Paulo, 2009).

3.4.4 The Colour

Within species which show a diverse difference between sapwood and heartwood, the natural color of heartwood is usually darker than that of the sapwood indeed, and very frequently the contrast is conspicuous. The color is normally from the chemical substance of heartwood which is generated by deposit, so that any color different cannot dramatically different. This did not means that through dramatically different that occur in the mechanical strength of the heartwood and sapwood can eventually be different in chemical deposit.

According some experimental research, the longleaf of the specimen from very resinous wood show that as strength of the wood increases then the resin is eventually increases and so also in when the wood got dry. This kind of resin is normally saturated from the heartwood and in some cases is called fat lighter. But building structure of fat lighter can be impervious to some insect like termite and rot and can be expanding to flammable (Grekin & Surini, 2008).

Figure 3.7: Diversion color of timber

3.5 Wood as an Orthotropic in Nature

Wood may be expressed in some situation as a material that exhibited orthotropic, that is, this is of unique that acquired and also independent in terms of mechanical strength properties in the direction of three (3) mutual perpendicular axes; Radial, Tangential and Perpendicular respectively as shown in the figure 3.8 (Parks, 2009).

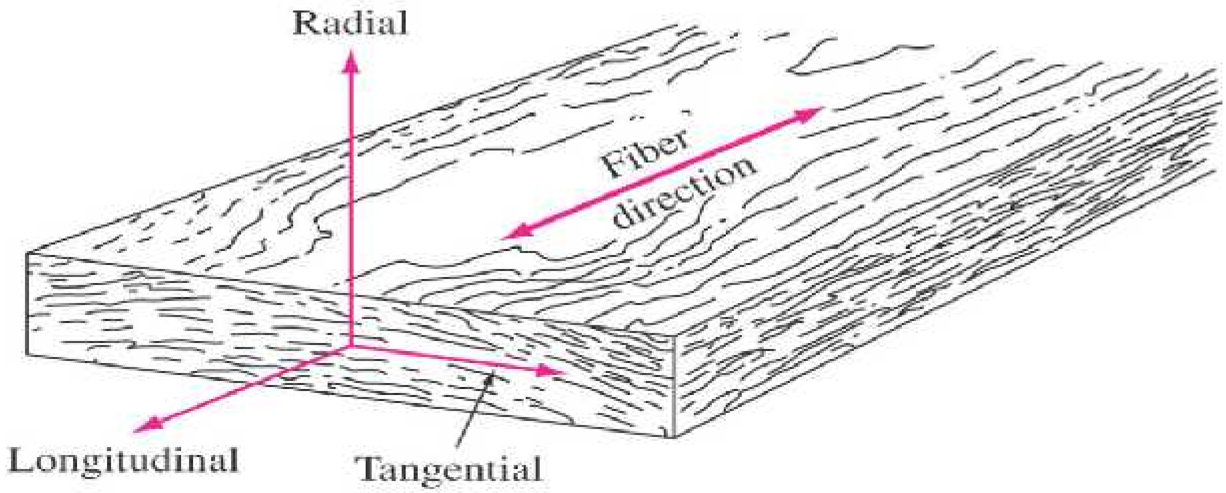

Figure 3.8: The 3 principle wood axes & its grain direction (Parks, 2009)

From the figure 3.8 above, L, the axis of longitudinal direction which is parallel to the fibre

The R is the radial axis that located normal to the growth and also is perpendicular to the to the timber fibre

The T is the tangential of the fibre, which is located perpendicular to the grain in other hand, is tangent to the fibre of growth ring respectively

To fully characterize the mechanical behavior of wood it is necessary to know the stress-strain relationship referred to the LRT (Longitudinal, Radial and Tangential) reference frame. The mechanical tests are the only way to obtain such solution, but several difficulties arise in making the right experimental measurement, particular for those concerning the identification of ultimate strength (US Endowment for Forest, 2010).

If the load is applied perpendicular to the longitudinal axis of the straws, the straw crushes because of the much weaker direction of the cellular walls. The bundle of straws concept shown in the figure on the right illustrates the nature of wood parallel to the grain which is strongest and perpendicular to the grain which is weakest (US Endowment for Forest, 2010).

It is the intention of this chapter to give an overview of timber as a structural material. This includes the description of wood as a fibred composite material on a micro scale1 and the specification of abnormalities like knots and fissures. Furthermore it is described how timber material is usually used in construction and the relevant material properties are recognized and defined.

In order to gain a better understanding of the reason for the special behavior of wood and timber material it is helpful to start thinking about where the wood and the timber are 'produced' in the stem of a tree (Daive, 2011).

3.7 Directional Strength Properties

As with most material, there is inherent variability in the strength of small, clear sample of wood under short-time loading. Added to this variability are the effects of duration of load and strength-reducing factors such as knot and others. Besides, wood exhibits directional properties when subjected to various stress states. The strength properties to consider are associated with normal and shear stresses parallel to the grain, perpendicular to the grain radially, and perpendicular to the grain tangentially. The difference in strength properties in the radial and tangential directions is seldom of significance in design, it is necessary only to differentiate between directions normal and also parallel to the grain respectively (Edwin, et-al, 1997).

3.7.1 Compression Parallel to the Grain

Wood usually fails under uni-axial compressive stresses by buckling of the fibres, this takes place on a 20^0 to 30^0 plane and sometimes referred to as a *Shear failure*. Upon seasoning from the green state to 15% moisture content, compressive strength is increased by 50 to 75% in small clear specimens and less in larger cross sections. The increase for larger specimens is limited because of defects introduced by drying (Edwin, et-al, 1997).

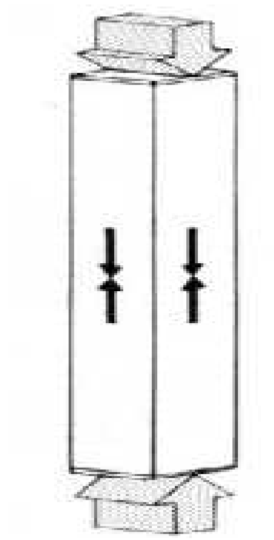

Figure 3.9: Compression parallel to the grain (Edwin, et-al, 1997)

3.8 Factors Affecting Strength Properties

3.8.1 Overview

Working stresses for timber are approximately 20% to 75% of the ultimate strength. The large variation of the factor of safety is due to the variability of the strength properties, which depend on moisture content, grain, density, knots, shake, splits, checks, and other factors.

3.8.2 Growth Characteristics and Strength

The effects of knots are to decrease strength because their grain and the surrounding grain is at a large angle to the maximum tensile or compressive stress. The effects in are more detrimental than in compression or shear. Thus for beams it is advantageous to locate the higher-grade sections of the timber in the maximum tensile stress zones. The mass modulus of elasticity for stress-grade lumber is little affected by the presence of knots.

There are other factors such as sloping grain, insect attack, pitch pockets, shakes, wane, compression wood, decay, checks, compression failure, tension, and so and fold that affect the strength of wood (Edwin, et-al, 1997)

3.8.2 Identification of Wood

Wood identification is one of the paramount important aspects in both primary and secondary level of agencies that know the values of wood timber in terms uses, those agencies are government agencies, industries, enforcements, botanies in the field of scientific, law enforcements, timber technologies, anthropologies, and so on. Wood identification can be refers to as the mainly way in which all the cell patterns of wood, characteristics, it features are recognized in a normal and accurate merely to it level of generic (Hartley & Merchant, 1995).

Due to wood timber are from so many different species, some species from the same genus but only can be identified from their properties, it really perform different function under the umbrella of the same environment and condition. There is high probability of having serious problem which can be raised if the species during manufacturing process can be mixed roughly without identified one another. So, therefore identification of timber very important, especially in countries likes USA, Canada, Australia and their environs respectively (Hartley & Merchant, 1995).

3.8.3 Environmental Conditions

As the moisture content of wood drops below 30% (the approximate fiber-saturation point indeed), its strength properties increase, with the exception of toughness, the table 3.1 below list the approximate variation of strength properties, the application range being from 2% to 25% moisture contents approximately indeed.

Reduction in water content from the fibre saturation point to zero is accompanied by radial shrinkage ranging from 4% to 6%, tangential shrinkage from 6% to 8%, and so also longitudinal shrinkage 0.1% to 0.3%. The relation between shrinkage and moisture content is linear.

If wood is kept either continuously dry or continuously wet, decay does not occur. Moisture and temperature are the prime factors affecting decay rate. Wood should not be direct contact with concrete or masonry where excessive moisture will be transferred to the wood.

Ventilated air spaces around untreated member or pressure treatment with preservatives retard or prevent decay (Hartley & Merchant, 1995)..

Table 3.1 Effect of moisture content on Strength Properties (Edwin, et-al, 1997)

Static Bending	% change per 1% in moisture content
Stress at proportional limit	5
Modulus of rupture	4
Modulus of elasticity	2
work to proportional limit	8
Work to maximum load	0.5
Impact bending, height of drop causing fracture	0.5
Compression parallel to the grain:	
Fiber stress at proportional limit	5
Maximum crushing strength	6
Compression perpendicular to grain:	
Fiber stress at proportional limit	5.5
Shear parallel to grain, maximum strength	3
Tension perpendicular to grain, maximum strength	1.5
Hardness :	
End	4
Side	2.5

3.8.4 Time-Load Effect

The strength properties of wood-timber are affecting by the duration of loading. The usual duration of load considered in design, and also the corresponding percent of 10-yar strength, can be tabulated below (Edwin, et-al, 1997).

Table 3.2: Duration of Maximum Load (Edwin, et-al, 1997)

Duration	Percent of 10-year strength
Impact	200
Wind or earthquake	133
Seven day	125
Two month (as for snow)	115
Permanent	99

3.9 Properties of Timbers used as Laboratory Material

3.9.1 Pine Timber (Pinus Radiata)

Pine is a versatile timber; it is one of the timbers that used for the full range of structural and decorative applications which including framing, lining, veneer, plywood, and glue laminated beams. When appropriately treated, it can be used for many exposed structural and non-structural applications respectively (Queensland, 2013).

Pine wood species also commonly known as Radiata wood is species natively from the North America west coast but now a day is classified as one of the world wide great plantation, this is can be commonly found is the countries like South Africa, Chile, N/Zealand, Australia(Queensland, 2013) and so on. in a country like Australia, pine is plant in almost all part of the country together with the ACT, even though planting in a commercial Queensland are most limited in the area to the southern highland respectively(Queensland, 2013; Tasmanian, 2008).

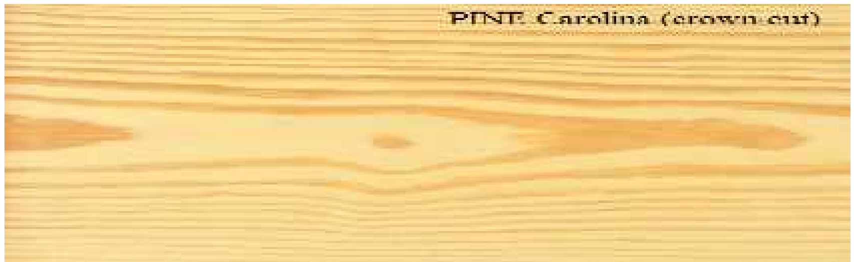

Figure 3.10: The Pine wood species

3.9.1.1 Wood Appearance

The Pine has a reddish-brown colour of heartwood and varying shades of yellow. The sapwood is normally pale yellow to white. The grain generally straight and often pronounced different in colour between early-wood and latewood which results in very distinctive figure when backsaw (Queensland, 2013).

3.9.1.2 Common Uses

Engineering: Preservative impregnated poles for frame construction, land poles and transmission poles

Construction*:* General purpose softwood used as dressed, seasoned timber in general house framing, lining, flooring, joinery, laminated beams, and mouldings. Preservative impregnated in sawn or round form in fencing, landscaping, retaining walls, playground equipment and also it use in the manufacture of scrimber (Queensland, 2013).

Decorative: pine is use furniture, plywood, turnery, outdoor furnishings (that is preservative impregnated), and carving respectively

Others: Pine is used in structural plywood, wood wool, scaffold planks, paper products, particleboard etc (Queensland, 2013).

3.9.2 Red Oak and its Properties

This is one of the most influence trade wood which name from the selected eight commercial wood species that come from the large compound of Oak group. It is one wood species that mostly grow in USA eastern part of the country, Red oak are more plentiful in USA and other part of the country than white oak wood species. This is the main the reason that transporting of Red Oak is most available across those countries than other types of wood, in standard sawn wood and in terms of veneer, all are in it specification and fully grading. North Cyprus also has Red Oak and is one commercial wood in the market industries (American Forest Design, 1992).

It is hard in terms of species and also heavy timber with medium stiffness and strength. It has the properties of highly crushing strength and also well condensation bend. It is recommended as the wood that has relatively worked, easily to use with machine, and also by using with screw and nail respectively. Red Oak and white Oak has equal appearance to each other, but in red oak, there rays which is slightly across it surface but has small enunciate shape. It is more porous structure than white oak at it end grain shape. It is known as grained wood because of it course in term of texture **(American Forest Design, 1992)** .

Figure 3.11: The Red Oak species.

3.9.2.1 Workability

Red Oak produces good result with hand and machine tools; it has moderately high shrinkage values, resulting in mediocre dimensional stability especially in flat-sawn boards. Can react with iron and cause staining and discoloration, responds well to steam-bending. Glues, finishes and stains respectively **(**American Forest Design, 1992**)**.

3.9.2.2 Common Uses

Red Oak is in Cabinetry, furniture, interior trim, flooring and also in veneer respectively.

3.9.3 Douglas-fir and its Properties

3.9.3.1 Overview

This is one of the best known timber species across the world. Especially in the countries like Columbia and London but apart from those countries, there are a lot of other countries have it and also used it one of the most commercial wood timber. In Columbia, there are main two different types of Douglas-fir; these are Coastal Douglas fir and interior Douglas fir. The Coastal Douglas fir are mostly found in varieties place located in a mainland of south and also found within the Vancouver, located in Island, but can be found in minority within the northern lean. In other hand, Interior Douglas fir, are mostly found along the southern part of British, Columbia, and in some part of the northern region **(Tasmanian. 2008)**.

Figure 3.12: the Douglas-fir timber (Forentek, 2006).

3.9.3.1 Characteristics of Douglas-fir Species:

- It is known for its distinctive attributes which including strength, durability and beauty
- It is golden-orange in colour;
- It is well known for its quality and range of grades & characteristics, including some fibre that is exceptionally straight and also fine-grained (Forentek, 2006).

3.9.3.2 Common Uses

Douglas-fir is generally used for construction and building purposes which are due to its strength advantages and availability of large dimensions from old growth trees. It is one of the finest timbers used for heavy structural purposes which including laminated arches and roof trusses respectively. Structurally, Douglas-fir is used in the form of timber, lumber, pilings and also plywood.

Douglas-fir is seen as a first class wood for the ma manufacturing of sashes, windows, doors etc. The wood timber is also used to produce a wide variety of products which include; millwork, flooring, furniture, veneer, cabinets, vats, construction of ship and boat, transmission poles and marine piling **(**Tasmanian. 2008).

3.9.4 Red Wood and its Properties

Red wood (Seqouia) is an American wood-species, obtained from one of the most world tallest trees, reaching over 90m in height and a trunk diameter of up to 3metre, but found only in the coastal region of California. It is well known in US and often marketed as redwood, but care must be taken should not be confused with European redwood, which is also call pine. Red wood trees species of California have been harvested since the time of the first Spanish settlers which is over 400 years back. It is a highly prized lumber product renowned for several unique features respectively (Kappler, 2009).

Figure 3.13: The Red Wood species

3.9.4.1 Physical Characteristics

- Red wood is a medium to deep red brown, non-resinous wood and straight grained.
- Though often grown slowly,
- It has a conspicuous growth ring figure
- It is light in weight which is about 20% lighter than European redwood (pine) (Kappler, 2009).

3.9.4.2 Technical Properties

- Redwood dries well and when dry is very stable in use.
- It is very resistance to decay.
- It is slowly grown timber in firm and moderately strong which works easily and takes excellent finish, provided that tools are kept very sharp.
- It is not prone to checking and splitting, and therefore, is less damaged by weathering
- It is more insect repellent in all-heartwood grades than other woods.
- It is superior in insulation value that is the minute cell structure with thousands of air-filled cavities account for thermal insulation values of redwood.
- It is an easily machined, easy to nail and saw and has superior gluing properties and also superior finish holding ability (Kappler, 2009).

3.9.4.3 Common Uses

- Redwood is an excellent material for window and door stock as well as other joinery purposes.
- It is used for tanks, vats, silo and also for the slats in water cooling towers.
- Its light weight makes it unsuitable for heavy structural work, but can be in farm building, greenhouses, garden furniture, deck covering and also for estate work respectively (Kappler, 2009).

3.10 Wood Used as Structural Materials

3.10.1 Overview

The advantages of timber as a material for all engineering factories is over emphasizes, this is because it has a tremendous important to engineering industries for building and construction reason. For example the timber used for industrial purposes has high some matrix lignin and hemicelluloses that give toughness to it and also the present of micro-fibrous of cellulose. In case of the commercial timber, failure mechanism of wood is the most consider in this aspect, this is because the mechanism fibre pulls release about 1.5 KJ/

m2 in term of toughness, where the actual measure has the value 15KJ/m2. For the case of energy releases, wood has a great enormous energy result from absorption that gives it very high toughness and reduces the risk of crack blunting, splitting parallel to grain, bending and so on (DoIpoms, 2013).

3.10.2 Advantages

Here are other some of the merit of wood timber used as structural industrial material:

- It has very low cost in term of production
- It has low absorption energy needed in term of production
- It is served as friendly material for our environment
- Wood can be renewed after used
- Wood has low density which makes it easier to transport
- Because of it sensible strength and low density, it has great specific strength
- There are lowest cost associated with the wood disposal
- It is non conductor of electricity
- It is term as non toxic material
- It is very poor in terms of thermal conductivity of a conductor
- In term of concentration of stress, it is weaken material that even screws and other sharp never weaken it (DoIpoms, 2013).

3.10.3 Disadvantages

These are some of the disadvantages of wood timber as structural material for engineering purposes:

- It is so large in term of variability species, and depends only in position of trunks and it growing within the species
- It is not stable in term of dimensional direction
- It is easy attack in the present of moisture, and reduce it strength

- Wood has high combustible when burn
- The factor such as electricity viscosity, and creep in timber has timely dependent in term of it deformation.
- It is very attack by termites, and other forms insects respectively
- It can be easily be burn at high temperature, temperature greater than 200 degree celcious
- It has very high in terms of anisotropic material (DoIpoms, 2013).

Because of the transportation of non crystal it is easily creep it cellulose section

Even though regard to the above disadvantages, also the wood timber remained the most essential and commonly construction and building used material across the world, apart from the building and construction, also it is used in the field of cricket, longbow furniture, hubs and so field ways in now days respectively(DoIpoms, 2013).

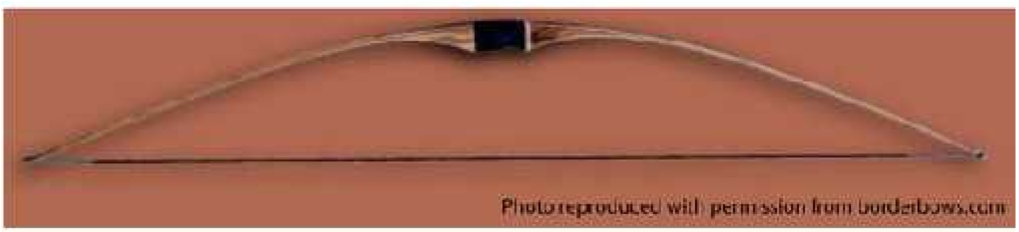

Figure: 3.14: Longbow (DoIpoms, 2013)

Figure 3.15 Wood-timber building (DoIpoms, 2013)

CHAPTER 4

METHODOLOGY

4.1 Overview

Due to the physical and mechanical strength characteristics of small cleared specimens, it is highly needed to classify timber species that widely existed. Due to the great variety of species that continually change the condition of supply, there is need to simplify its variability. In this case there are some factors that have support to be considered.

According to Canada Forest Product Laboratory Organization which is presently known as Forintek Canada, there are 2 methods of for sizing small clear specimens of timber species for wood test; Primary method which allow the use of 2 x 2in cross section for evaluation of physical and many mechanical properties of woods and the secondary method which allowed the use of 1x1in cross section of wood for evaluation of compression parallel to grain, hardness, impact bending, static etc (Riyanto & Gupta, 1998; Designation: D149-09).

Therefore, in this research thesis, secondary was choose to use for conducting laboratory experiment, so many examples of research journals were used the secondary method for evaluation of mechanical properties as mentioned before. This can be view by follow previous research that cited from journals and other good sources respectively.

Table 4.1: Softwood Dimensional Lumber Standard Sizes According Canada & North American (Wikipedia, 2010)

Nominal (In)	Actual	Nominal (Inch)	Actual
1x2	3/4x1 ½ in (19x38mm)	2x2	1 ½ x1 ½ in (38x38mm)
1x3	3/4x2 ½ in (19x64mm)	2x3	1 ½ x 2 ½ in (38x64mm)
1x4	3/4x3½ in (19x89mm)	2x4	1 ½ x 5 ½ in (38x89mm)
1 x 6	¾ x 5 ½ in (19x184mm)	2x6	1 ½ x 5 ½ in (38x140mm)
1x8	3/4 x 7 ¼ in (19x184mm)	2x8	1 ½ x 5 ½ in (38x184mm)
1x10	3/4 x9 ¼ in (19x235mm)	2x10	1 ½ x 9 ¼ in (38x235mm)
1x12	3/4 x11 ¼ in (19x286mm)	2x12	1 ½ x 11 ¼ in (38 x 286mm)

4.1.1 Main Laboratory Work

Four different wood species; Douglas fir, Pine, Redwood and Red Oak were cut into size 20 x 89 x 127 mm, each species has four pieces of the same size (making total of 16 pieces), then all the wood was dried in an oven drying machine for about 24 hours (1 day). Then the samples are divided into four groups for test:

- One for Non-soaking (Oven dried).
- One that was soaked for 2.4 hours.
- One that was soaked for 24 hours.
- One that was soaked for 8 days.

The weight of the samples was taken before and soaking, then “Compression test” was conducted in each group by using compressive machine. The compressive strength, Critical Load, and the specific gravity of each species were detected. The moisture content was calculated from the weights of the samples before and after soaking respectively.

SOME ASSUMPTIONS ABOUT THE WOOD SPECIMENS

1. It is assume that all woods samples were free from any internal defect that causes weight loss and also affect the wood strength
2. It is assume that the fundamental structure of woods do not change, and also anisotropic and hygroscopic nature of woods.
3. It is assume that the woods were just cut from it source, this was the reason for drying for about 24 hours before soaking.

4.2 Equipments Required for Laboratory Work

4.2.1 Oven Dried Machine

This is a vacuum or machine used for drying the wood timber specimen at a particular temperature stipulated, usually, a well ventilated oven drying machine is the one with temperature round between 101^0C to 105^0C, which is the most acceptable record temperature needed for drying of wood specimen or section. The industries that usually used to test the wood using this method should the suitable forced ventilation, electrical heated drying oven and also thermostatically controlled equipment respectively.

Figure 4.1: The Oven Drying Machine

4.2.2 The Weight Balance

The weight balance is used weighing the wood specimen or beam balance which has a sensitive ranges from 100mg up to 100g (that is for small specimen weighed balance) and also expressed in decimal system of number that simplified the calculations. There are so many types of weighed balance used for weighing the wood specimens, we have the brass weighed balance, stainless steel and iron weighed balances, but from all, stainless weighed balance likely and more used than the others.

If routine tests are to be carried out on many sections, much time can be carried out many sections, much time can be saved by using mainly semi automatic or fully automatic balance which eliminates partially or entirely the handling of weight respectively. Such a balance must read to 100mg and also suitable types having a capacity of 500g or to say more than that is readily available. The balance should be located in a position that can be sheltered from droughts, and also is near test piece preparation area and the drying Oven.

Figure 4.2: The Wooden Weight Balance

4.2.3 The Compression Machine

There are so many machine devices that can be determined the properties of wood compression which rage in specialized contest, and are designed for a particular standard. It can use some combination, some with force gauge and others with indicator load cell respectively.

The fixtures of compression test indicate that designed in order to supply and encourage high stiffness and maintained the measurement of accurate deformation together with axial load respectively, the hardness test machine can be an example and provide a suitable penetration depth of compressive ball.

The Universal testing machine is the most common tensile testing that widely used today in our laboratory and easily to operate. For the case of it shape and picture, figure 4.10 show the universal compression testing machine, it has two cross heads; one to apply tension to the test timber specimen and the other is for adjusted for the length of the specimen respectively (Mark, 2010)..

It has two (2) cross heads: one is driven to apply tension to the test specimen and the other one is adjusted for the length of the specimen respectively. The testing machine has the proper capabilities for the test specimen being tested **(**Mark, 2010).

Figure 4.3: The Compression Machine

4.3 Th**e Wood Used in the Laboratory Test**

The timbers used in laboratory test are Douglas fir, Pine, Red wood and Red Oak. It was cut from the factory in standard size 20 x 89 x 127mm in accordance with the EN code of practice.

Figure 4.4: Timbers used in Laboratory Test

Each species are of four different pieces, making the total of sixteen pieces. It was sure that all the timber samples are free from defect, damages or any hole on it. This is because due to the present of any damage might affect the entire result of the laboratory test.

4.4 Drying of Wood by Oven Drying Method

4.4.1 Overview

Oven-drying method can over-estimate the true moisture content if the wood contains significant amounts of volatile material that evaporates with the moisture during oven drying. This can occur in species containing natural volatile oils or resins, but the effect is not often large enough to be important, and is usually ignored in mostly practice. Moreover, the errors may be significant in wood that has been treated with preservatives.

The wood it dried at temperature 101^0C for about 24 hours as it required by the code as required which need the oven drying machine that dried small clear wood for testing at controlled temperature between 101^0C to 105^0C, and normally the temperature below 100^0C can be dried wood completely and also the temperature above 105^0C may caused wood to be singe, therefore suitable controlled heated oven should be maintained.

Figure 4.5: The Wood Drying in Process

4.4.2 Weighing of Wood after Drying

Immediately after 24 hours, the wood was removed from the oven dried machine and weight and record. All the 16 samples of wood was oven dried, then after 24 hours and removed from the oven dried machine it was weight and recorded the weight. Then the wood was divided into four groups samples one species for each group; first group for non-soaking, second group for 2.4 hours soaking, third group for 24 hours soaking and last group for 8 days soaking respectively. But the one for non-soaking and that of 2.4 hours was started oven. Then the one that can be soaked for 2.4 hours was

Figure 4.6 Weighing and recording the dried wood

4.5 Soaking of Wood

4.5.1 Overview

After weighing of the wood samples, all the 16 samples of the wood was grouping into four categories as stated earlier, that is the group is for non-soaking (1 Douglas fir, 1 Pine, 1 Red wood and 1 Red oak), and is the same for all other groups; 2.4 hours, 24 hours and 8 days soaking groups making the total of 16 wooden samples respectively. Since the first group is for non-soaking, then no need to discussed it here.

The three rubber basin contained water was provided for soaking of the three groups; 2.4 hours, 24 hour and 8 days, and each basin was signed for the time duration of the soaking period as shown in the figure 4.6.

Figure 4.7: The three Rubber Buckets for Soaking

4.4.2 Wood Soaking for 2.4 hours

The first group for soaking is 2.4 hours soaking which will be complete within the day after oven dried of the wood. It was recorded the weight after removing from the oven drying machine and then soaked into the water. It makes sure that the all the four sample of the wood was completely immersed in the water. Due to the over floating of wood in the water, then the heavy bottle was used over it to make sure that all the wood was immersed completely inside the water as shown the figure 4.8.

Likewise the for 24 hours and 8 days, was soaked and it make sure that the wood was immersed completely inside the water so that accurate soaking was to be obtained and avoid getting error measurement as shown in the figure 4.7.

Figure 4.8 The Wood Soaking groups

Figure 4.9 The wood soaked for 2.4 hours

After 2.4 hours the first group for soaking was removed the water, reweighed it and the reading recorded. It was make sure that the wood was toweled it with cloth (handkerchief) before it weighed so that avoid getting error measurement during the calculation of moisture content.

The same thing for the 24 hours and 8 days was removed immediately when the duration of time is complete, it removed from the water reweighed and recorded the reading. For 24 hours group was after 1 day the wood was in water and for 8 days soaking group, was removed after 8 days the wood was in water and within this period it make sure that there is nothing can touched the wood and water that the wood was immersed, the water do not change till to the stipulated time duration for soaking.

4.6 Determination of Moisture Content

4.6.1 Overview

There are many methods used determining the moisture content, the one used in this research thesis is Soaking and Oven drying method. For the test to be comparable, it is necessary to know the moisture content of the specimens at the zone of failure. This is getting from the weighed measured of the wood after oven dried, before soaking and the reading of the wood getting after soaking, by using the following formula(Hartley & Merchant, 1995).:

$$\text{Moisture Content MC} = \frac{\text{Initial mass} - \text{Oven dry mass}}{Oven\ dry\ maas}\ 100\% \qquad (1)$$

The above formula can be expressed clearly as:

$$MC = \frac{Weighed\ after\ soaking - weighed\ before\ soaking}{weighed\ before\ soaking}\ 100\% \qquad (2)$$

The moisture content of the each group was calculated separately, but it is better to understand that for the first group, that is for non-soaking, there is no water inside the wood, so therefore it has zero reading for moisture content.

The moisture content of the all wood group species was calculated and tables the result clearly for 2.4 hours, 24 hours and 8 days soaking respectively.

4.7 Wood Compression Test

4.7.1 Overview

The test was done by using wooden test compressive machine in order to determine compressive strength, specific gravity, and Critical Load for each sample of wood in it group. The wood sustained in a compressive machine parallel to grain woods

Figure 4.10: The Wood Test Compressive Machine [NEU Civil Lab]

4.7.2 Compression test for non-soaking wood

The compression was carried out first for non-soaking and it is for every individual species which conducted parallel to the grain of the sample. Before the compression test, the detected computer machine was taken the size of the sample and weight of the sample after soaking respectively. It give out the graph strength of each wood sample in accordance the compression strength has increase till to the point that the wood is buckle as shown in pained figure 4.10

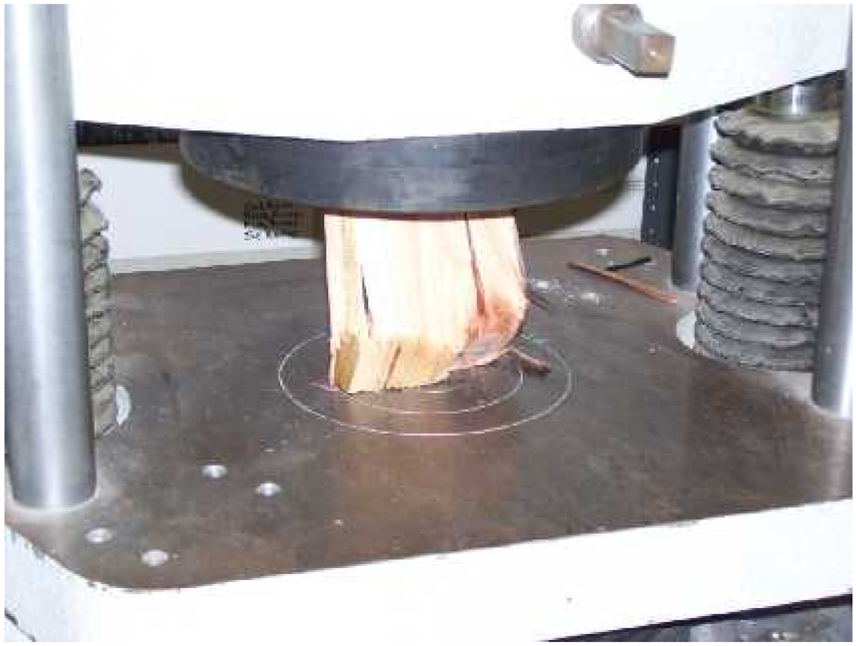

Figure 4.11 the compression test in progress parallel to grain

Figure 4.12 the paint record of wood strength from the computer

The value of the maximum load, compressive strength, and Unit Weight was recorded for all samples respectively.

Also the same thing for the other groups, that is 2.4 hours, 24 hours and 8 days groups, was also done compression test in the same procedure as above.

4.7.3 Precaution

The following are some precautions taking during laboratory test:

- It ensures that all 16 woods samples are signed before soaking.
- It ensures that the soaking buckets were signed to prevent confusion..
- Used heavy object on woods so that to prevent over floats of the woods.
- Woods should be toweled before reweighed after soaking.
- It ensures that the weighed balance initially read from zero.
- Tap water was used in the experiment, because it is the average allowable water for experimental test, not salty or rain water.

CHAPTER 5

TEST RESULT & DISCUSSION

5.1 The Test Result

5.1.1 Weight of the timber after Oven Drying

Immediately after removing the wood from the oven drying machine which was lasted for about 24 hours at temperature 101^0 C. then it weighed and the reading was recorded which was the reading for wood before soaking, as tabulated in table 5.1 below.

The table 5.1 gives the weight of the four timber species after oven dry for 24 hours at the temperature 101^0 C.

Table 5.1: Weight of the timber after Oven Drying

Wood types	Weight (g)
Douglas fir	112.6
Pine	123.1
Red wood	127.6
Red Oak	131.3

5.1.2 The Compression Test Result

Table 5.2, 5.3, 5.4, and 5.5, predict the result of the compression test of the 4 different timbers for different amount of time; table 5.2 is for the dry wood (that is non-soaking in water), table 5.4 is for the 2.4 hours soaking, table 5.6 is for the 24 hours soaking (one day), and table 5.8 is for the 8 days soaking respectively.

Table 5.2: Compression Result for non-soaking test

Wood type	Weight (g) Non-Soaking	Max. Load (KN)	Compressive strength (MPa)	Unit Weight (Kg/m3)
Douglas fir	112.6	12.5	1.1	0.500
Pine	123.1	13.6	1.2	0.544
Red Wood	127.6	27.9	3.0	0.566
Red Oak	131.3	21.6	1.9	0.579

Table 5.3: Compression Result for 2.4 hours test

Wood Type	Weight (g) After Soaking	Max. Load (KN)	Compressive Strength (MPa)	Unit Weight (Kg/m3)
Douglas fir	124.1	7.9	0.7	0.549
Pine	142.0	11.1	1.0	0.628
Red Wood	160.0	13.7	1.2	0.708
Red Oak	144.4	19.3	1.7	0.641

Table 5.4: Compression Result for 24 hours test

Wood Type	Weight (g) After Soaking	Max. Load (KN)	Compressive Strength (MPa)	Unit Weight (Kg/m3)
Douglas fir	151.0	9.7	0.9	0.668
Pine	148.5	8.4	0.7	0.659
Red Wood	188.4	13.3	1.2	0.832
Red Oak	162.9	16.3	1.4	0.544

Table 5.5: Compression Result for 8 days test

Wood Type	**Weight (g) After Soaking**	**Max. Load (KN)**	**Compressive Strength (MPa)**	**Unit Weight (Kg/m3)**
Douglas fir	155.8	3.4	0.3	0.690
Pine	165.5	4.6	0.4	0.734
Red Wood	237.7	6.8	0.6	1.053
Red Oak	206.0	9.5	0.8	0.911

5.1.3 Moisture Content Result

The moisture contents, for Non-soaking timber (dry wood), for soaking for 2,4 hours, 24 hours and 8 days was calculated, by considering the weight of the timbers before soaking and after soaking

NOTE: it is very important to note that Non-soaking wood, the weight of the after oven dried do not change. So therefore, it has zero reading of moisture content, because the woods do not content any water in it.

Table 5.6; predict the result of the calculated moisture content for; non-soaking, 2.4 hours, 24 hours and 8 days by considering the weight before and after soaking. It is also very important to understand that, all the timbers have same weight before soaking, that is table 5.1, then their weight after soaking is by considering; table 5.2, 5.3, 5.4 and 5.5 respectively.

Table 5.6: The Result Calculation of Moisture Content

Wood Type	Non Soaking (%)	For 2.4hrs Soaking (%)	For 24hrs Soaking (%)	For 8 days Soaking (%)
Douglas fir	0.0	10.2	34.1	38.4
Pine	0.0	15.3	20.6	34.4
Red Wood	0.0	25.4	47.6	86.3
Red Oak	0.0	10.0	24.1	56.9

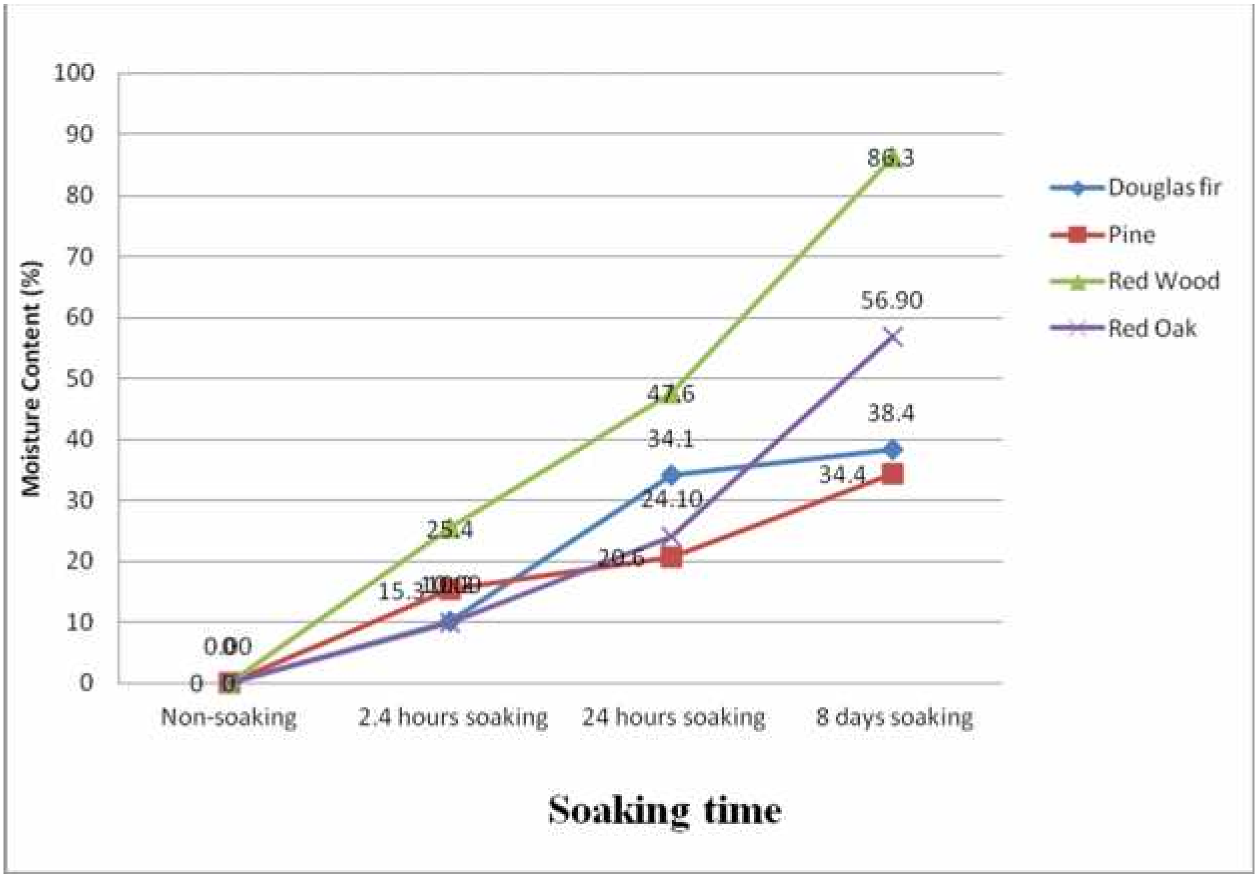

Figure 5.1: Comparison of MC for Tested Woods per soaking time

The moisture content percentage differences at 8 days soaking are: Redwood--Red oak is 34%, for Redwood—Douglas fir is 55% and the Redwood ---Pine is 60%.

5.1.4 The Compressive Strength

5.1.4.1 Overview

Table 5.12 is the table that gathered all laboratory test result for every group used in the laboratory test that is for non-soaking, 2.4 hour soaking, 24 hours soaking and 8 days soaking, while table 5.13 is the average mean for table 5.12 respectively.

Table 5.7: The Result calculation of Compressive Strength

Wood Type	Non Soaking (kPa)	For 2.4hrs Soaking (kPa)	For 24hrs Soaking (kPa)	For 8 days Soaking (kPa)
Douglas fir	1100	700	500	300
Pine	1200	1000	700	400
Red Wood	2500	1200	1000	600
Red Oak	1900	1700	1400	800

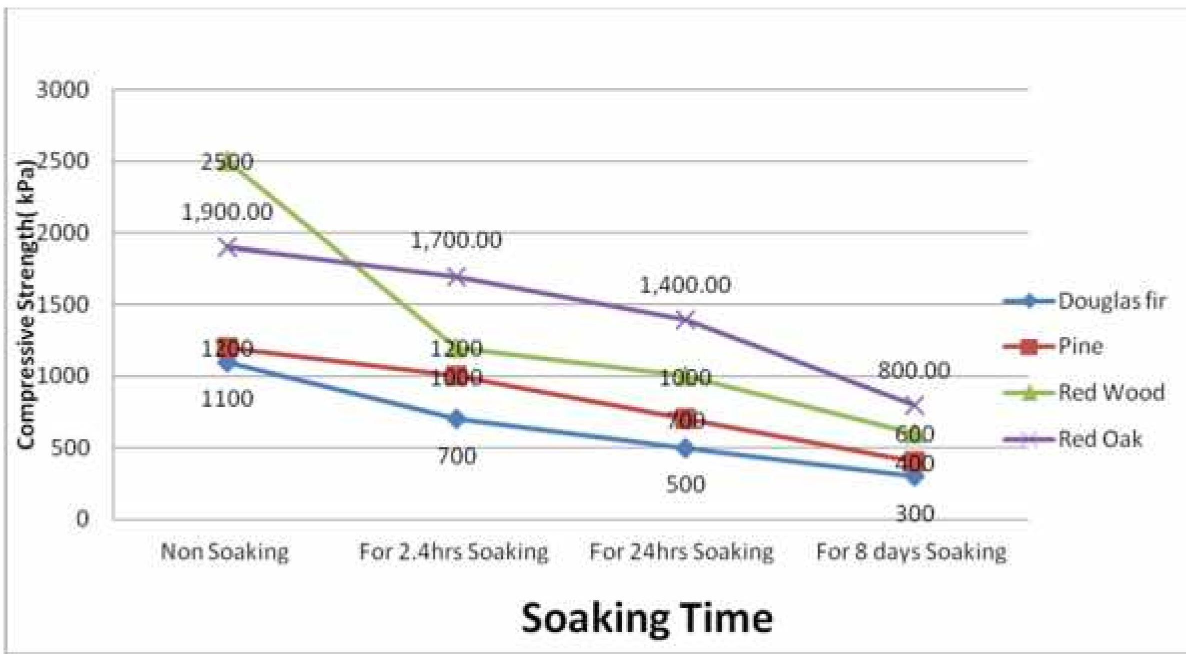

Figure 5.2: the Comparison of CS for Tested Woods per soaking time

5.1.5.1 Woods Percentage Differences in Compressive Strength

Redwood is more strength than other woods at non-soaking stage but Red Oak is more strength than other woods at 8 days soaking stage. The percentage differences were calculated as shown in the table 5.8 and table 5.9 below.

Table 5.8: Percentage Differences in CS for Non-soaking

Woods Comparison	Percentage Differences (%)
Redwood-----Red Oak	24
Redwood-----Pine	52
Redwood---- Douglas fir	56

Table 5.9: Percentage Differences in CS for 8 days soaking

Woods Comparison	Percentage Differences (%)
Red Oak ------ Redwood	25
Red Oak ------ Pine	50
Red Oak ----- Douglas fir	63

5.1.5 Relationship between the Moisture Content and Compressive Strength of Results

5.1.5.1 Overview

Here is describes the relationship between moisture content and compressive strength of each individual tested wood result for non-soaking, 2.4 hours, 24 hours and 8 days soaking that sorted out from the table 5.10 and table 5.11 respectively.

1. **Douglas fir**

Table 5.10: Relationship between CS and MC of Douglas fir

Compressive Strength CS (kPa)	Moisture Content MC (%)
1100	0.0
700	10.2
500	34.1
300	38.4

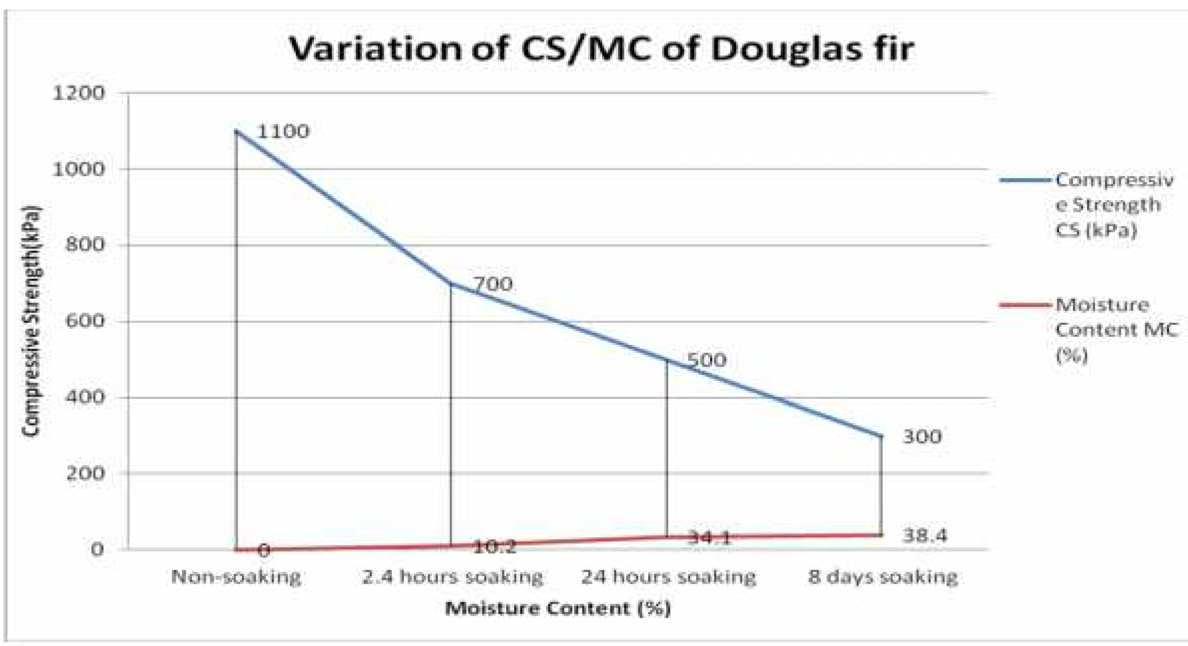

Figure 5.3: Relationship between CS and MC of Douglas fir

2. Pine

Table 5.11: Relationship between CS and MC of Pine

Compressive Strength (psi)	Moisture Content (%)
1200	0.0
1000	15.3
700	20.6
400	34.4

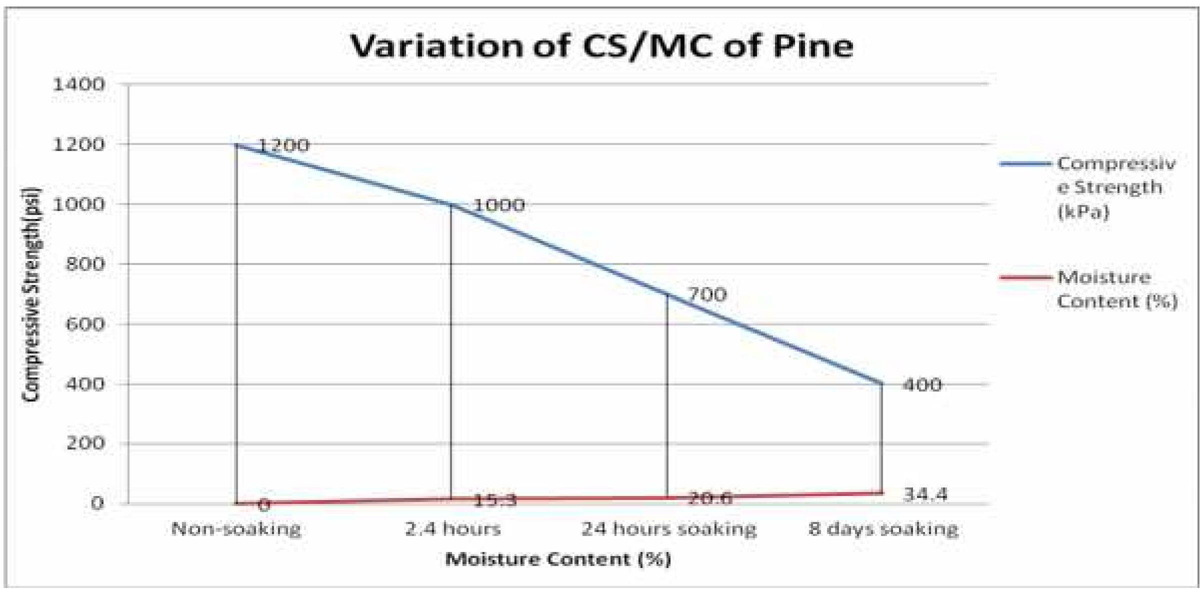

Figure 5.4: Relationship between MC and CS of Pine

3. Redwood

Table 5.12: Relationship between the CS and MC of Redwood

Compressive Strength (kPa)	Moisture Content (%)
2500	0.0
1200	25.4
1000	47.6
600	86.3

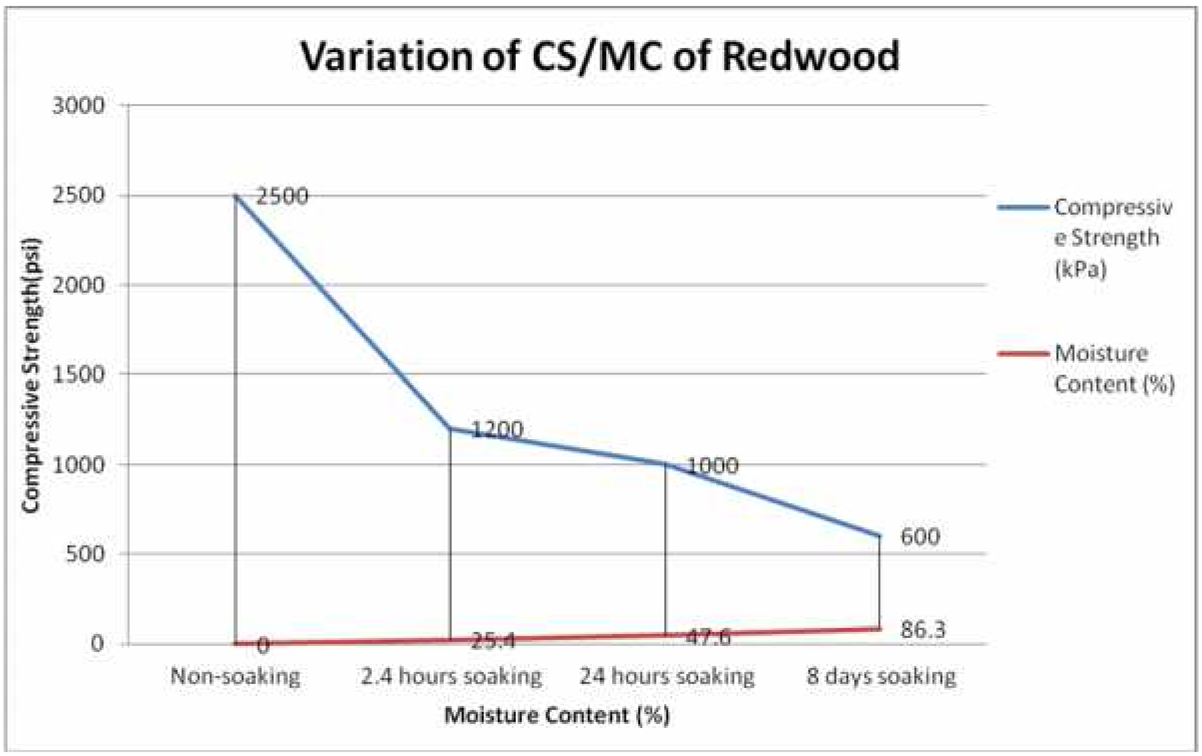

Figure 5.5: Relationship between CS and MC of Redwood

4. Red Oak

Table 5.13: Relationship between the CS and MC of Red Oak

Compressive Strength (CS) (kPa)	Moisture Content (MC) (%)
1900	0.0
1700	10.0
1400	24.1
800	56.9

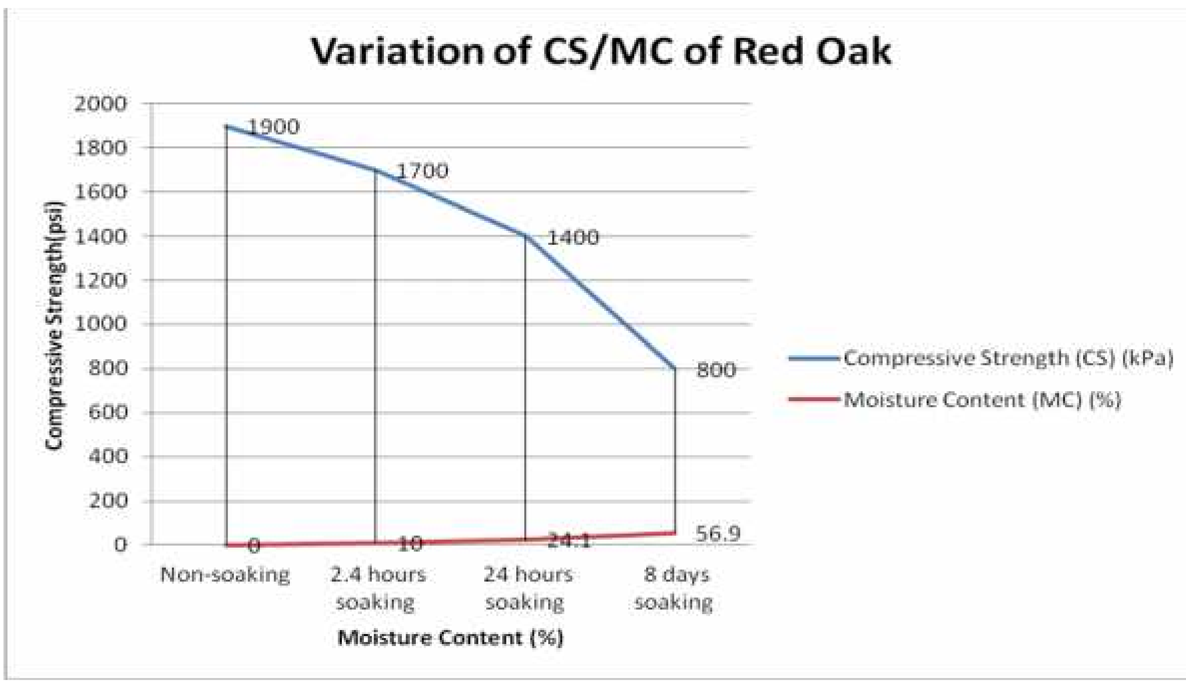

Figure 5.6: Relation between CS and MC of Red Oak

5.1.6 The Percentage Different in Reduction of Compressive Strength for Soaking Time

Table 5.14: The percentage differences in CS per Soaking Time

Soaking Time	Percentage Reduction in Compressive Strength (%)			
	Douglas fir	Pine	Redwood	Red Oak
2.4 hours	36	16	24	10
24 hours	54	41	52	26
8 days	73	66	76	57

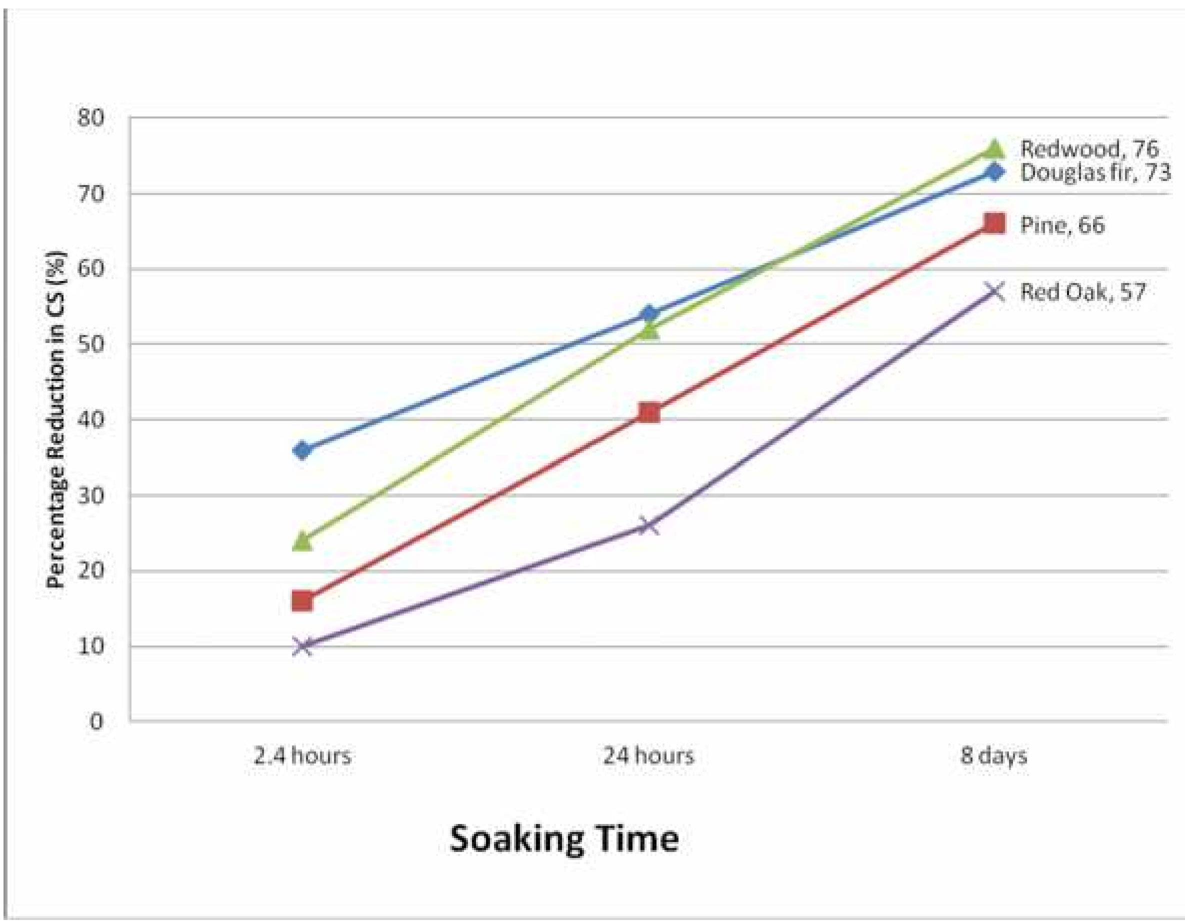

Figure 5.7: Percentage Different in Reduction of CS for Tested Woods

5.1.7 The Maximum Load Result

The table 5.12 below is the result for Maximum Load of the wood during compression test for Non-soaking, 2.4 hours, 24 hours and 8 days wood soaking respectively

Table 5.15: The Maximum Load Result for tested woods

Wood Type	**Non Soaking (KN)**	**For 2.4hrs Soaking (KN)**	**For 24hrs Soaking (KN)**	**For 8 days Soaking (KN)**
Douglas fir	12.5	9.7	7.9	3.4
Pine	13.6	11.1	8.4	4.6
Red Wood	27.9	13.7	13.3	6.8
Red Oak	21.6	19.3	16.3	9.5

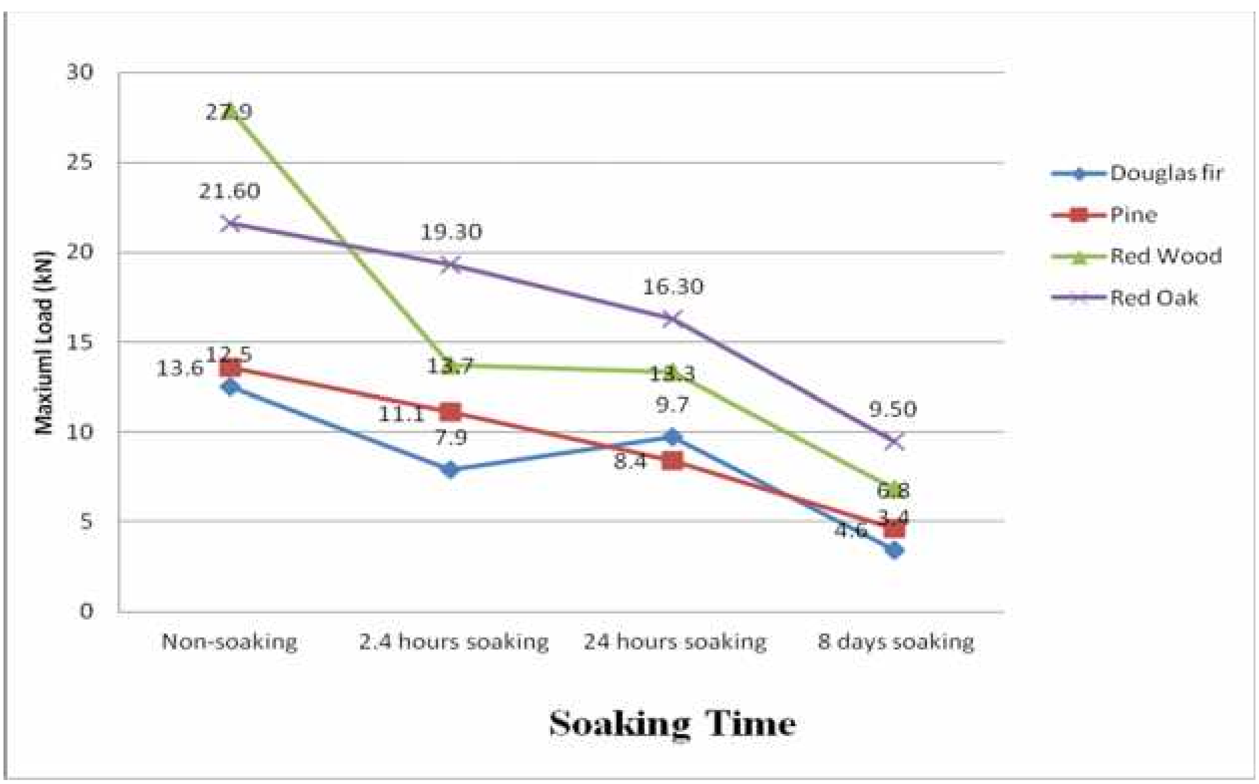

Figure 5.8: Variation of Maximum Load for Tested Woods per soaking time

5.1.8 Unit Weight of Woods

The table 5.15 summarizes the unit weight of woods studied, according to research investigation, the unit weight of woods is solely depend on moisture content, as the former increase, the later increases also.

Table 5.15: Unit Weight of the Woods studied

Wood Type	Non Soaking (Kg/m3)	2.4hours Soaking (Kg/m3)	24hours Soaking (Kg/m3)	8 days Soaking (Kg/m3)
Doughlas fir	0.500	0.549	0.668	0.690
Pine	0.544	0.628	0.659	0.734
Red Wood	0.566	0.708	0.832	1.053
Red Oak	0.579	0.641	0.544	0.911

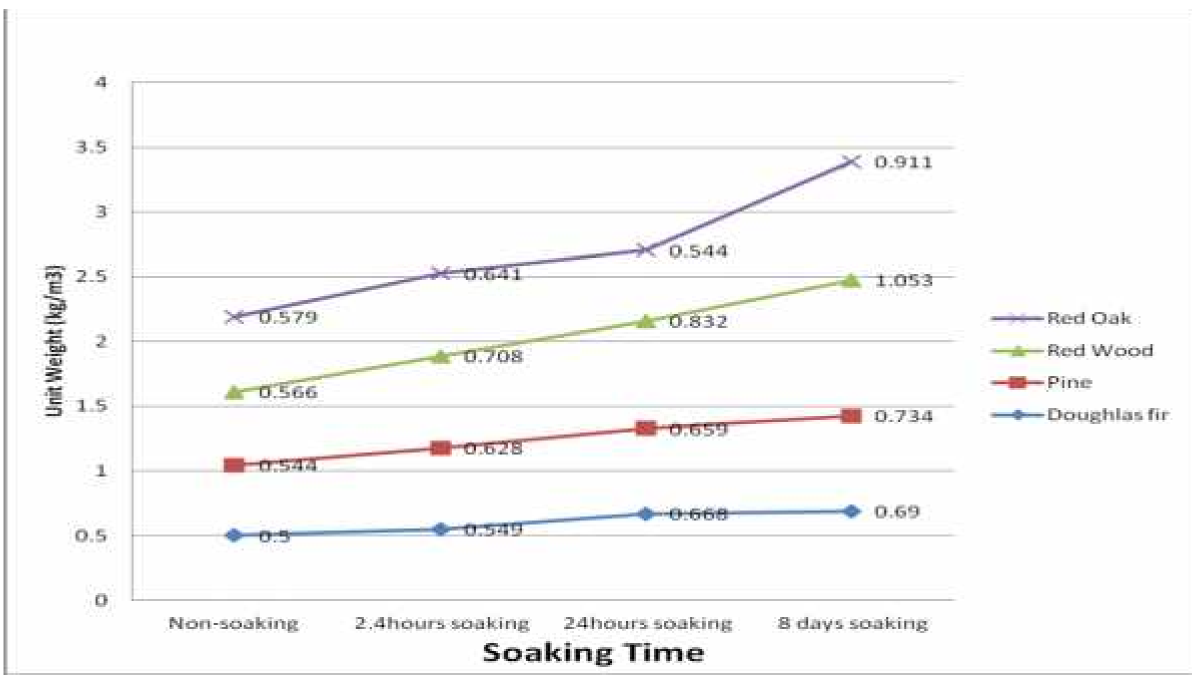

Figure 5.9: Variation of Unit weight for Tested Woods per Soaking Time

5.2 Discussion of Test Results

From the result obtained above, observation has shows that, the strength of woods is change highly with water content from the strong timber to weak one, which has some implication that can be discussed as follow.

The result indicate that an increase in woods moisture content through soaking the woods, lower the strength (stiffness) of the woods. That is the higher the moisture content the lower the strength and vice versa. This can be seen by merely looking the figure 5.1, figure 5.2, figure 5.3 and figure 5.4, where there would be heavy falling down of strength of the wood, in other hand, the moisture content as shown in the summary, table 5.6 increases with an extreme variation of the amount of soaking hours.

Also under compression there is very signed of weakening effect as moisture reduce the bonding between the wood timber which as a result make the cell walls very easier to collapse.

According to the table 5.6, predict the summary of the calculated moisture content that obtained from Non-soaking, 2.4 hours, 24 hours and 8 days soakings for tested woods. From figure5.5 for comparison of moisture content, it shows that the moisture content tested woods increases (rise up) with increase of soaking hours, but initially the tested woods have zero moisture content. This is because there is no water (moisture) in the during compression strength, by taking Douglas fir as an example has 0% at non-soaking, but at for 2.4 hours, 24 hours and 8 days are 10.2%, 34.1% and 38.4% and hence it was observed that Redwood has the highest value of moisture content (86.3%) at 8 days. The reason why there is high absorption of moisture, it is because the small clear specimens were used and they were in natural state not coated with any chemical treatment, and also there is free movement of air from wood cell cavities and pores, this is the reason for rapid hygroscopic of woods.

In table 5.7, give the calculated weight for compressive strength for non-soaking, 2.4 hours soaking, 24 hours soaking and 8 days soaking, the result showed that the strength of the wood is decreases as the increase of time of wood in water. This is due to the load that applied parallel to grain and instantaneously the failure that engaged by the timbers through individual fibre of wood species.

Also table 5.8 and table 5.9 gives the woods percentage differences of compression strength at non-soaking and at 8 days soaking. At non-soaking Redwood has the highest compressive strength than other woods studied, and at 8 days soaking Red Oak has the highest value of compressive strength than other woods studied, the percentage differences between each individual wood than the other were mention in the table respectively.

Also Table 5.13 show the percentage differences in reduction of compressive strength for each individual wood studied, from the result it shows that the highest percentage in reduction is detected from 8 days soaking, figure5.11 show the relation in percentage differences reduction for woods compressive strength.

Tables 5.9, 5.10, 5.11, and 5.12 give the relationship between Compressive strength and moisture content for each wood; that is Douglas fir, Pine, Redwood and Red oak respectively. The figure 5.5, 5.6, 5.7 and 5.8 described between them, for non-soaking, 2.4 hours soaking, 24 hours soaking and 8 days soaking. It can be observed that from the individual table as mentioned, Redwood has the highest strength for both compressive strength than the others at non-soaking (CS=2500kPa), then follow by the Red oak (CS=1900kPa), then follow Pine (CS=1200kPa), and then follow by Douglas fir (CS=1100kPa) but at 8 days soaking Red Oak has the highest values (CS=800kPa), then follow by Redwood (CS=600Pa), then follow by Pine (CS=400kPa), and follow by Douglas fir (CS=300kPa) respectively.

Also the summary of maximum Load of the woods obtained parallel to grain were shown in table 5.13, the values plotted in figure 5.11, which shows the same cases as for compressive strength of woods studied respectively.

CHAPTER 6

CONCLUSION & RECOMMENDATION

6.1 Conclusion

The following conclusions can be drawn from the present research study:

- From the experimental results obtained, it is clear that different timber species have different properties, but it is very possible to understand their general behavior through conducting an experiment using oven drying and soaking method
- According to the result obtained, the compressive strength of woods is inversely proportional to the to the water content, this means that an increase in both of them, the moisture content decreases, so also the strength of the woods.
- Loading direction of the timber affects both the two mechanical strength properties remarkably; this is because of the anisotropic nature of wood species. Among the four woods tested the one that has a minimum anisotropy in mechanical strength properties was observed in Redwood timber, then follow by Red Oak, then follow by Pine and then follow by Douglas fir species at non-soaking state. But at 8 days soaking state, the Red Oak has the highest compressive strength than other tested wood, and then follows by Red wood, Pine and Doughlas fir orderly.
- The percentage differences in reduction of compressive strength for Douglas at 2.4 hours, 24 hours, and 8 days are; 36%, 54%, and 73% for Pine wood are; 16%, 41% and 66%, for Redwood are, 24%, 52% and 76% for Red oak are 10%, 26, and 57% respectively.
- There is a very good correlation linearly between the specific gravity (density) of wood timber and the compressive strength. Among the tested wood; Douglas fir, Pine, Red wood and Red Oak, as the specific gravity of the timber increases the compressive strength increase. This clearly showed that the maximum crushing strength in compression parallel to grain and the modulus of elasticity are most closely and also related to the specific gravity of the tested timbers.

6.2 Recommendation

Based upon the testing results obtained in this research study, here are some recommendations with regard for further investigation;

- Due to wood hygroscopes, it is recommended to use in a place where there is no much moisture (water) than the place where there is moisture; this is because it has the highest rate of soaking than the other woods studied.
- Redwood observed to have the highest compressive strength at non-soaking state than the other woods studied and as such it is recommended for use in hard strength work where there is no moisture than the other woods and Red Oak in a hard strength work where there is moisture than other woods studied.
- It is also recommended that, timber wood used for construction purposes must be adequately dried. This will reduced/prevents stain and decay and also improve the strength properties the wood.
- In case of further the research on the same topic, critical load and Specific gravity of the woods should be considered.

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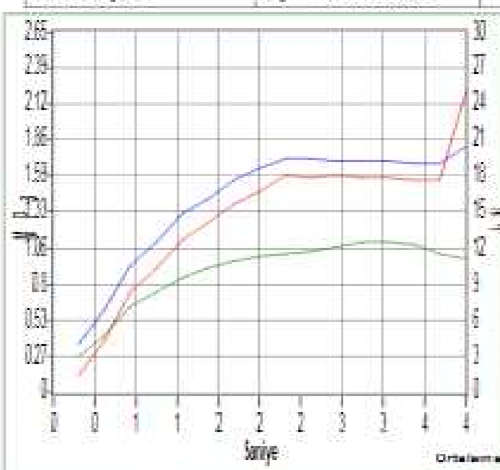
APPENDICES

Appendix i: Laboratory Compression Test Result for Non-soaking

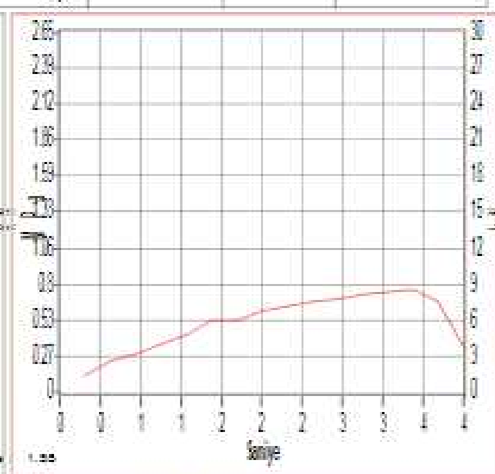
YAKIN DOĞU ÜNİVERSİTESİ LABORATUVARI BETON BASINÇ DAYANIM DENEY RAPORU

Rapor Tarihi				Referans No	

FİRMA VE ŞANTİYE BİLGİLERİ		DENEY SONUÇLARI			
İnşaat Sahibi		Gerilme (Mpa)	Kırım Kuvveti (KN)	Ağırlık (gr)	Birim Ağırlık(Kg/m3)
Deneyi Yaptıran		2.5	27.9	145.0	0.641
İnşaat Adresi		1.9	21.2	0.0	0.000
Standart	TS EN 206-1 / TS EN12390-3	1.1	12.7	120.0	0.531
		0.7	5.5	96.0	0.425
NUMUNE BİLGİLERİ		0.0	0.0	0.0	0.000
Numuneyi Alan		0.0	0.0	0.0	0.000
Üretici Firma					
Döküm Tarihi					
Kırım Tarihi					
Alındığı Yer (Kiriş,Kolon vs)		Numune Adedi			
Beton Sınıfı		Yaş 1			
Numune Boyutları	Küp 127.0x89.0x20.0	Yaş 2			



Ortalama 1.55



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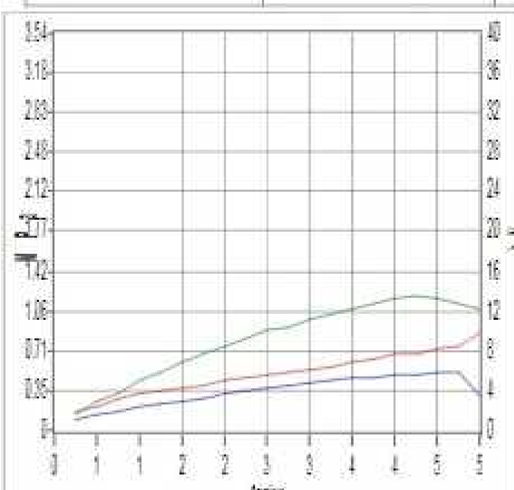
Appendix ii: Laboratory Compression Test Result for 2.4 hours soaking

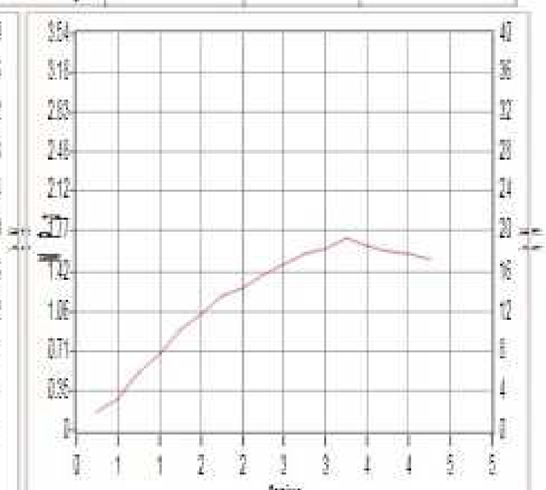
YAKIN DOĞU ÜNİVERSİTESİ LABORATUVARI BETON BASINÇ DAYANIM DENEY RAPORU

Rapor Tarihi				Referans No	

FİRMA VE ŞANTİYE BİLGİLERİ		DENEY SONUÇLARI			
İnşaat Sahibi		Gerilme (Mpa)	Kırım Kuvveti (KN)	Ağırlık (gr)	Birim Ağırlık(Kg/m3)
Deneyi Yaptıran		1.0	11.1	142.0	0.628
İnşaat Adresi		0.7	7.9	124.0	0.649
Standart	TS EN 206-1 / TS EN12390-3	1.2	13.7	160.0	0.708
		1.7	19.3	145.0	0.641
NUMUNE BİLGİLERİ		0.0	0.0	0.0	0.000
Numuneyi Alan		0.0	0.0	0.0	0.000
Üretici Firma					
Döküm Tarihi					
Kırım Tarihi					
Alındığı Yer (Kiriş,Kolon vs)		Numune Adedi			
Beton Sınıfı		Yaş 1			
Numune Boyutları	Küp 89.0x127.0x20.0	Yaş 2			



Ortalama 1.15



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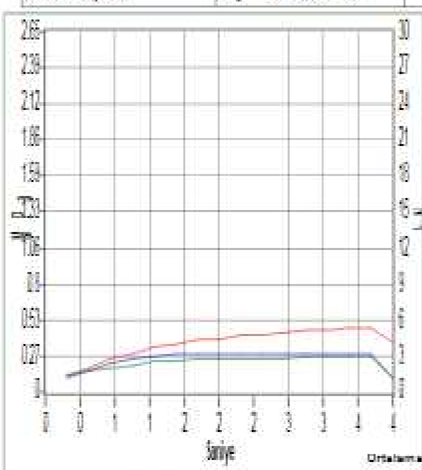
Appendix iii: Laboratory Compression Test Result for 24 hours soaking

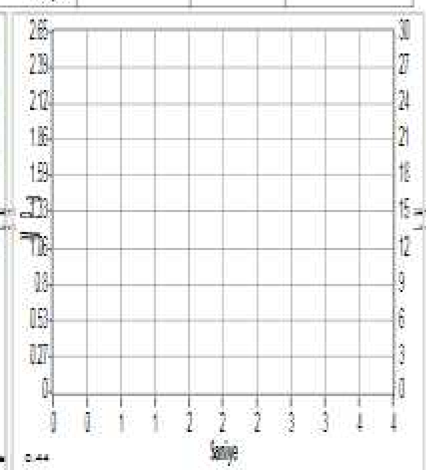
YAKIN DOĞU ÜNİVERSİTESİ LABORATUVARI BETON BASINÇ DAYANIM DENEY RAPORU

Rapor Tarihi	30/05/2014			Referans No	

FİRMA VE ŞANTİYE BİLGİLERİ		DENEY SONUÇLARI			
İnşaat Sahibi		Gerilme (Mpa)	Kırım Kuvveti (KN)	Ağırlık (gr)	Birim Ağırlık(Kg/m3)
Deneyi Yapıran		0.8	6.6	236.0	1.053
İnşaat Adresi		0.3	3.4	156.0	0.690
Standart	TS EN 206-1 / TS EN12390-3	0.4	4.6	166.0	0.734
		0.0	0.0	0.0	0.000
NUMUNE BİLGİLERİ		0.0	0.0	0.0	0.000
Numuneyi Alan		0.0	0.0	0.0	0.000
Üretici Firma					
Döküm Tarihi					
Kırım Tarihi					
Alındığı Yer (Kiriş,Kolon vs)		Numune Adedi			
Beton Sınıfı		Yaş 1	5 days		
Numune Boyutları	Küp 127.0x89.0x20.0	Yaş 2			



Ortalama 0.44



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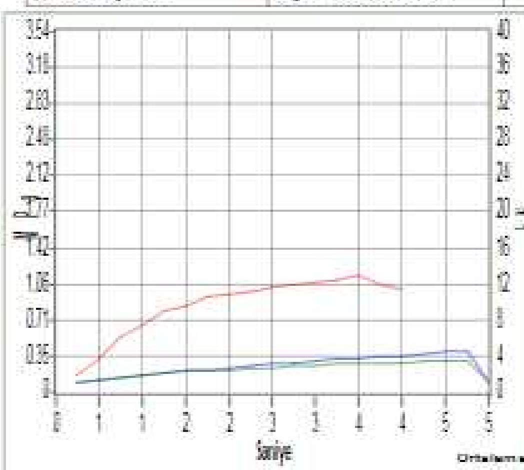
Appendix iv: Laboratory Compression Test Result for 8 days soaking

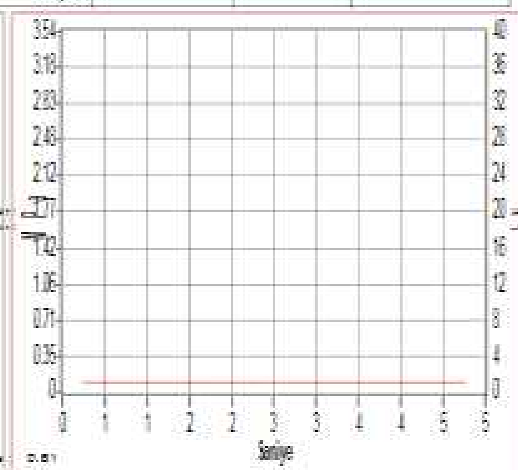
YAKIN DOĞU ÜNİVERSİTESİ LABORATUVARI BETON BASINÇ DAYANIM DENEY RAPORU

Rapor Tarihi				Referans No	

FİRMA VE ŞANTİYE BİLGİLERİ		DENEY SONUÇLARI			
İnşaat Sahibi		Gerilme (Mpa)	Kırım Kuvveti (KN)	Ağırlık (gr)	Birim Ağırlık(Kg/m3)
Deneyi Yaptıran		1.1	12.9	163.0	0.721
İnşaat Adresi		0.7	8.0	145.0	0.641
Standart	TS EN 206-1 / TS EN12390-3	0.5	5.3	205.0	0.907
		0.1	1.2	126.0	0.557
NUMUNE BİLGİLERİ		0.0	0.0	0.0	0.000
Numuneyi Alan		0.0	0.0	0.0	0.000
Üretici Firma					
Döküm Tarihi					
Kırım Tarihi					
Alındığı Yer (Kiriş,Kolon vs)		Numune Adedi			
Beton Sınıfı		Yaş 1			
Numune Boyutları	Küp 59.0x127.0x20.0	Yaş 2			



Ortalama 0.81



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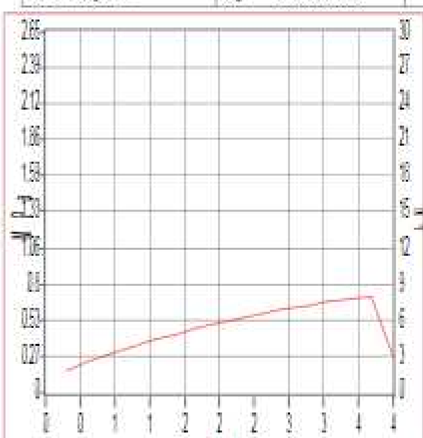
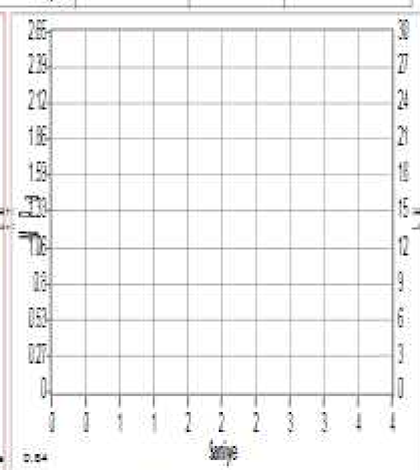
YAKIN DOĞU ÜNİVERSİTESİ LABORATUVARI BETON BASINÇ DAYANIM DENEY RAPORU

Rapor Tarihi	30/05/2014			Referans No	mousa thesis

FİRMA VE ŞANTİYE BİLGİLERİ		DENEY SONUÇLARI			
İnşaat Sahibi	neu	Gerilme (Mpa)	Kırım Kuvveti (KN)	Ağırlık (gr)	Birim Ağırlık(Kg/m3)
Deneyi Yaptıran	mustafa turk	0.5	9.5	206.0	0.911
İnşaat Adresi		0.0	0.0	238.0	1.053
Standart	I S EN 206-1 / I S EN12390-3	0.0	0.0	0.0	0.000
		0.0	0.0	0.0	0.000
NUMUNE BİLGİLERİ		0.0	0.0	0.0	0.000
Numuneyi Alan		0.0	0.0	0.0	0.000
Üretici Firma					
Döküm Tarihi					
Kırım Tarihi					
Alındığı Yer (Kiriş,Kolon vs)		Numune Adedi			
Beton Sınıfı		Yaş 1	8		
Numune Boyutları	Küp 127.0x59.0x20.0	Yaş 2			



Ortalama 0.54



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